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Paris, London, July 2015

THE WORLD NUCLEAR INDUSTRY

STATUS REPORT 2015

BY Mycle Schneider
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WITH Julie Hazemann
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FOREWORD Jonathon Porritt

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Paris, London, July 2015

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NOTE

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

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Foreword

By Jonathon Porritt¹

There's been no diminution in the intensity of the debate about the role of nuclear power in tomorrow's low-carbon world. Indeed, it seems to become more intense by the day. Articles of historical faith seem to matter much more to protagonists on both sides of that debate than strictly dispassionate analysis. And that's precisely why the *World Nuclear Industry Status Report (WNISR)* plays such a critical role in informing both experts and lay people, updating a longitudinal dataset with scrupulous care and attention to detail every year.

As we know, however, people read the same data in very different ways, leading to very different conclusions. So I can only give you mine, without any attempt at spurious neutrality! And my headline conclusion is a simple one: the impressively resilient hopes that many people still have of a global nuclear renaissance are being trumped by a real-time revolution in efficiency-plus-renewables-plus-storage, delivering more and more solutions on the ground every year.

One of the least understood aspects of today's nuclear debate is *pace of change*: just how fast is R&D converting into prototype and early-investment prospects; just how fast is innovation of that kind converting into near-commercial or fully-commercial projects; and just how fast are those projects converting into scalable roll-out programmes with substantive measurable outcomes.

Every year that passes reveals a widening gap between what is happening with the nuclear industry (forensically laid bare by successive Status Reports) and how so-called alternatives become a new paradigm (based on efficiency, renewables, energy storage and distribution), as portrayed by a wide range of commentators in the energy debate – from the International Energy Agency and mainstream investment banks through to entrepreneurs and NGOs. It's an extraordinary story that emerges from this analytical approach to the relative pace of change in both competing paradigms.

Simply by presenting year-on-year data as to the operational status of nuclear power programmes all around the world, WNISR remorselessly lays bare the gap between the promise of innovation in the nuclear industry and its delivered results.

For instance, back in the 1990s, there was huge enthusiasm for a potential “nuclear renaissance” through what were called Generation III reactors – designed to address the huge problems then confronting the industry in terms of safety, cost and construction complexity. These promises (which were themselves reminiscent of some of the earliest claims made on behalf of nuclear power back in the 1950s and 1960s) were instrumental in persuading both George Bush and Tony Blair in recommitting to nuclear power programmes in the USA and UK respectively.

Twenty years on, not one of the Generation III reactor designs is yet in service. And the kind of reduced costs that were being talked about at that time have been proved entirely illusory: by 2013, the projected costs of Generation III designs had increased eightfold. As the WNISR authors put it: “By May 2015, there were 18 reactors of designs claimed to meet Generation III+ criteria under construction. Only two were still on time, and the rest were two to nine years late. So on

¹ Jonathon Porritt is Co-Founder and Trustee of [Forum for the Future](#) and former Chairman of the [U.K. Sustainable Development Commission](#).

the face of it, the claims that these designs would be easier to build appear no better based than the cost claims.”

Undaunted by this grinding reality, the nuclear industry is now increasingly active in talking up the prospects for Generation IV reactor designs, which will (we are told) address all the same problems that Generation III designs were supposed to address. Right now, for instance, there’s an outspoken lobby making the case for Small Modular Reactors – an idea which is readily badged as Generation IV but actually goes back to the 1960s. Then the 1980s. Then the 1990s. Then the early 2000s! As the International Energy Agency commented in 2002, in an era when it was rather more bullish about nuclear power: “The main reason for this stalemate is that we, in all our doings, continue to rely on nuclear technology developed in the 1950s, which had its roots in military applications which cannot exclude absolutely the possibility of a severe accident and which has reached its limits from an economic point of view.

For those who’ve now somewhat given up on Small Modular Reactors and other so-called “advanced nuclear reactors”, there’s always the promise of an entirely new nuclear value chain based not on uranium but on thorium – another proposition that has been around for more than 50 years. And what’s remarkable here is that even the keenest advocates of thorium acknowledge that it couldn’t possibly make a substantive, cost-effective contribution to the world’s need for low-carbon energy for at least another 20 years.

The consistent history of innovation in the nuclear industry is one of periodic spasms of enthusiasm for putative breakthrough technologies, leading to the commitment of untold billions of investment dollars, followed by a slow, unfolding story of disappointment caused by intractable design and cost issues. Purely from an innovation perspective, it’s hard to imagine a sorrier, costlier and more self-indulgent story of serial failure.

This is not the place to develop a full comparison with what I’ve called “the alternative paradigm”, but in each of those four core elements (efficiency, renewables, storage and grids) the pace of change is breathtaking, dramatic, and potentially disruptive on a scale that dwarfs anything the nuclear industry would ever dare to suggest these days after 60 years of perennially depressed expectations.

The best the nuclear industry offers the world today, as we focus more and more relentlessly on accelerated decarbonisation, is providing no more than the same amount of relatively low-carbon electricity in 2050 as it provides today – roughly 10% of global demand. And that’s primarily because the current rate of new build (with 62 reactors under construction as of mid-2015—more than a third of which are in China—with at least 47 suffering delays of varying degrees of severity) will struggle to keep up with the rate of decommissioning as nuclear fleets age all around the world and life extension programmes become both more expensive and more controversial.

Such modest expectations sound increasingly forlorn when set against the emerging prospects of a secure, efficient, distributed energy economy, powered primarily by renewables and smart storage technologies.

This increasingly stark contrast between two very different innovation paradigms is not restricted to today’s understandably partisan advocates of renewable energy. A number of key players are busy transitioning from one paradigm to the next, with two major European utilities leading the way. In December 2014, Germany’s biggest utility, E.ON, announced that it would split in two, retaining the E.ON brand in a company focussing on renewables, networks and “customer solutions”, whilst leaving its “legacy assets” (including nuclear and coal-fired power stations) in a

new company called Uniper. And in April 2015, GDF Suez (now Engie) issued the following statement of intent: “We have one conviction: the energy model of tomorrow will be in 3D: Decarbonized, thanks to the development of renewable energies; Digitized, by deploying intelligent networks; and Decentralized.”

The authors of WNISR have been tracking the contrast between nuclear and renewables for a number of years, and provide a very timely update. The astonishing changes in the solar industry epitomise the general direction of travel:

There now seems to be a general recognition that the fall in production costs of renewable energy technologies, particularly solar photovoltaics (PV), coupled with the expected falling costs of electricity storage, will accelerate the transformation of the power sector. UBS, in a report published in June 2015, stated: “We believe solar will eventually replace nuclear and coal, and be established as the default technology of the future to generate and supply electricity.” An important driver is the realization that solar PV will increasingly be deployed without subsidy, unlike the technology cost curves for nuclear power.

So how long will it take before those seemingly inextinguishable hopes in the promise of nuclear will be finally overwhelmed by the delivered realities of an alternative model that gains momentum not just year on year but month by month? From an innovation standpoint, the answer is absolutely clear: it’s already happened. The static, top-heavy, monstrously expensive world of nuclear power has less and less to deploy against today’s increasingly agile, dynamic, cost-effective alternatives. The sole remaining issue is that not everyone sees it that way—as yet.

A handwritten signature in black ink that reads "Jonathon Porritt". The signature is written in a cursive, flowing style with a long horizontal line extending from the bottom of the last name.

Executive Summary and Conclusions

Key Insights in Brief

- Japan without nuclear power for a full calendar year for the first time since the first commercial nuclear power plant started up in the country 50 years ago.
- Nuclear plant construction starts plunge from fifteen in 2010 to three in 2014.
- 62 reactors under construction—five fewer than a year ago—of which at least three-quarters delayed. In 10 of the 14 building countries *all* projects are delayed, often by years. Five units have been listed as “under construction” for over 30 years.
- Share of nuclear power in global electricity mix stable at less than 11% for a third year in a row.
- AREVA, technically bankrupt, downgraded to “junk” by Standard & Poor's, sees its share value plunge to a new historic low on 9 July 2015—a value loss of 90 percent since 2007
- China, Germany, Japan—three of the world's four largest economies—plus Brazil, India, Mexico, the Netherlands, and Spain, now all generate more electricity from non-hydro renewables than from nuclear power. These eight countries represent more than three billion people or 45 percent of the world's population.
- In the UK, electricity output from renewable sources, including hydropower, overtook the output from nuclear.
- Compared to 1997, when the Kyoto Protocol on climate change was signed, in 2014 there was an additional 694 TWh per year of wind power and 185 TWh of solar photovoltaics—each exceeding nuclear's additional 147 TWh.

The *World Nuclear Industry Status Report 2015* provides a comprehensive overview of nuclear power plant data, including information on operation, production and construction. The WNISR assesses the status of new-build programs in current nuclear countries as well as in potential newcomer countries. This edition provides an analysis of the evolution of construction starts over time. There are also two new chapters, the first describes the serious delays of Generation III+ reactor projects (including the EPR, AP1000, AES-2006) and analyses their origins. The second looks at the history and development status of so-called advanced reactors. The Fukushima Status Report gives an updated overview of the standing of onsite and offsite issues four years after the beginning of the catastrophe.

The Nuclear Power vs. Renewable Energy chapter provides global comparative data on investment, capacity, and generation, especially from nuclear, wind and solar.

Finally, Annex 1 presents a country-by-country overview of all 30 countries operating nuclear power plants, with extended Focus sections on China, France, and the United States—plus Japan.

Reactor Status and Nuclear Programs

Startups and Shutdowns. In 2014, just as in 2013, five reactors started up (three in China, one in Argentina, one in Russia) and one was shut down (Vermont Yankee in the U.S.). In the first half of 2015, four reactors started up in China and one in South Korea, while two were shut down (Doel-1 in Belgium² and Grafenrheinfeld in Germany).

Operation and Construction Data³

Reactor Operation. There are 30 countries operating nuclear power plants in the world, one less than a year ago.⁴ A total of 391 reactors (three more than a year ago) have a combined installed capacity of 337 GW⁵ (5 GW more than a year ago). Not a single unit generated power in Japan in 2014, and WNISR classifies 40 Japanese reactors⁶ as being in Long-Term Outage (LTO).⁷ Besides the Japanese reactors, one Swedish reactor (Oskarshamn-2) meets the LTO criteria and its majority owner has called for its early closure. There are two units that were in LTO in WNISR2014 that now fall outside the category: one South Korean reactor, Wolsong-1, was restarted in June 2015, and one Indian reactor, Rajasthan-1, is to be decommissioned. Ten reactors at Fukushima Daiichi and Daini are considered permanently closed and are therefore not included in the count of operating nuclear power plants. As of early July 2015, it appears likely that at the most two reactors (Sendai-1 and -2 in Kyushu Prefecture) will restart in Japan during 2015.

The nuclear industry remains in decline: The 391 operating reactors—excluding LTOs—are 47 fewer than the 2002 peak of 438, while the total installed capacity peaked in 2010 at 368 GW before declining by 8 percent to 337 GW, which is comparable to levels last seen two decades ago. Annual nuclear electricity generation reached 2,410 TWh in 2014—a 2.2 percent increase over the previous year, but 9.4 percent below the historic peak in 2006.

Share in Power Mix. The nuclear share of the world's power generation remained stable⁸ over the past three years, with 10.8 percent in 2014 after declining steadily from a historic peak of 17.6 percent in 1996. Nuclear power's share of global commercial primary energy production also remained stable at 4.4 percent, the lowest level since 1984.⁹

As in previous years, the “big five” nuclear generating countries—by rank, the United States, France, Russia, South Korea and China—generated over two-thirds (69 percent in 2014) of the world's nuclear electricity in 2014. The U.S. and France account for half of global nuclear generation, and France produces half of the European Union's nuclear output.

² On 18 June 2015, the Belgian Parliament voted legislation to extend the lifetime of Doel-1 and -2 by ten years. However, that decision remains subject to the approval by the national nuclear safety authority. See also section on Belgium in Annex 1.

³ See Annex 1 for a country-by-country overview of reactors in operation and under construction as well as the nuclear share in electricity generation and primary energy.

⁴ Unless otherwise noted, the figures indicated are as of 1 July 2015.

⁵ All figures are given for nominal net electricity generating capacity. GW stands for gigawatt or thousand megawatt.

⁶ Including the Monju reactor, shut down since 1995, listed under “Long Term Shutdown” in the International Atomic Energy Agency (IAEA), Power Reactor Information System (PRIS), database.

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 Less than 0.2 percentage points difference between the three years, a level that is certainly within statistical uncertainties.

⁹ According to BP, “Statistical Review of World Energy”, June 2015.

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-2015 stood at 28.8 years. Over half of the total, or 199 units, have operated for more than 30 years, including 54 that have run for over 40 years. One third (33) of the U.S. reactors have operated for more than 40 years.

Lifetime Extension. The extension of operating periods beyond original design basis is licensed differently from country to country. While in the U.S. about three-quarters of the reactors have already received license extensions for up to a total lifetime of 60 years, in France, only 10-year extensions are granted and the safety authorities made it clear that there is no guarantee that all units will pass the 40-year in-depth examinations. Furthermore, the proposals for lifetime extensions appear in conflict with the French government's target to reduce the nuclear share from the current three-quarters to half by 2025. In Belgium, 10-year extensions for two (now three) additional reactors were voted by Parliament but not yet approved by the safety authority; these extensions would not jeopardize the legal nuclear phase-out goal for 2025.

Lifetime Projections. If all currently operating reactors were shut down at the end of a 40-year lifetime, by 2020 the number of units would be 19 below the end of 2014 number, with the installed capacity rising by 1.5 GW. In the following decade to 2030, 188 units (178 GW) would have to be replaced—five times the number of startups achieved over the past decade. If all licensed lifetime extensions were actually implemented and achieved, the number of operating reactors would still only increase by four, and adding 21 GW in 2020 and until 2030, an additional 154 GW (169 new reactors) would have to start up to replace shutdowns.

Construction. As in previous years, fourteen countries are currently building nuclear power plants. As of July 2015, 62 reactors were under construction—five fewer than in July 2014—with a total capacity of 59 GW—5 GW less than a year ago. Almost 40 percent of the projects (24) are in China.

- The current average time since work started at the 62 units under construction is 7.6 years.
- All of the reactors under construction in 10 out of 14 countries have experienced delays, mostly year-long. At least three-quarters (47) of all units under construction worldwide are delayed. The 15 remaining units under construction, of which nine are in China, began work within the past three years or have not yet reached projected start-up dates, making it difficult to assess whether or not they are on schedule.
- Five reactors have been listed as “under construction” for more than 30 years. The U.S. Watts Bar-2 project in Tennessee holds the record as its construction began in December 1972. Two Russian units (BN-800, Rostov-4) and Mochovce-3 and -4 in Slovakia have also been worked on for over 30 years. Khmelnytski-3 and -4 in Ukraine are approaching the 30-year mark, with construction times reaching 29 and 28 years respectively. Furthermore, having announced the cancellation of the construction agreement with Russia, that project is expected to experience further delays.
- Two units in India, Kudankulam-2 and the Prototype Fast Breeder Reactor (PFBR), have been listed as “under construction” for 13 and 11 years respectively. The Olkiluoto-3 building site in Finland will reach its tenth anniversary in August 2015, and its owner has stopped announcing planned startup dates.
- The average construction time of the latest 40 units (in nine countries) that started up since 2005—all but one (in Argentina) in Asia or Eastern Europe—was 9.4 years with a large range from 4 to 36 years.

Construction Starts & New Build Issues

Construction Starts. In 2014, construction began on three reactors, one each in Argentina, Belarus, and the United Arab Emirates (UAE). This compares to 15 construction starts—of which 10 were in China alone—in 2010 and 10 in 2013. China did not start a single new construction in 2014, but had done two in the first half of 2015—so far the world's only starts

in 2015. Historic analysis shows that construction starts in the world peaked in 1976 at 44. Between 1 January 2011 and 1 July 2015, first concrete was poured for 26 new plants worldwide—fewer than in a single year in the 1970s.

Construction Cancellations. Between 1977 and 2015, a total of 92 (one in eight) of all construction sites were abandoned or suspended in 18 countries in various stages of advancement.

Newcomer Program Delays. Only two newcomer countries are actually building reactors—Belarus and UAE. Further delays have occurred over the year in the development of nuclear programs for most of the more or less advanced potential newcomer countries, including Bangladesh, Egypt, Jordan, Poland, Saudi Arabia, Turkey, and Vietnam.

Generation III Delays

Twenty-nine years after the Chernobyl disaster, none of the next-generation or so-called Generation III+ reactors has entered service, with construction projects in Finland and France many years behind schedule. Of 18 units of Generation III+ design (eight Westinghouse AP1000, six Rosatom AES-2006, four AREVA EPR), 16 are delayed by between two and nine years. A number of causes for delays have been assessed: design issues, shortage of skilled labor, quality-control issues, supply chain issues, poor planning either by the utility and/or equipment suppliers, and shortage of finance. Standardization did not take place, and the introduction of modularized design seems to have simply shifted the quality issues from construction sites to module factories. Serious defects found in several French pressure-vessel forgings could scuttle the entire EPR enterprise.

Advanced Nuclear Reactor Development Status

The concept for Small Modular Reactors (SMR) has been around for decades. Over a dozen basic designs have been discussed. In the U.S., where the government has been funding SMR development since the 1990s, the Nuclear Regulatory Commission has still not received a licensing application for any SMR design. In Russia, a Floating Point Unit design, a sort of swimming reactor, was licensed in 2002. The construction of two reactors began in 2007 but has been delayed repeatedly, partly for financial reasons. In South Korea an SMR design called System-Integrated Modular Advanced Reactor (SMART) has been under development for 20 years. The design was approved by the regulator in 2012, but no unit has been sold. In China, one SMR of the high-temperature gas cooled reactor is under construction. In South Africa, the Pebble Bed Modular Reactor—for a long time considered the most advanced SMR project in the world—was abandoned in 2010, after public expenditure of about US\$1 billion, because it attracted no private investors or customers. The design was never completed. India has been developing an Advanced Heavy Water Reactor (AHWR) since the 1990s, but none is under construction. In February 2014, Argentina started construction on a small unit, based on the pressurized water reactor, called CAREM, a domestic design that has been under development since the 1980s, reportedly at a cost of US\$17,000 per installed kW_e, a record for reactors currently under construction in the world. Despite extensive government aid, U.S. development of SMRs is gaining far less market traction than publicity, as SMRs are initially far costlier than uncompetitively costly large reactors, their postulated learning curve relies upon an ability to reduce their cost has never been demonstrated anywhere for nuclear technology, and they face a formidable competitive landscape dominated by efficiency and renewable technologies already decades ahead in capturing their own economies of mass production.

Economics and Finances

AREVA Debacle. The French state controlled integrated nuclear company AREVA is technically bankrupt after a cumulated four-year loss of €8 billion and €5.8 billion current debt on an annual turnover of €8.3 billion. On 9 July 2015, AREVA's share value plunged to a historic low, 90 percent below its 2007 peak. The company will be broken up, with French-state-controlled utility EDF expected to take the majority stake in the reactor building and maintenance subsidiary AREVA NP that will then be opened up to foreign investment. The move could turn out highly problematic for EDF as its risk profile expands.

Hinkley Point C and State Aid. In December 2014, the U.K. model of Contract for Difference (CFD), a kind of feed-in tariff agreement for nuclear electricity that would provide a generous long-term subsidy for new-build, was accepted by the EU Commission following a formal enquiry into the Hinkley Point C project. However, the Austrian government has filed a complaint with the European Court of Justice against the decision with the Luxemburg government announcing it will join. Separately ten energy companies have also filed a complaint. Serious concerns about the project are reported from within the British Treasury, and needed investors have not yet materialized.

Operating Cost Increases. In some countries (including Belgium, France, Germany, Sweden, and the U.S.), historically low inflation-adjusted operating costs have escalated so rapidly that the average reactor's operating cost is barely below, or even exceeds, the normal band of wholesale power prices. This has led to a number of responses from nuclear operators. The largest nuclear operator in the world, the French-state-controlled utility EDF, has requested significant tariff increases to cover its operating costs. In Germany, operator E.ON closed one of its reactors six months earlier than required by law. In Sweden, at least four of the ten units will be shut down earlier than planned because of lower than expected income from electricity sales and higher investment needs. In the U.S., utilities are trying to negotiate with state authorities support schemes for reactors that they declare are no longer competitive in current market conditions. In Belgium, it is uncertain whether Electrabel (GDF-Suez) will be able to restart two reactors with serious defects in their pressure vessels.

Fukushima Status Report

Over four 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. This assessment includes analyses of onsite and offsite challenges that have arisen since and remain significant today.

Onsite Challenges. At present, radiation levels remain very high inside the reactor buildings (several Sievert per hour) and make human intervention there impossible. The problem is compounded by difficulties with various types of robots that have got stuck in the buildings and had to be abandoned. Molten fuel debris removal is planned at units 1 and 2 in the first half of Financial Year (FY) 2020, and at unit 3 in the second half of FY2021. A 30–40-year period is expected to be needed to complete decommissioning, with work to begin in December 2021. Whether these timelines can be implemented remains questionable.

Large quantities of water (about 300 cubic meters per day) are continuously injected to cool the fuel debris. To reduce storage requirements for contaminated water, operator Tokyo Electric Power Company (TEPCO) installed decontamination systems and re-injects partially decontaminated rather than fresh water. However, the systems have achieved only low operation rates because of technical problems and human errors.

Furthermore, due to underground intrusion of water into the basements, which are already filled with highly contaminated water, the net amount to be stored continues to increase by 300 to 400 tons every day, the equivalent of an additional 1,000-cubic-meter storage tank every 2.5 days. The storage capacity onsite is now 800,000 cubic meters, the equivalent of

320 Olympic swimming pools. A groundwater bypass system and a Frozen Soil Wall are in preparation. However, the first trials of the ice wall have been disappointing.

- **Unit 1.** May 2015 marked the beginning of the removal of the building cover—which was installed to reduce the dispersion of radioactive substances to the environment—in order to allow the debris to be removed before starting to unload the spent fuel from the storage pool.
- **Unit 2.** Decommissioning has not progressed beyond the preparatory stages because of high radiation levels.
- **Unit 3.** Debris has been removed from the spent fuel pool and preparations are underway for spent fuel removal.
- **Unit 4.** The first significant milestone, the removal of the spent fuel from the cooling pool, was reached in December 2014. The spent fuel—equivalent in quantity to the other three reactor pools' contents combined—presented a significant potential hazard in case of a spent-fuel fire.

Offsite Challenges. According to government figures, the number of evacuees from Fukushima Prefecture as of January 2015 was about 120,000 (vs. 164,000 at the peak in June 2013). About 3,200 people have died for reasons related to the evacuation, such as decreased physical condition or suicide (all classified as “earthquake-related deaths”). Among these, about 1,800 people (more than half) are from Fukushima Prefecture. Many evacuated people have given up on returning to their homes even if the restrictions are lifted.

Decontamination Wastes. Waste generated by decontamination activities inside and outside the evacuation area has reached more than 157,000 tons by the end of 2014, according to government estimates.

Cost of the Accidents. The Japanese Government has not provided a comprehensive total accident cost estimate. However, data for individual cost categories already total US\$100 billion, of which about 60 percent is for compensation, without taking into account such indirect effects as impacts on food exports and tourism.

Nuclear Power vs. Renewable Energy Deployment

The power sector is in a period of profound transformation. New technology and policy developments favor decentralized systems and renewable energies. As these are generally not owned by incumbent electricity utilities, these developments are at best unfavorable and potentially a real threat for the nuclear industries and utilities.

Investment. After two years of decline, global investment in renewable energy increased to US\$270 billion (+17 percent) in 2014, close to the all-time record of US\$278 billion in 2011, and four times the 2004 total. China alone spent over US\$83 billion in 2014 (31 percent of the world's total), about half each on wind and solar—totaling nine times the amount it invested in nuclear power (US\$9.1 billion). Global investment decisions on new nuclear power plants also remained an order of magnitude below renewables investments.

Installed Capacity. Almost half (49 percent) of the added global electricity generating capacity was new renewables (excluding large hydro), including 49 GW for new wind power (up from 34 GW added in 2013) and 46 GW of solar photovoltaics (up from 40 GW added in 2013). China accelerated its deployment of wind with 23 GW being added—up from 16 GW added in 2013—equaling 45 percent of the global increase in 2014 and with a total of 115 GW wind capacity installed already exceeding its 2015 goal of 100 GW. China also added 3 GW of nuclear capacity, 65 percent of the global increase.

Since 2000, wind added 355 GW and solar 179 GW—respectively eighteen and nine times more than nuclear with 20 GW. Taking into account the fact that 41 reactors with 37 GW capacity are currently in LTO, operational nuclear capacity meanwhile fell by 17 GW.

Electricity Generation. On average, an installed nuclear kilowatt produces nearly twice the annual electricity of a renewable kilowatt (mix of sources excluding big hydroelectric dams). Nevertheless, in terms of actual production, Brazil, China, Germany, India, Japan, Mexico, the

Netherlands, and Spain—a list that includes three of the world’s four largest economies—now all generate more electricity from non-hydro renewables than from nuclear power. These eight countries represent more than three billion people or 45 percent of the world’s population. In China, as in the previous two years, in 2014, electricity production from wind alone (158 TWh), exceeded that from nuclear (124 TWh). In the UK, renewables, including hydropower, overtook nuclear output in 2014 for the first time in decades. In the U.S., since 2001, the average growth rate for renewable energy generation has been five percent per year. Of all U.S. electricity, 13 percent was generated by renewables in 2014,¹⁰ up from 8.5 percent in 2007.

In 2014, annual growth for global generation from solar was over 38 percent, for wind power over 10 percent, and for nuclear power 2.2 percent. Compared to 1997, when the Kyoto Protocol on climate change was signed, in 2014 an additional 694 TWh of wind power was produced globally and 185 TWh of solar photovoltaics electricity, each surpassing nuclear’s additional 147 TWh. The figures for the European Union illustrate the rapid decline of the role of nuclear: during 1997–2014, wind produced an additional 242 TWh and solar 98 TWh, while nuclear power generation *declined* by 47 TWh. In short, the data does not support claims that nuclear production can be expanded faster than, or even nearly as fast as, modern renewables, whose small units and lower capacity factors are more than offset by their short lead times, easy manufacturability and installation, and rapidly scalable mass production.

¹⁰ U.S.EIA, “Renewables share of U.S. energy consumption highest since 1930s”, 28 May 2015, see <http://www.eia.gov/todayinenergy/detail.cfm?id=21412>, accessed 14 June 2015.

Introduction

*"For all intents and purposes,
AREVA is dead."*

Forbes/Business Blog
4 June 2015¹¹

*"The Way Humans Get Electricity Is About
to Change Forever."*

Bloomberg New Energy Finance
23 June 2015¹²

The challenge to select and assess the outstanding events of the year for the release of the July 2015 edition of the *World Nuclear Industry Status Report* turned out to be particularly tough: For the first time in 45 years, Japan was without nuclear electricity (and no lights went out) and, indeed, without any operating industrial nuclear facility or even research reactor; AREVA, the self-proclaimed "global leader in nuclear energy", went technically bankrupt; China, the global leader in new-build, launched a construction site after a 15-month break; in the U.K., concerning the French sponsored new-build project, there are "growing suspicions" (*Financial Times*)¹³ that the Treasury "would not be disappointed if Hinkley [Point C] never happened"; the French draft Energy Bill passed the second reading at the French National Assembly stipulating the reduction of the nuclear share from three quarters to about half by 2025; and so on.

While this report attempts to provide an overview of essential events of the past year its main aim is to identify and highlight the trends.

Hinkley Point C stands for events and trends. The project was meant to represent the first nuclear new-build decision in the U.K. for decades, the beginning of a new era of nuclear investment, a sign for the country, for Europe as a whole and far beyond. After years of negotiations and the approval by the European Commission of the proposed deal between the French group Électricité de France (EDF) and the U.K. government, the parties involved kept stating that a final agreement was imminent. Today, the project is in a shambles. The selected builder, the French majority state owned company AREVA that was also to provide ten percent of the capital investment, is technically bankrupt. The selected strategic investor, the French majority state owned group EDF supposed to bail out AREVA, struggles with a €34 billion (US\$38 billion) debt load and chronically negative cash flow. Credit-rating company Moody's didn't wait long after the French government's decision on 3 June 2015 to have EDF acquire a majority stake in AREVA's reactor-building subsidiary AREVA NP and the following day issued a warning that the move could be "credit negative", as it could "increase EDF's business risk profile and weigh on its credit metrics".¹⁴ This announcement comes only weeks after Moody's in April 2015 downgraded EDF to A1, associated with a negative outlook, arguing that "risks associated with the transition of EDF's

¹¹ *Forbes*, "France's Nuclear Industry Dream Faces Melt-Down At Expense Of State Coiffers, Tax Payers", 4 June 2015, see <http://www.forbes.com/sites/marcelmichelson/2015/06/04/frances-nuclear-industry-dream-faces-melt-down-at-expense-of-state-coiffers-tax-payers/>, accessed 8 June 2015.

¹² *Bloomberg New Energy Finance (BNEF)*, "The Way Humans Get Electricity Is About to Change Forever", 23 June 2015, see <http://www.bloomberg.com/news/articles/2015-06-23/the-way-humans-get-electricity-is-about-to-change-forever>, accessed 3 July 2015.

¹³ *Financial Times*, "French reactor problems cast doubt on UK nuclear power plant", 14 June 2015, see <http://app.ft.com/cms/s/b8741dd0-1048-11e5-bd70-00144feabdc0.html>, accessed 23 June 2015.

¹⁴ Moody's Investors Service, "EDF's anticipated acquisition of AREVA NP majority stake could be credit negative", 4 June 2015.

French power generation and supply activities from a predominantly regulated cost-reflective tariff model towards an increasing exposure to market power prices”.¹⁵ The share of domestic electricity volumes that EDF sells to end-customers under regulated tariffs is expected to decrease from 84 percent in 2014 to less than 50 percent in 2016. In May 2015, Standard & Poor's, the other large credit-rating agency, also revised EDF's outlook to "negative" reflecting "the potential unfavorable developments that could stress EDF further, including declining power prices, a possible transaction with nuclear services provider AREVA, or risks on nuclear new builds.”¹⁶ These nuclear new builds include AREVA's Olkiluoto-3 project in Finland and EDF's Flamanville-3 construction site, both delayed for at least five years, confronted with numerous technical problems and about three times over budget, as well as the “development of its investment decision on its Hinkley Point C nuclear project in the U.K., notably regarding construction risks and financing plans”.¹⁷ In a dedicated section, this report identifies some of the reasons for these substantial delays and cost overruns not only for the EPR but for practically all of the so-called Generation-III reactors.

Around 40 percent of the financing for Hinkley Point is to come from Chinese investors, a prospect fiercely attacked by Dieter Helm, UK Government Advisor and Special Advisor to the European Commissioner for Energy: “It is a no-brainer. Add in the military and security issues of letting Chinese state-owned companies into the heart of the British nuclear industry, and it seems positively perverse to prefer Chinese government money to British government money in so sensitive a national project.”¹⁸ Finally, the Austrian Chancellor himself announced, on 29 June 2015, the Government's legal case at the European Court of Justice against the European Commission approval of the Hinkley Point deal: “We lodge a complaint and that is an important signal for all of Europe”, Chancellor Werner Faymann stated and added: “This complaint shall not only have suspensive effect for the subsidy, but especially also a dissuasive effect for investors, and not only in Great Britain but all over Europe”.¹⁹ The Government of Luxemburg and ten renewable energy utilities have already announced they would follow the example.

The case of Hinkley Point C thus illustrates many of the international nuclear industry's dilemma for the future. Excessive lead times, tremendous financing difficulties because of the sheer size of the investments, substantial technical and legal hurdles, uncertain implementation conditions and ferocious competitors especially on the decentralized level in a rapidly changing sector environment. One question sticks out: Too big to matter?

The question is not only relevant for future investments, it is acute today. With power generation assets that cost much more than planned to operate and don't operate the number of hours per year as planned, the large traditional utilities see their profit margins fade away. Few have started

¹⁵ Moody's, “Moody's downgrades EDF to A1; negative outlook”, 16 April 2015.

¹⁶ Standard & Poor's, “Electricite de France Outlook Revised to Neg On Heightened Exposure To Unregulated Activities; 'A+/A-1' Ratings Affirmed”, 7 May 2015, see <http://www.standardandpoors.com/enUS/web/guest/article/-/view/type/HTML/id/1397578>, accessed 27 May 2015.

¹⁷ Ibidem.

¹⁸ Dieter Helm, “British energy policy – what happens next?”, 16 June 2015, see <http://www.dieterhelm.co.uk/node/1407>, accessed 24 June 2015.

¹⁹ Bundeskanzleramt Österreich, “Werner Faymann: 'Österreich reicht Klage gegen die Subventionierung des AKW Hinkley Point ein’”, Press Release, 23 June 2015, see http://www.bundeskanzleramt.at/site/cob_59880/currentpage_0/8169/default.aspx, accessed 24 June 2015.

to radically adjust to new circumstances. The internal controversy about the future of the business remains lively.

On 8 June 2015, the U.S. utility industry listened to Elon Musk, innovative entrepreneur, mainly known for the Tesla electric car, the photovoltaic power leasing leader SolarCity²⁰ and the recent Power Wall residential battery concept. *Energy Wire* reported the following exchange between electricity utility executives²¹:

“I don't buy the fact that this [traditional utility model] is a declining business,” said Tom Fanning, CEO of Southern, the largest investor-owned utility in the Southeast of the U.S.

“Even though that's what the numbers say?” Christopher Crane, CEO of Exelon, the largest nuclear operator in the U.S., interjected. (...)”

“So then if distributed generation is eroding your growth, own distributed generation”, stated Fanning.

The problem? Nuclear utilities have almost never invested into distributed generation. This is logical, as decentralization is the opposite to their business model that operates according to the old paradigm of centralized generation–transportation over substantial distances–distribution to final consumers. But if consumers start generating their own power—over two million households in Australia, around 1.5 million in Germany—and countless families, businesses and public administrations elsewhere follow suit, what will the large traditional electricity utilities sell to whom?

It is surprising to what extent the recovery strategies elaborated in France to save the national nuclear champions AREVA and EDF fall short of addressing the issues of the real world. There is no significant export market for AREVA's reactors and as this report shows, ongoing projects are constantly delayed and most potential new markets don't meet the reality check. What is certain is that the projects in Finland and France have turned into a liability rather than an asset. While Hinkley Point might be just another €1.5 billion loss. At the same time, EDF's client base is shrinking and electricity consumption is stagnating at best, while maintenance, backfitting and upgrading costs are increasing rapidly. Certainly a “negative outlook”.²²

What is spectacular is the extent to which the nuclear industry is appearing to ignore reality. In March 2013, the late Luc Oursel, then AREVA's CEO, predicted that six reactors in Japan would be back online by the end of that year and that his company was counting on ten new reactor orders

²⁰ Less known than the Tesla car, SolarCity has revolutionized investment schemes in decentralized solar systems in the U.S. SolarCity custom-designs, installs, finances and maintains photovoltaic systems on the basis of a guaranteed kWh sales price that is usually 10-15 percent below the local utility rate. SolarCity claims to be “America's largest solar power provider” and to “provide one out of every four new solar electricity systems nationwide”. See company website at <http://www.solarcity.com/company/about>, accessed 24 June 2015. Many other companies have since copied the business model that has turned into the dominant implementation scheme for solar electricity in the U.S.

²¹ *EnergyWire*, “Utilities—CEOs grapple with an elephant in the room – the future of electricity”, 22 June 2015, see <http://www.eenews.net/stories/1060020624>, accessed 24 June 2015.

²² For a recent independent analysis of the French nuclear industry's record see Yves Marignac, Manon Besnard, “Nucléaire français: l'impasse industrielle”, 23 June 2015, see <http://www.greenpeace.org/france/PageFiles/300718/20150623Rapport-Nucl%C3%A9aireFrance-ImpasseIndustrielle.pdf>; a 5-page English summary is at <http://www.greenpeace.org/france/Global/france/openspace/150630FrenchNuclearDeadlockReport-ExecSummary.pdf>; both accessed 3 July 2015.

by the end of 2016.²³ Two years later, no reactor is operating in Japan and 18 months from the deadline not a single new reactor order has materialized. In 2003, Westinghouse predicted a 36-month construction schedule for its AP1000 reactor.²⁴ Twenty-six months into the construction of the first two units to be built in the U.S., the estimated time to completion is an *additional* 48 months, which would bring the total construction time to 74 months or more than twice the original estimate. “Nuclear Could Replace Fossil Fuels in Less than a Decade”, said a headline of trade agency *NucNet* in May 2015, quoting a study that had simply extrapolated the building ratios during the peak construction periods in France and Sweden on a global scale.²⁵ Russia has been particularly prolific with announcements of new nuclear projects. But even long-time World Nuclear Association strategist Steve Kidd considers it “reasonable to suggest that it is highly unlikely that Russia will succeed in carrying out even half of the projects in which it claims to be closely involved (...)”.²⁶ Indeed, the Russian builders aren't doing well neither. In February 2015, Moody's downgraded Atomenergoprom—100 percent subsidiary of Rosatom, as integrated nuclear group also building reactors it is comparable to the French AREVA—to “junk” (Ba1) and assigned a “negative outlook”.²⁷ The lack of realism and overblown market expectations drive nuclear companies and traditional utilities into ruin.

Some say that the nuclear industry has to address the size issue and develop models with reduced capacity, so-called Small and Medium-size Reactors, also labeled Small Modular Reactors or SMRs. “SMRs could be a way forward for the European nuclear industry because they are easier to manage, finance, get regulatory approval for, and even [win] public support”, a recent industry conference heard.²⁸ WNISR2015 provides an overview of history and status of SMRs and other “advanced reactor” designs. The concept of small reactors has been around for decades and any commercial-scale application still seems many years away and can therefore hardly be expected to represent a game changer for nuclear power. Amory Lovins, Chief Scientist at the Rocky Mountain Institute, stated: “The basic challenge of the economies-of-mass-production model is that another kind of SMR, Small Modular Renewables (and efficiency), can scale down much better and is already decades ahead in exploiting its own formidable economies of mass production. Nuclear SMRs can never catch up.”²⁹

²³ *Les Echos*, “Areva table sur la relance de six réacteurs au Japon en 2013”, 5 March 2013, see http://www.lesechos.fr/05/03/2013/LesEchos/21389-080-ECH_areva-table-sur-la-relance-de-six-reacteurs-au-japon-en-2013.htm, accessed 25 June 2015.

²⁴ Regis A. Matzie, “The AP1000 Reactor Nuclear Renaissance Option”, 26 September 2003.

²⁵ *NucNet*, “Nuclear Could Replace Fossil Fuels in Less than a Decade, Researchers Say”, 18 May 2015, see <http://www.nucnet.org/all-the-news/2015/05/18/nuclear-could-replace-fossil-fuels-in-less-than-a-decade-researchers-say>, accessed 27 June 2015.

²⁶ Steve Kidd, “The world nuclear industry – is it in terminal decline?”, *Nuclear Engineering International (NEI)*, 6 October 2014, see <http://www.neimagazine.com/opinion/opinionthe-world-nuclear-industry-is-it-in-terminal-decline-4394815/>, accessed 7 June 2015.

²⁷ Moody's, “Rating Action: Moody's takes rating actions on six Russian utility and infrastructure GRIs; assigns negative outlook”, 25 February 2015, see <https://www.moody.com/research/--PR319091>, accessed 4 June 2015.

²⁸ *Nucnet*, “SMRs Could Be The Way Forward For Europe, Conference Told”, 16 June 2015, see <http://www.nucnet.org/all-the-news/2015/06/16/srms-could-be-the-way-forward-for-europe-conference-told>, accessed 25 June 2015.

²⁹ Amory B. Lovins, personal communication, 15 June 2015.

General Overview Worldwide

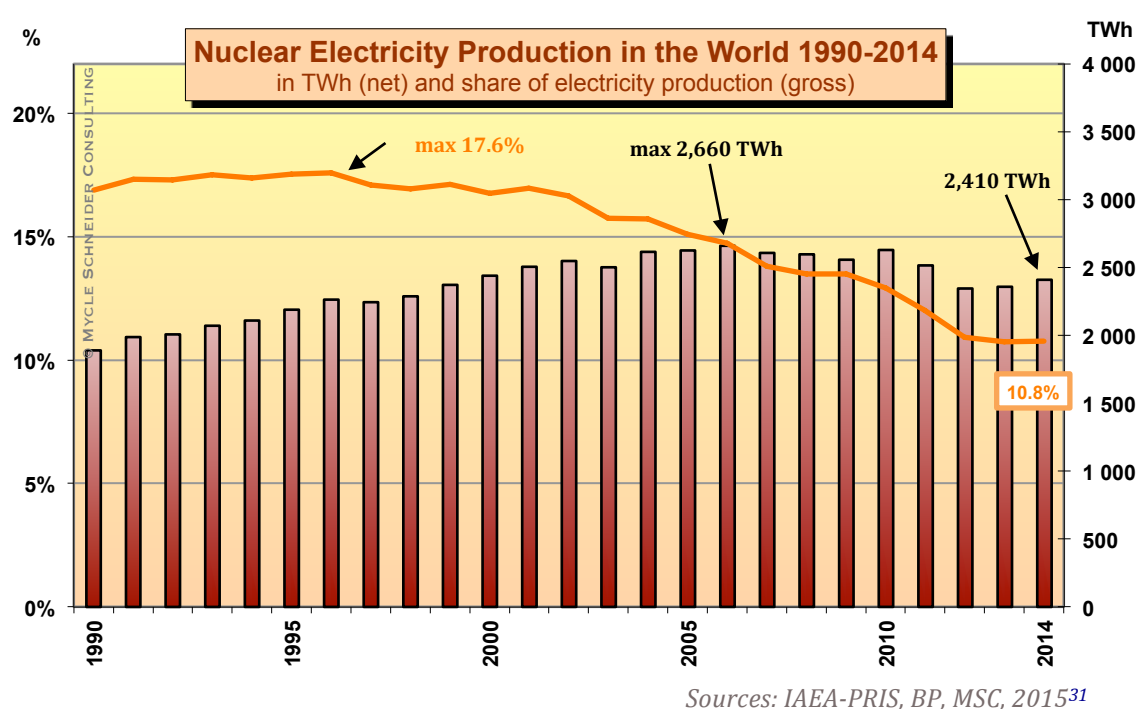
Introduction

The world's nuclear statistics remain distorted by political choice. Four years after the Fukushima events started unfolding on 11 March 2011, all of the official references continue to misrepresent the real and very concrete effects of the disaster on the Japanese nuclear program: its entire nuclear reactor fleet (with the exception of the six units at Fukushima Daiichi and an additional five units recently officially closed), that is 43 units, are still considered “in operation” or “operational”. In reality, no nuclear power was generated in Japan since September 2013 and many of the “operational” units will likely never generate any power again, which is certainly the case for the four Fukushima Daini reactors.

Overview—The Role of Nuclear Power

As of the middle of 2015, 30 countries were operating nuclear reactors for energy purposes, one less (Japan) than in previous years. Nuclear power plants generated 2,410 net terawatt-hours (TWh or billion kilowatt-hours) of electricity in 2014³⁰, a 2.2 percent increase, but still less than in 2000 and 9.4 percent below the historic peak nuclear generation in 2006 (see Figure 1.)

Figure 1: Nuclear Electricity Generation in the World



³⁰ 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 www.iaea.org/programmes/a2/index.html. Production figures are net of the plant's own consumption unless otherwise noted.

³¹ BP stands for BP plc; MSC for Mycle Schneider Consulting.

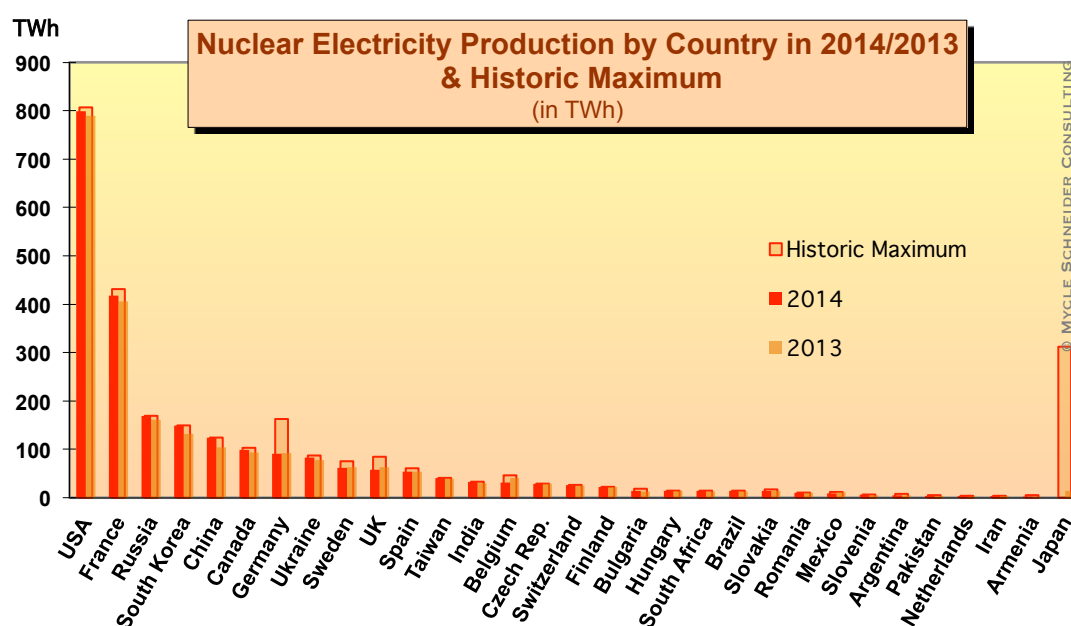
Nuclear energy's share of global commercial electricity generation remained stable over the past three years³², but declined from a peak of 17.6 percent in 1996 to 10.8 percent in 2014³³.

In 2014, nuclear generation increased in 19 countries, declined in nine, and remained stable in three³⁴. A surprising eight countries (China, Hungary, India, Russia, Slovenia, South Africa, South Korea, Taiwan) achieved their greatest nuclear production in 2014, although, of these, only China and Russia started up new reactors over the year. Apparently, none of the six other countries implemented uprating³⁵ during the year. The increases are therefore likely to be due to better operational management or earlier uprating as the respective load factors increased significantly. (See Figure 2.)

As in the previous years, the “big five” nuclear generating countries—by rank, the United States, France, Russia, South Korea and China—generated over two thirds (69 percent in 2014) of all nuclear electricity in the world and two countries alone, the U.S. and France accounted for half of global nuclear production.

The three countries that have phased out nuclear power (Italy, Kazakhstan, Lithuania) and Armenia all generated their historic maximum of nuclear electricity in the 1980s. Several other countries' nuclear power generation peaked in the 1990s, among them Belgium, Canada, Japan, and the U.K. A further six countries' nuclear generation peaked between 2001 and 2005: Bulgaria, France, Germany, South Africa, Spain, and Sweden.

Figure 2: Annual Nuclear Power Generation by Country and Historic Maximum



Sources: IAEA-PRIS, MSC, 2015

³² +0.04 percentage points in 2014 compared to 2013 and -0.15 percentage points compared to 2012. In 2015, BP corrected the 2013 figure from 10.76 percent to 10.74. These differences are no doubt within statistical uncertainties.

³³ BP, “Statistical Review of World Energy”, June 2015.

³⁴ Less than 1 percent variation from the previous year.

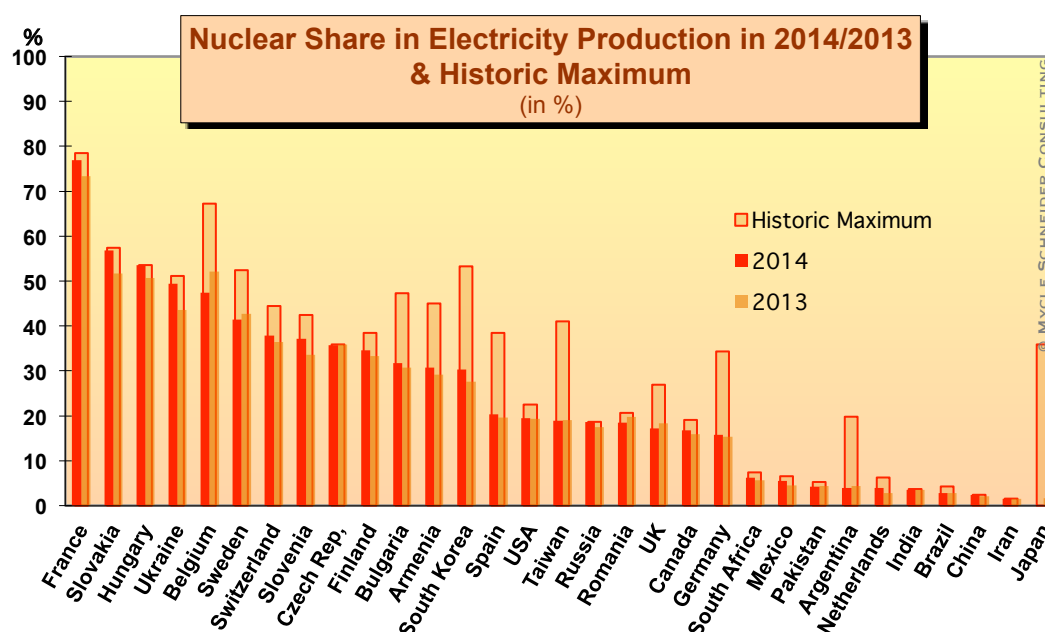
³⁵ Increasing the capacity of nuclear reactors by equipment upgrades e.g. more powerful steam generators or turbines.

According to the latest assessment by *Nuclear Engineering International*, which assesses about 400 of the world's nuclear reactors, the global annual load factor of nuclear power plants slightly increased to 72 percent (+1.4 percent), but is still significantly below the 77 percent in 2010.³⁶

Slovenia's one-reactor program achieved the highest load factor in 2014 with 100 percent, followed by Romania (95.2 percent), Taiwan (93.7 percent) and Finland (93.4 percent).³⁷ Romania and Finland lead the lifetime load factors with 91.3 and 87.5 percent respectively. However, the two countries only operate two and four reactors respectively.

Amongst the larger nuclear programs, the most remarkable annual changes in 2014 in load factor performance are reported, on the positive side, from South Korea (+9.2 percentage points, recovering from the quality-control scandal), South Africa (+7.2 percent) and Ukraine (+5.4 percentage points could not make up for the 2013 drop of 6.3 percentage points due to major upgrading work) and on the negative side from Belgium (-14 percentage points mainly triggered by the continuing problem with pressure vessel faults at two reactors) and China (-7 percentage points).

Figure 3: Annual Nuclear Share in Electricity Mix by Country and Historic Maximum



Sources: IAEA-PRIS, MSC, 2015

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 historic maximum (see Figure 3).

³⁶ Nuclear Engineering International (NEI) load factor definition: "Annual load factors are calculated by dividing the gross generation of a reactor in a one-year period by the gross capacity of the reactor (sometimes called output), as originally designed, multiplied by the number of hours in the calendar year. The figures are expressed as percentages. Where a plant is uprated, the revised capacity is used from the date of the uprating."

³⁷ Unless noted otherwise, all load factor figures in this report are from Caroline Peachey, "Load Factors to end December 2014", NEI, May 2015 (print version).

There were three exceptions in 2015 besides Iran, which started its first and sole nuclear reactor only in 2012:

- China exceeded its previous maximum of 2.2 percent, already achieved in 2003, to reach 2.4 percent. The 0.2 percentage-point increase was achieved with a three times higher nuclear power output in 2014 than in 2003.
- Hungary beat its 25-year-old record by 3.2 percentage points to reach 53.6 percent.
- Russia increased its 2012 record by 0.8 percentage points to 18.6 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 showed far more startups than shutdowns (52/30), while in the decade 2001–2010, shutdowns outweighed startups (35/32). In other words, 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 the mid-2015, the startup of 24 reactors did not match the shutdown of 32 units over the same period—largely as a result of the events in Fukushima. In 2014, five reactors started up (three in China, one in Argentina, one in Russia) and one was shut down (Vermont Yankee in the U.S.). In the first half of 2015, four reactors started up in China and one in South Korea, while two were shut down (Doel-1 in Belgium³⁸, Grafenrheinfeld in Germany). In addition, five closures were announced in Japan.³⁹ All 40 reactors, except for one (Argentina) that started up over the past decade are in Asia (China, India, Iran, Japan, Pakistan, South Korea), or Eastern Europe (Romania, Russia, Ukraine).⁴⁰ With 18 units, China started up by far the largest fleet, followed by India (7) and South Korea (5).

The International Atomic Energy Agency (IAEA) in its online database Power Reactors Information System (PRIS) still counts 43 units in Japan in its total number of 438 reactors “in operation”⁴¹; yet no nuclear electricity has been generated in Japan since September 2013 and it is currently unclear whether any unit will restart operations in 2015.⁴² The year 2014 was the

³⁸ On 18 June 2015, the Belgian Parliament voted legislation to extend the lifetime of Doel-1 and -2 by ten years. However, the decision remains subject to the approval by the national nuclear safety authority. See also section on Belgium in Annex 1.

³⁹ The *World Nuclear Industry Status Report* (WNISR) modifies the statistics retroactively according to the latest electricity generation of the officially shutdown units, which was in 2010 (2) and 2011 (3), which raises the number of units taken off the grid in Fukushima-year 2011 from 19 to 22. This number is likely to rise further, with additional final closure announcements to be expected in Japan.

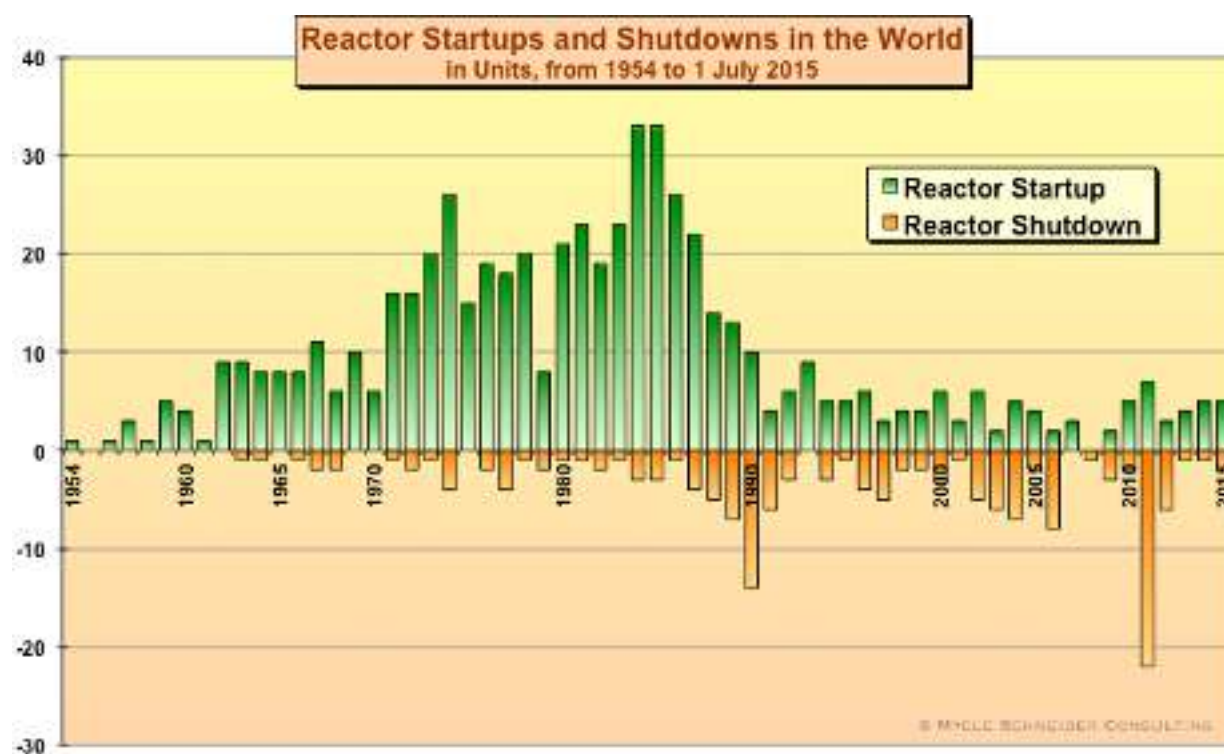
⁴⁰ The last units to start up in the Western world were Argentina’s Atucha-2 in 2014 after 33 years of construction, Brazil’s Angra-2 in 2000 after 24 years, and Civaux-2 in France in 1999 after 8.5 years.

⁴¹ IAEA, “Power Reactor Information System”, see <http://www.iaea.org/pris/>, accessed 27 June 2014.

⁴² On 8 June 2015, the Japanese regulator announced the “discovery of numerous incomplete documents and erroneous written entries” concerning the Sendai nuclear power plant—Sendai is at this point considered the most advanced site in the restart attempts in Japan—and that it was “redoing portions of the pre-service inspections”. The Japan Atomic Industrial Forum (JAIF) stated that “it seems pointless to hope that the power

first in which there was zero nuclear electricity generation in Japan since its first commercial reactor Tokai-1 was connected to the grid on 10 November 1965, almost 50 years ago (see Figure 5). Only two reactors (Ohi-3 and -4) operated in 2013 and ten in 2012. In fact, as of June 2015, no commercial nuclear facility is operating in Japan, including uranium enrichment, fuel fabrication and reprocessing plants. In addition, no research reactor is functioning. In other words, four years after the Fukushima disaster began unfolding, the entire Japanese nuclear industry is shut down.

Figure 4: Nuclear Power Reactor Grid Connections and Shutdowns, 1954-2015



Sources: IAEA-PRIS, MSC, 2015

The unique situation in Japan needs to be reflected in world nuclear statistics. The attitude taken by the IAEA, the Japanese government, utilities, industry and research bodies as well as other governments and organizations to continue considering the entire stranded reactor fleet in the country as “in operation” or “operational” is increasingly misleading.

The IAEA actually does have a reactor-status category called “Long-term Shutdown” or LTS.⁴³ 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”. As illustrated in the *World Nuclear Industry Status Report (WNISR) 2013*, one could argue that all but two Japanese reactors fit the category that year. And for two days in

company can restart the unit during the summer”. See JAIF, “NRA to Partially Redo Pre-service Inspections at Sendai-1”, 10 June 2015.

⁴³ See IAEA Glossary, at www.iaea.org/pris/Glossary.aspx, accessed 27 June 2014.

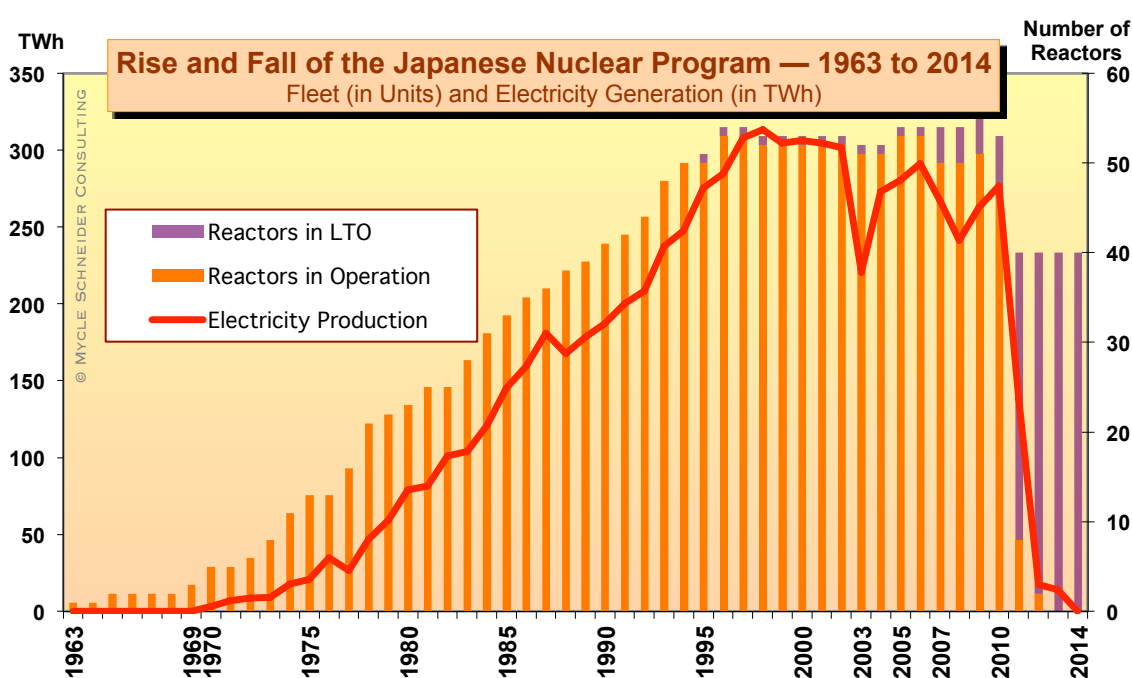
January 2013, the IAEA moved 47 units to the LTS category on the IAEA-PRIS website, before that action was abruptly reversed and ascribed to clerical error.⁴⁴

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.

Tatsujiro Suzuki, former Vice-Chairman of the Japan Atomic Energy Commission (JAEC) has called the establishment of the LTO category an “important innovation” with a “very clear and empirical definition”.⁴⁵

Figure 5: Rise and Fall of the Japanese Nuclear Program 1963–2014



Sources: IAEA-PRIS, MSC, 2015

Applying this definition to the world nuclear reactor fleet leads to considering 40 Japanese units in LTO, as 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. Annex 2 provides a detailed overview of the status of the Japanese reactor fleet. In addition, the IAEA classifies as LTS the fast breeder reactor

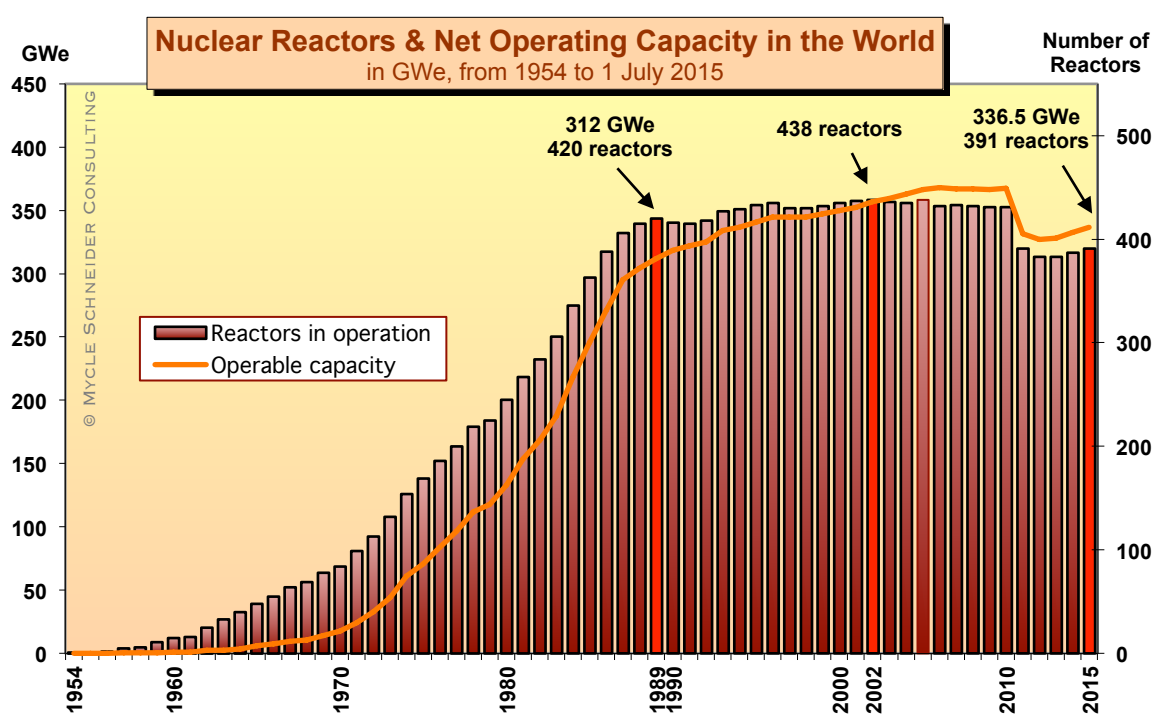
⁴⁴ See detailed accounts on WNISR, see www.WorldNuclearReport.org.

⁴⁵ Tatsujiro Suzuki, “Foreword”, WNISR2014, see http://www.worldnuclearreport.org/WNISR2014.html#_Toc268768687, accessed 6 July 2015.

Monju⁴⁶, because it was shut down after a sodium fire in 1995 and has never generated power since. It also meets WNISR's LTO criterion. Besides the Japanese reactors, the Swedish reactor Oskarshamn-2, shut down for modernization since June 2013, falls into the LTO category. The South-Korean unit Wolsong-1, shut down since 2012, was restarted in June 2015, while the definitive closure of the Indian reactor Rajasthan-1, offline since 2004, was announced in September 2014⁴⁷. Consequently, both units were taken off the LTO list. The total number of nuclear reactors in LTO as of 1 July 2015 is therefore 41; yet all but one (Monju) are considered by the IAEA as "in operation".

As of 1 July 2015, a total of 391 nuclear reactors are operating in 30 countries, up three units (+0.5 percent) from the situation one year ago. The current world fleet has a total nominal electric net capacity of 337 gigawatts (GW or thousand megawatts), up from 333 GW (+1.2 percent) one year earlier (see Figure 6).

Figure 6: World Nuclear Reactor Fleet, 1954–2015



Sources: IAEA-PRIS, MSC, 2015

For many years, the net installed capacity has continued to increase more than the net increase of numbers of operating reactors. This was a result of the combined effects of larger units replacing smaller ones and, mainly, technical alterations at existing plants, a process known as uprating. In the United States, the Nuclear Regulatory Commission (NRC) has approved 156 uprates since 1977. These included, in 2014, five minor uprates of 1.6 percent and two substantial ones (Peach Bottom-2 and -3) with 12.4 percent. The cumulative approved uprates in the United States total

⁴⁶ The IAEA also considers the Spanish reactor Garoña in LTS, while WNISR considers it shut down permanently.

⁴⁷ *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 24 June 2015.

7.3 GW,⁴⁸ most of which have already been implemented. A similar trend of uprates and major overhauls in view of lifetime extensions of existing reactors is seen in Europe. The main incentive for lifetime extensions is their considerable economic advantage over new-build. Upgrading but extending the operating lives of older reactors usually also yields lower safety margins than replacement with more modern designs.

It appears, however, that the incentives and opportunities for power uprates are decreasing, as the number of units with pending applications in precursor country U.S. dropped from 20 in 2011 to one in 2014 at Catawba-1 for a minor 1.7 percent increase. In addition, minor uprates of 1.6 percent are “on hold” at the three Oconee units. The total capacity increase that would occur, should all four uprates be implemented, would be limited to 61 MW—insignificant (0.06 percent of installed nuclear capacity) on a U.S. scale.⁴⁹

The use of nuclear energy remains limited to a small number of countries, with only 30 countries, or 15.5 percent of the 193 members of the United Nations, operating nuclear power plants as of June 2015 (see Figure 2). Close to half of the world’s nuclear countries are located in the European Union (EU), and in 2014 they accounted for 34.5 percent of the world’s gross nuclear production,⁵⁰ with half that EU generation in France.

Overview of Current New Build

Just as one year ago, currently 14 countries are building nuclear power plants (see Table 1). After the 3/11 events, Japan halted work at two units, Ohma and Shimane-3, which had been under construction since 2007 and 2010 respectively. Officially, construction “partially resumed” at Ohma in October 2012⁵¹ and Shimane-3 has remained “under construction”, according to the Japan Atomic Industrial Forum (JAIF)⁵² and IAEA statistics. However, in view of the current situation in Japan, it seems increasingly unlikely that these plants will be completed, as it will be hard enough for the industry to get its completed but stranded plants restarted (see Japan Focus). The two units are therefore not included in the WNISR number of units under construction.

As of the middle of July 2015, 62 reactors are considered here as under construction, five fewer than WNISR reported a year ago. Four-fifths of all new-build units (50) are in Asia and Eastern Europe, of which half (24) are in China alone. Over 60 percent (38) of the units under construction are located in just three countries: China, India, and Russia. Ten projects started construction in 2013, in the U.S. (4), China (3), Belarus (1), South Korea (1) and United Arab Emirates (1). Three building sites were launched in 2014—one each in Argentina, Belarus, and

⁴⁸ Nuclear Regulatory Commission (NRC), “Approved Applications for Power Uprates”, Updated 26 August 2014, see www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed 10 June 2015.

⁴⁹ NRC, “Pending Applications for Power Uprates”, Updated 30 April 2012, see www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/pending-applications.html, accessed 10 June 2015.

⁵⁰ BP, “Statistical Review of World Energy”, June 2015. BP corrected the 2013 value from 35.7 percent to 35.2 percent.

⁵¹ J-Power, “2014 Annual Report”, August 2014, see <http://www.jpowers.co.jp/english/ir/pdf/2014.pdf>, accessed 11 June 2015.

⁵² JAIF, “Nuclear Power Plants in Japan”, 22 May 2013.

United Arab Emirates (UAE). In the first half of 2015, China restarted construction on the only two projects that got underway in the world. However, some Chinese sources indicate that these are still two “leftover” units from pre-3/11 planning and cannot be considered a part of a new series.

Table 1: Nuclear Reactors “Under Construction” (as of 1 July 2015)⁵³

Country	Units	MWe (net)	Construction Start	Grid Connection	Delayed Startup (Units)
China	24	23,738	2009-2015	2015-2021	15
Russia	8	6,262	1983-2010	2015-2019	8
India	6	3,907	2002-2011	2015-2019	6
USA	5	6,320	1972-2013	2016-2020	5
South Korea	4	5,360	2008-2013	2016-2018	4
UAE	3	4,035	2012-2014	2017-2019	?
Belarus	2	2,218	2013-2014	2019-2020	?
Pakistan	2	630	2011	2016-2017	2
Slovakia	2	880	1985	2016-2017	2
Ukraine	1	1,900	1986-1987	2019	2
Argentina	1	25	2014	2018	?
Brazil	1	1,245	2010	2018	1
Finland	1	1,600	2005	2018	1
France	1	1,600	2007	2017	1
Total	62	59,033	1972-2015	2015-2021	47

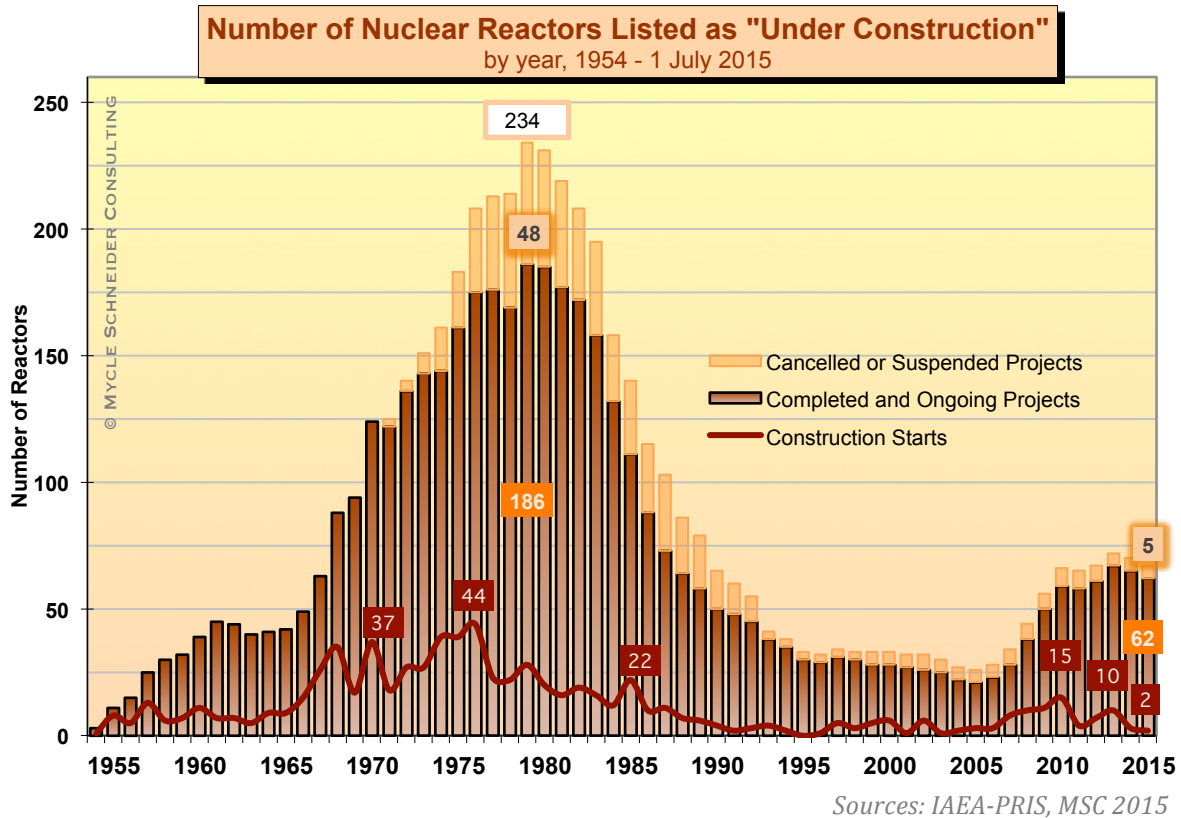
Sources: IAEA-PRIS, MSC, 2015

The current number of active building sites is the highest since 1990 (including later abandoned units) but is still relatively small compared to a peak of 234 units—totaling more than 200 GW—in 1979. However, many of those projects (48) were never finished (see Figure 7.) 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 by 4.6 GW (–7.3 percent) to 59 GW, with an average unit size of 952 MW (see Annex 11 for details).

⁵³ For further details see Annex 11.

Figure 7: Nuclear Reactors Under Construction



Construction Times

Construction Times of Reactors *Currently Under Construction*

A closer look at projects currently 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 2015, the 62 reactors currently being built have been under construction for an average of 7.6 years.
- All reactors under construction in 10 out of 14 countries have experienced mostly year-long delays. At least three-quarters (47) of all building sites are delayed. The 15 remaining units under construction in the world, of which nine are in China, were begun within the past three years or have not yet reached projected start-up dates, making it difficult to assess whether or not they are on schedule.
- Five reactors have been listed as “under construction” for more than 30 years. The U.S. Watts Bar-2 project in Tennessee holds the record, as construction started in December 1972, but was subsequently frozen. It failed to meet new startup dates, was again delayed in 2014, and is now scheduled for commercial operation in June 2016. Two Russian units (BN-800, Rostov-4) and Mochovce-3 and -4 in Slovakia have also been worked on for over 30 years. Khmel'nitski-3

and -4 in Ukraine are approaching the 30-year mark with construction times reaching 29 and 28 years respectively.⁵⁴

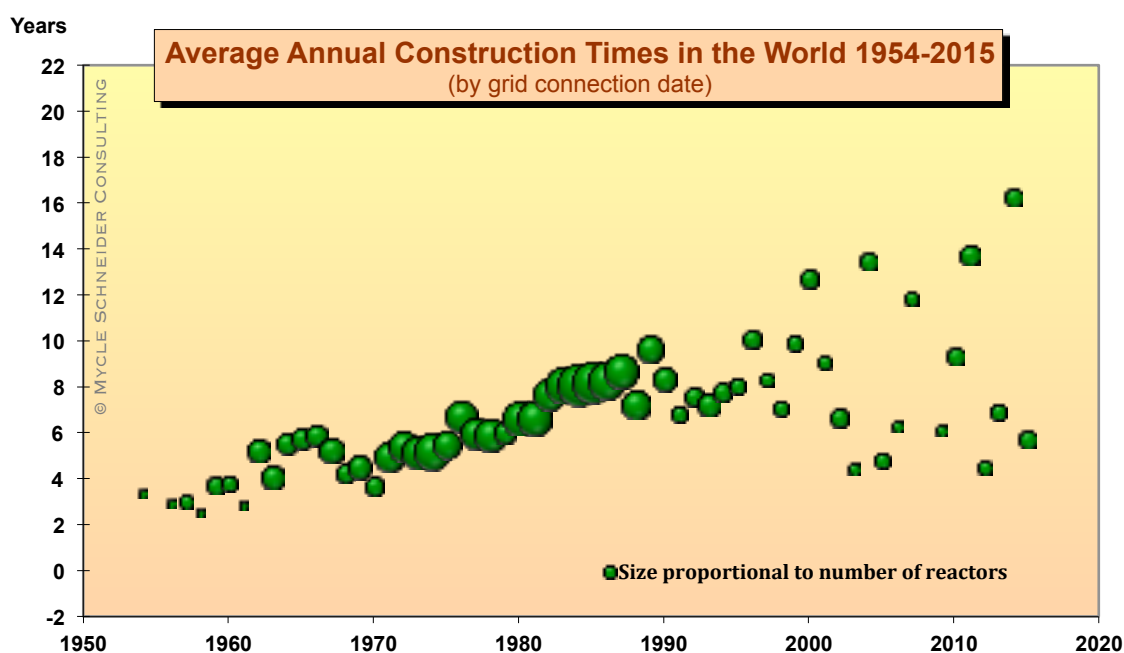
- Two units in India, Kudankulam-2 and the Prototype Fast Breeder Reactor (PFBR), have been listed as “under construction” for 13 and 11 years respectively. The Olkiluoto-3 reactor project in Finland will reach its tenth anniversary in August 2015.

The lead time for nuclear plants includes not only construction times but also lengthy licensing procedures in most countries, complex financing negotiations, and site preparation.

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 8 illustrates, construction times of reactors completed in the 1970s and 1980s were quite homogenous, while in the past two decades they have varied widely. Average construction time of the five units—three Chinese, one Russian, and one Argentinian that took 33 years to complete—that started up in 2014 was 16.3 years, while it took an average of 5.8 years to connect five units—four Chinese and one South Korean—to the grid in the first half of 2015.

Figure 8: Average Annual Construction Times in the World 1954–July 2015



Sources: MSC based on IAEA-PRIS 2015

⁵⁴ The Ukrainian Government announced on 23 June 2015 that it decided to cancel the agreement with Russia and the Russian builder Atomstroyexport claiming Russia's “failure to meet its obligations”. The Czech company Skoda JS is said to be picking up the task to complete construction. Source: *World Nuclear News (WNN)*, “Ukraine prepares to cancel Khmel'nitski agreement with Russia”, 24 June 2015, see <http://www.world-nuclear-news.org/NN-Ukraine-prepares-to-cancel-Khmel'nitski-agreement-with-Russia-2406201501.html>, accessed 24 June 2015.

Table 2: Reactor Construction Times 2005–2015

Construction Times (in years) Startups between 2005 and July 2015				
Country	Units	Mean Time	Min	Max
China	18	5.7	4.4	11.2
India	7	7.3	5.1	11.6
South Korea	5	4.9	4	6.4
Japan	3	4.6	3.9	5.1
Russia	3	28.0	25.3	31.9
Argentina	1	32.9	32.9	32.9
Iran	1	36.3	36.3	36.3
Pakistan	1	5.3	5.3	5.3
Romania	1	24.1	24.1	24.1
Total	40	9.4	3.9	36.3

Sources: IAEA-PRIS, MSC, 2015

Construction Starts and Cancellations

The number of annual construction starts⁵⁵ in the world peaked in 1976 at 44, of which 11 projects were later abandoned. In 2010, there were 15 construction starts—including 10 in China alone—the highest level since 1985. However, in 2014, the level had dropped to three units and China did not launch a single new construction. Between 2011 and 1 July 2015, first concrete was poured for 26 new plants worldwide—less than in a single year in the 1970s.

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. French 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 cancellations.⁵⁶

⁵⁵ Generally, a reactor is considered under construction when the base slab of the reactor building is being concreted. Site preparation work and excavation are not included.

⁵⁶ French Atomic Energy Commission (CEA), “Elecnucl – Nuclear Power Plants in the World”, 2002. The section “cancelled orders” has disappeared after the 2002 edition.

Figure 9: Construction Starts in the World 1951 – 1 July 2015

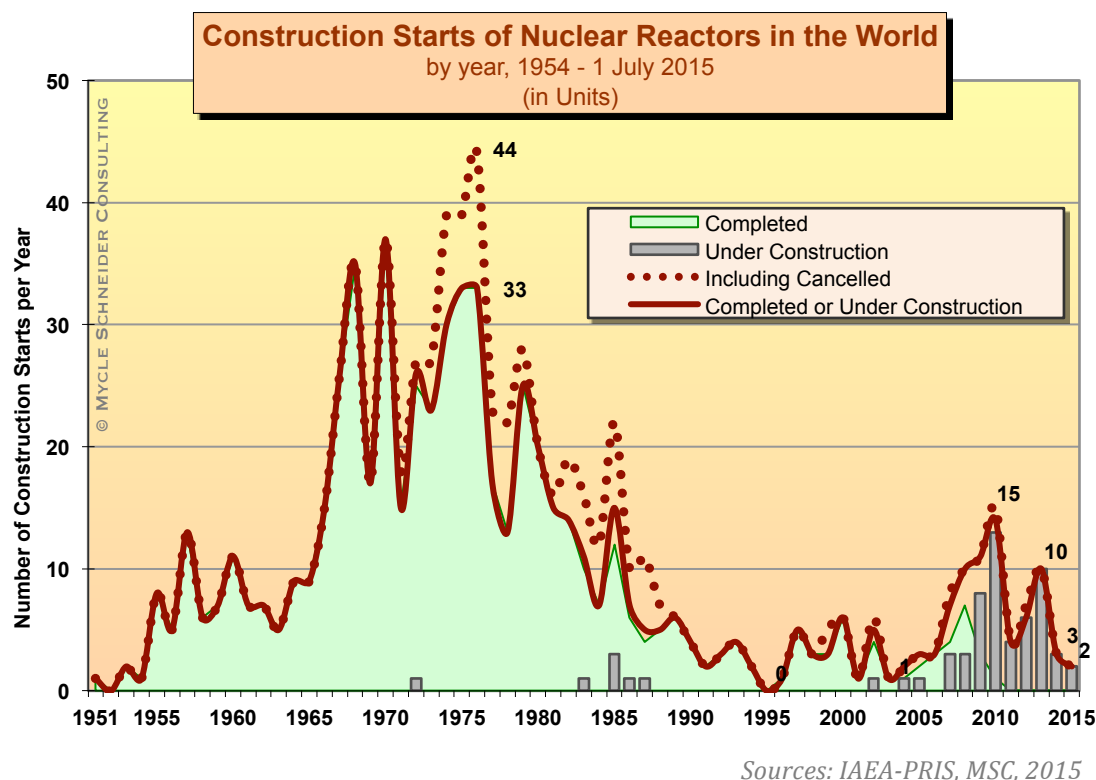
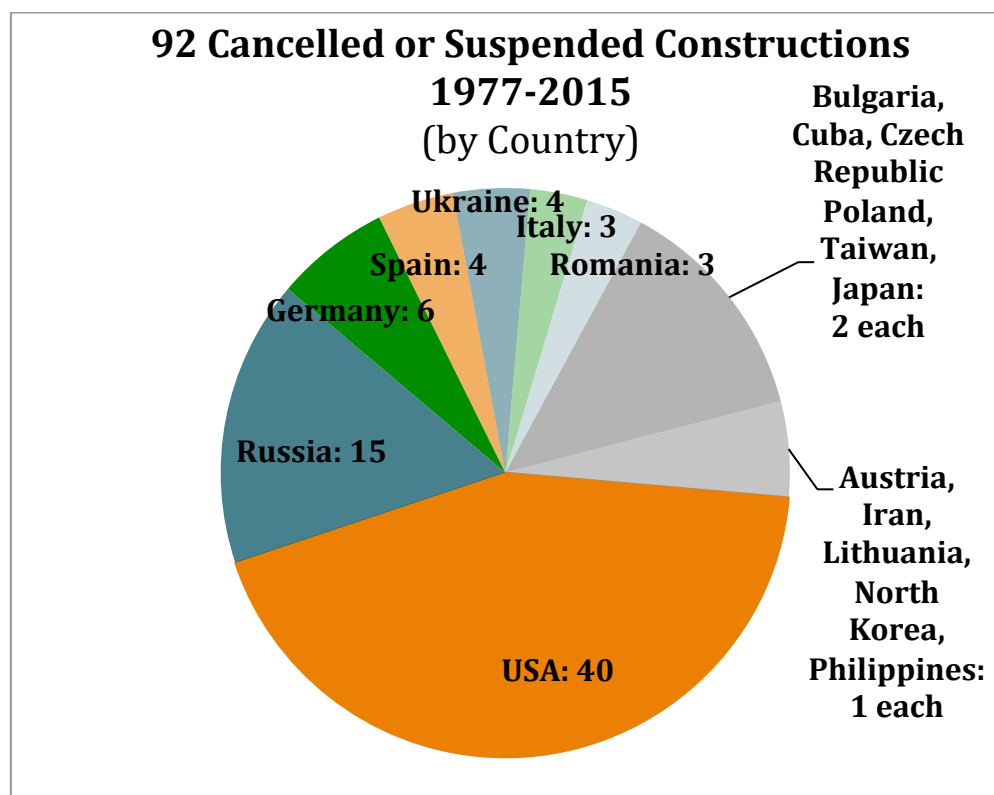


Figure 10: Cancelled or Suspended Reactor Constructions 1977 – 2015



Of the 748 reactor projects launched since 1951, at least 92 units (12.3 percent) in 18 countries have been abandoned, of which 87, according to the IAEA, between 1977 and 2012—no earlier or later IAEA data available—at various stages after they had reached construction status. Over three-quarters (71) of the cancellations happened during a 12-year period between 1982 and 1993, 11 were decided prior to this period, and only 10 over the 20-year period between 1993 and 2012.

Two thirds (61 units) of all cancelled projects were in three countries alone—the U.S. (40), Russia (15), and Germany (6). Some units were actually 100 percent completed—including Kalkar in Germany and Zwentendorf in Austria—before the decision was taken not to operate them.

There is no thorough analysis of the cumulated economic loss of these failed investments.

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-2015 stands at 28.8 years.⁵⁷ Some nuclear utilities envisage average reactor lifetimes of beyond 40 years and even up to 60 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 NRC. As of June 2014, 74 of the 99 operating U.S. units have received an extension, with another 18 applications being under NRC review.⁵⁸ Since WNISR2014, three license renewals (Limerick-1 and -2, Callaway-1) have been granted and two additional ones applied for (LaSalle-1 and -2).

However, only one of the 33 units that have been shut down in the U.S. had reached 40 years on the grid—Vermont Yankee, the latest one to be closed, in December 2014, at the age of 42. In other words, at least a quarter of the reactors connected to the grid in the U.S. never reached their initial design lifetime. On the other hand, of the 99 currently operating plants, 33 units have operated for more than 40 years. In other words, 45 percent of the units with license renewals have already entered the life extension period, and that share is growing rapidly with the mid-2015 average age of the U.S. operational fleet standing at 35.6 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 29 years on average, and the oldest have started 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. The French utility Électricité de France (EDF) has clearly stated that, for economic reasons, it plans to prioritize lifetime extension beyond 40 years over large-scale new-build. Having assessed EDF's lifetime extension outline, ASN stated:

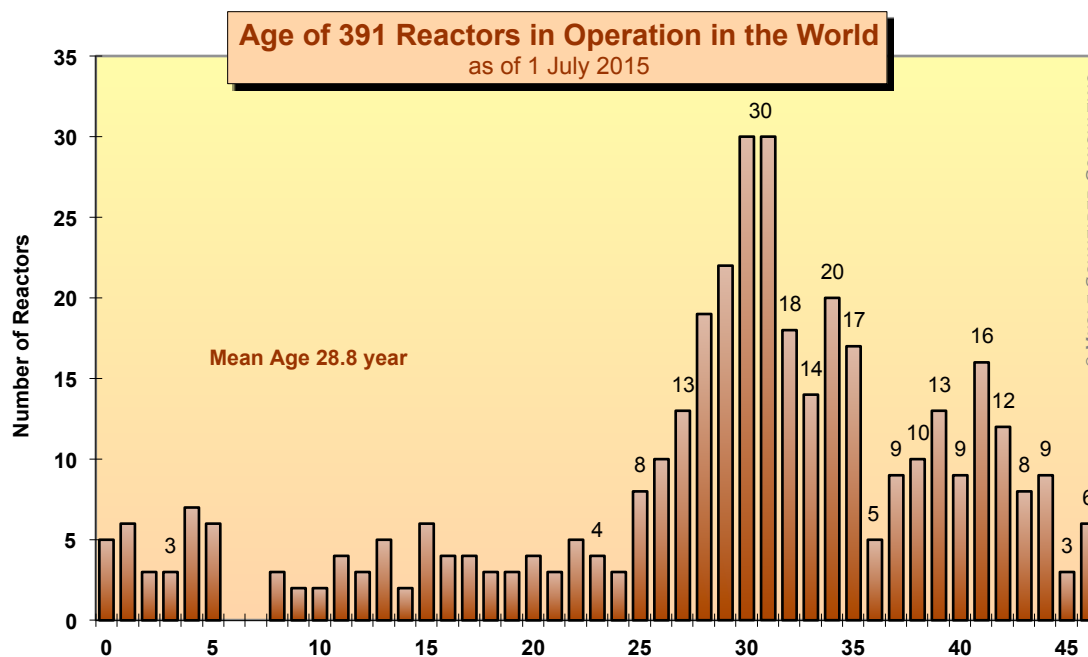
ASN requested additional studies and underlined the fact that if operation of the existing reactors were to be extended beyond 40 years, they would be operating alongside other reactors around the world of more

⁵⁷ 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.

⁵⁸ NRC, "Status of License Renewal Applications and Industry Activities", see www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 29 June 2015.

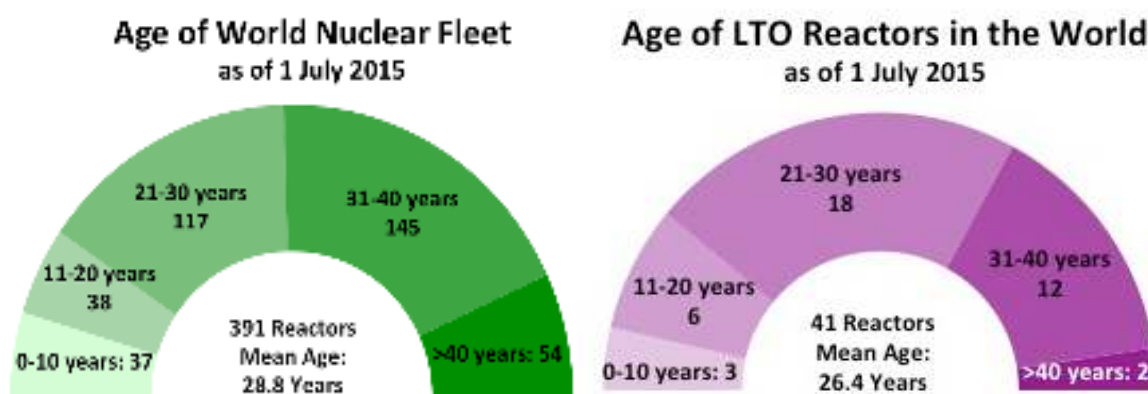
recent design and compliant with significantly strengthened safety requirements. Through its requests, ASN thus restated that the reactor operating life extension desired by EDF was in no way a foregone conclusion. Over and above the question of management of aging, it is also dependent on an ambitious safety reassessment aiming to achieve a level as close as possible to that of a new reactor.⁵⁹

Figure 11: Age Distribution of Operating Nuclear Power Reactors



Sources: IAEA-PRIS, MSC, 2015

Figure 12: Age Distribution of Operating and LTO Reactors in the World



Sources: IAEA-PRIS, MSC, 2015

In fact, only five French reactors have so far received a permit to extend their operational life from 30 to 40 years, and even then only under the condition of significant upgrading. The draft Energy Bill introduced by Minister Ségolène Royal in June 2014, which passed the second reading

⁵⁹ Autorité de Sûreté Nucléaire (ASN), "ASN report abstracts—on the state of nuclear safety and radiation protection in France in 2013", 2014.

at the National Assembly in May 2015, caps the installed nuclear operating capacity at the current level. This would mean that prior to the startup of the European Pressurized Water Reactor (EPR) under construction in Flamanville, an equivalent nuclear generating capacity has to be shut down. Incidentally, this would be close to the capacity of the country's oldest reactors at Fessenheim that President François Hollande vowed to close down by the end of 2016, the previously planned startup date for Flamanville-3. The draft Energy Bill also confirms the target to reduce the nuclear share in France's power generation from 75 to 50 percent by 2025. If ASN gave the go-ahead for all of the oldest units to operate for 40 years, 22 of the 58 French operating reactors would reach that age already by 2020. In fact, in order to reach the 50-percent goal by 2025 and significantly increase the renewable energy share, at constant power consumption, more than 20 units will need to be closed by 2025.

According to an independent assessment⁶⁰, lifetime extension beyond 40 years will probably be very expensive—between €1 billion and €4 billion (US\$1.4–5.5 billion) per reactor—depending on the required safety level. Because of the different costs associated with lifetime extensions at each reactor and other considerations (geographical distribution, overall target to reduce the nuclear share, etc.) EDF will probably attempt to extend lifetimes of only some of its units.

In assessing the likelihood of reactors being able to operate for up to 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, Figure 13). As of mid-2015, 54 of the world's operating reactors have exceeded the 40-year mark (16 more than one year ago).⁶¹ As the age pyramid illustrates, that number could rapidly increase over the next few years. A total of 199 units have already exceeded age 30.

The age structure of the 162 units already shut down completes the picture. In total, 52 of these units operated for more than 30 years and of those, 19 reactors operated for more than 40 years (see Figure 14). Many units of the first generation designs only operated for a few years. Considering that the average age of the 162 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 beyond seems rather optimistic. The operating time prior to shutdown has clearly increased continuously, as Figure 14 shows. But while the average annual age at shutdown got close to 40 years, it only passed that age once: in 2014, when the only such unit shut down that year (Vermont Yankee in the U.S.) after 42 years of operation.

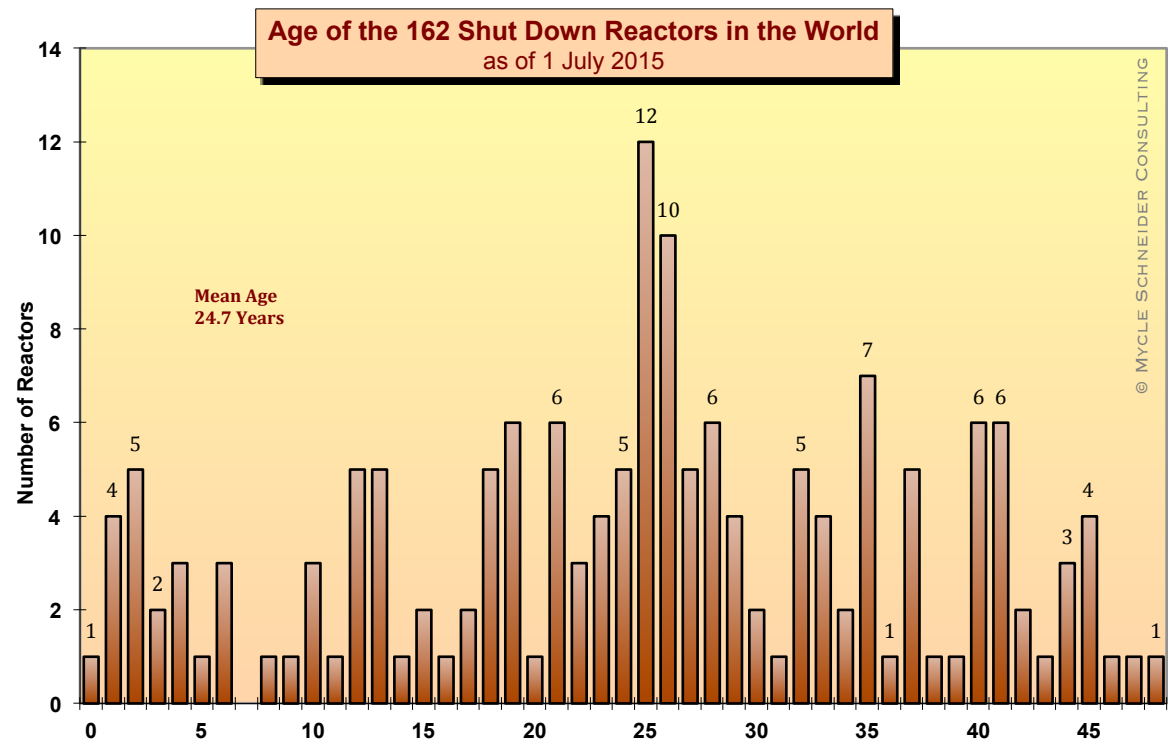
As a result of the Fukushima nuclear disaster, more pressing questions have been raised about the wisdom of operating older reactors. The Fukushima Daiichi units (1 to 4) were connected to the grid between 1971 and 1974. The license for unit 1 had been extended for another 10 years in February 2011, 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

⁶⁰ Yves Marignac, "L'échéance des 40 ans pour le parc nucléaire français—Processus de décision, options de renforcement et coûts associés à une éventuelle prolongation d'exploitation au-delà de 40 ans des réacteurs d'EDF", WISE-Paris, commissioned by Greenpeace France, February 2014, see <http://www.greenpeace.org/france/PageFiles/266521/greenpeace-rapport-echance-40-ans.pdf>, accessed 7 June 2015.

⁶¹ WNISR considers the age starting with grid connection, and figures are rounded by half-years.

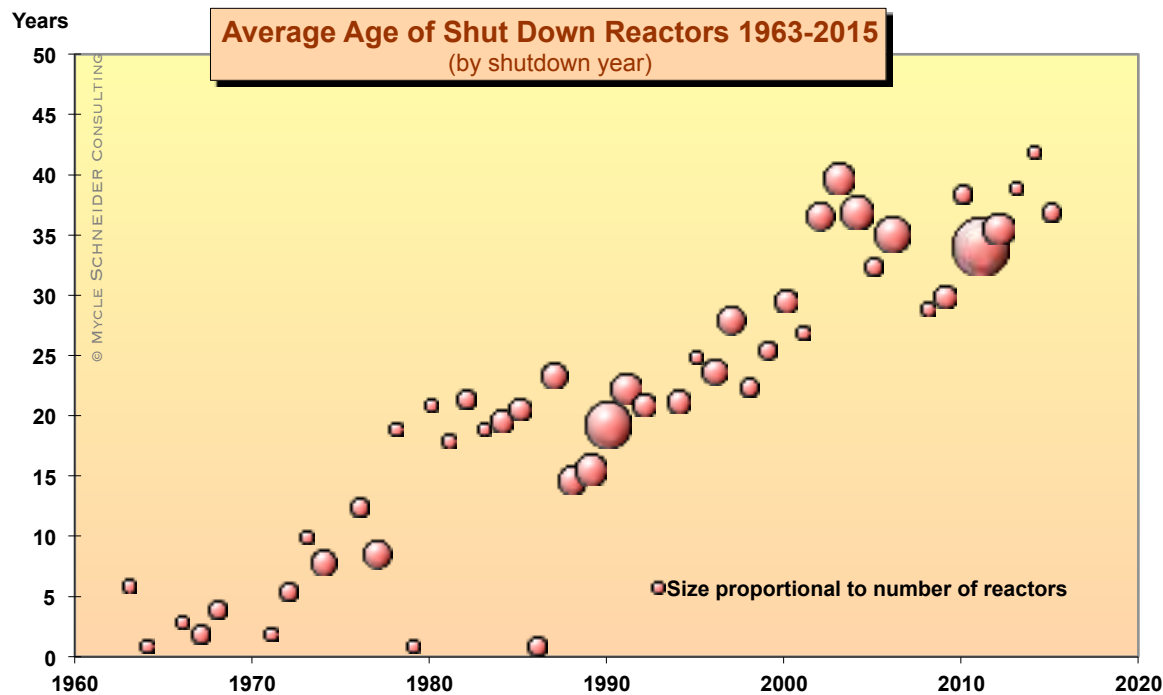
clear that the 3/11 events had an impact on previously assumed extended lifetimes in other countries as well, including in Belgium, Switzerland, and Taiwan.

Figure 13: Age Distribution of 162 Shut Down Nuclear Power Reactors



Sources: IAEA-PRIS, MSC, 2015

Figure 14: Average Age Profile of Shut Down Nuclear Power Reactors



Sources: IAEA-PRIS, MSC, 2015

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 15), assumes a general lifetime of 40 years for worldwide operating reactors (not including reactors in LTO, as they are not considered operating), with a few adjustments, while a second scenario (Plant Life Extension or PLEX Projection, see Figure 16) takes into account 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. Even with 62 units under construction as of 1 July 2015—all of which are assumed to have gone online by 2021, an installation rate of about 11 per year—installed nuclear capacity would only raise by 1.5 GW by 2020, which is marginal. However, in total, 19 additional reactors would have to be ordered, built and started up prior to the end of 2020 in order to maintain the status quo of the number of operating units. This corresponds to about four additional grid connections per year and would raise the annual startups to 15. This installation rate would be four times as high as the actual 35 grid connections over the decade 2005-2014. In the following decade to 2030, 188 new reactors (178 GW) would have to be connected to the grid to maintain the status quo, five times the rate achieved over the past decade.

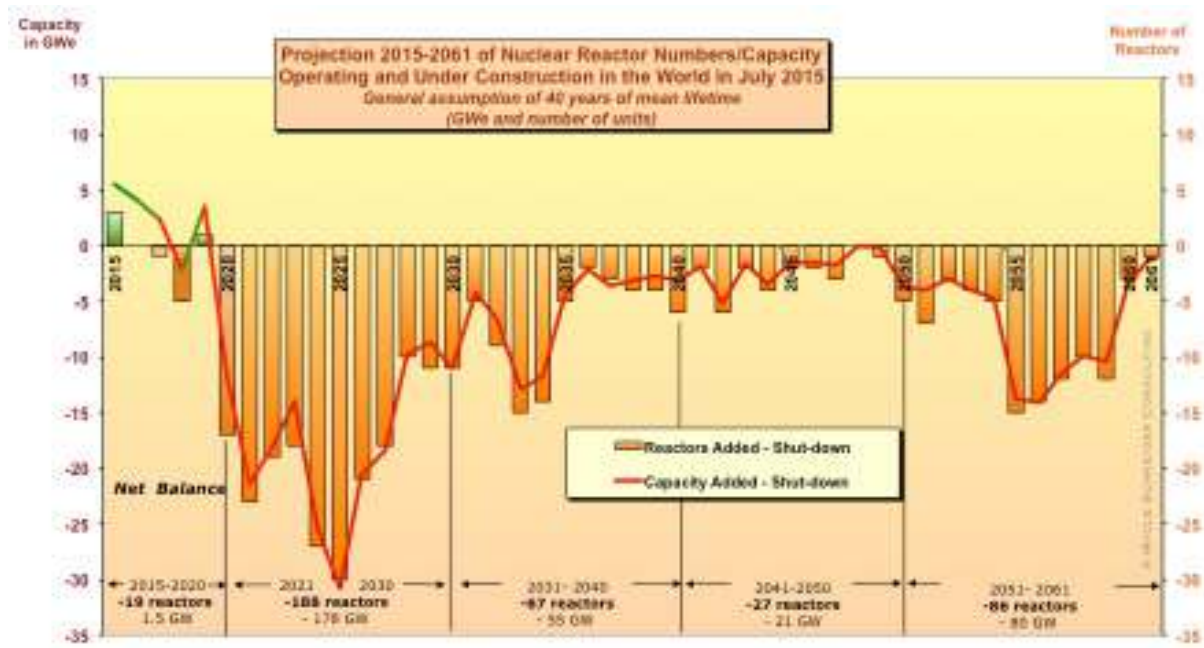
The achievement of the 2020 targets will mainly depend on the number of Japanese reactors currently in LTO possibly coming back on line and the development pattern of the Chinese construction program. Any major achievements outside these two countries in the given timeframe are highly unlikely given the existing difficult financial situation of the world's main reactor builders and utilities, the general economic environment, widespread skepticism in the financial community, and generally hostile public opinion—aside from any other specific post-Fukushima effects.

As a result, the number of reactors in operation will stagnate at best but will more likely decline over the coming years unless lifetime extensions beyond 40 years become widespread. Such generalized lifetime extensions are, however, even less likely after Fukushima.

Also, soaring maintenance and upgrading costs, as well as decreasing system costs of nuclear power's main competitors, create an economic environment with sharply decreasing bulk electricity prices that already led to premature plant closures, notably in the U.S. and Germany, as discussed below.

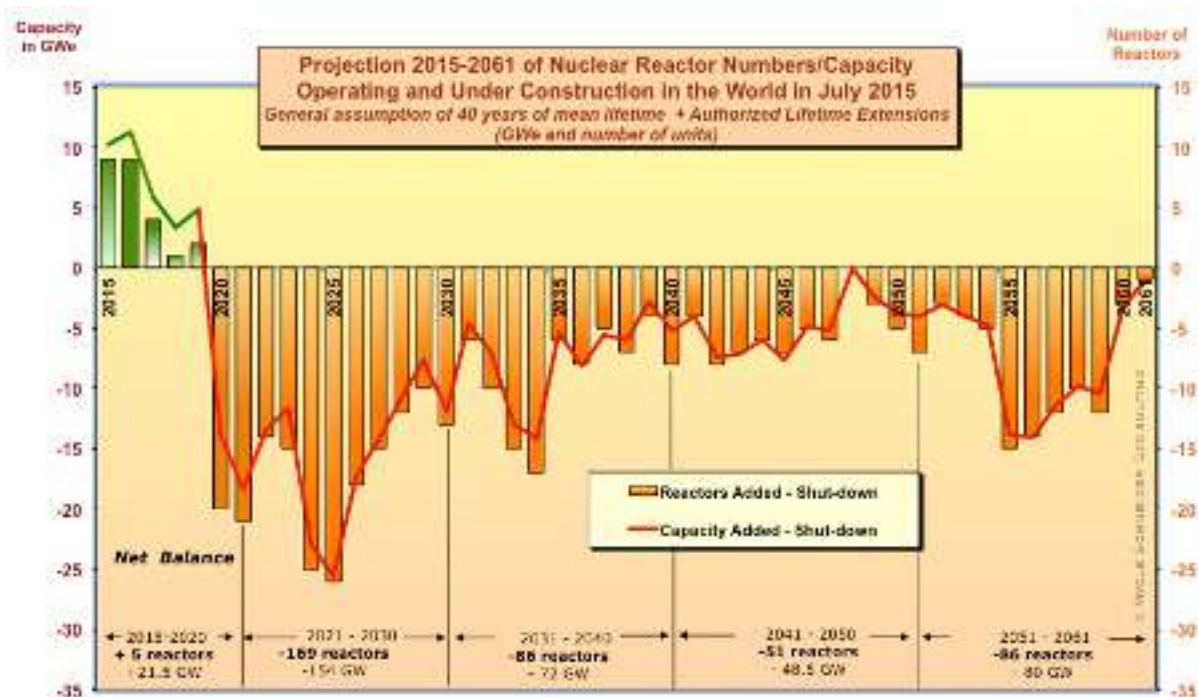
Developments in Asia, and particularly in China, do not fundamentally change the global picture. Reported figures for China's 2020 target for installed nuclear capacity have fluctuated between 40 GW and 120 GW in the past. The freeze of construction initiation for almost two years and new siting authorizations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

Figure 15: The 40-Year Lifetime Projection (not including LTOs)



Sources: IAEA-PRIS, WNA, various sources compiled by MSC 2015

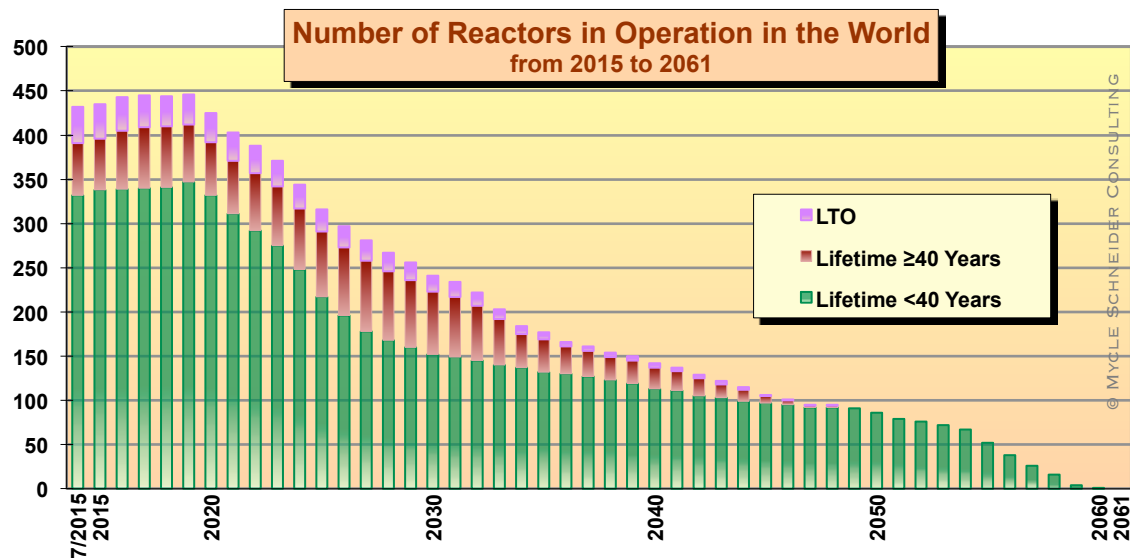
Figure 16: The PLEX Projection (not including LTOs)



Sources: IAEA-PRIS, WNA, various sources compiled by MSC 2015

In addition, the average construction time for the 18 units started up in China over the past decade was 5.7 years. At present, 27 units with about 25 GW are under construction and scheduled to be connected by 2020, which would bring the total to 51 GW (see China Focus). The controversy about whether new reactors should be allowed not only in coastal but also inland sites, is restricting the number of suitable sites immediately available.

Figure 17: Forty-Year Lifetime Projection versus PLEX Projection
(in numbers of reactors)



Sources: IAEA-PRIS, US-NRC, MSC 2015

We have also modeled 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 have increased by only four (down from an increase of eight in the WNISR2014 projection) and the installed capacity would grow by 21 GW. In the following decade to 2030, still 169 new reactors (154 GW) would have to start up to replace shutdowns. In other words, the overall pattern of decline would hardly be altered: it would merely be delayed by some years (see Figure 16 and Figure 17).

Potential Newcomer Countries

A number of countries are actively developing and some are constructing nuclear power plants for the first time. Many of these countries have long-held plans to develop nuclear energy, for decades in some countries. Only two newcomer countries that are actually building nuclear power plants for the first time (Belarus and United Arab Emirates [UAE]), and one more reportedly has signed commercially binding contracts (Turkey). Others have announced more or rather less concrete plans for new-build (Bangladesh, Egypt, Jordan, Lithuania, Poland, Saudi Arabia, and Vietnam).

There have been important changes over the last few years with many countries rolling back from previously ambitious plans. This is in marked contrast to a 2012 IAEA analysis that expected

Bangladesh, Belarus, Turkey, UAE, and Vietnam to start building their first nuclear power plants in 2012 and that Jordan and Saudi Arabia could follow in 2013.⁶²

In all cases for these potential first-time nuclear countries, even in the relatively rich Middle East, finance remains a criterion, if not the decisive one, in determining the choice of technology. However, what is striking is the extent to which in recent years the Russian industry has expanded its export policy through financial backing, with proposed projects in countries that are building reactors for the first time, as well as new proposals with financing in countries like Finland and Hungary that already have operating nuclear power plants. The current situation in Ukraine raises questions over both the political support for such projects (especially in Europe) and—with the threat of widening economic sanctions against Russia—its ability to fund all of the projects. The credibility of many of these projects is questioned also within the industry. Long-time World Nuclear Association (WNA) strategist Steve Kidd considers it “reasonable to suggest that it is highly unlikely that Russia will succeed in carrying out even half of the projects in which it claims to be closely involved (...)”.⁶³

Other increasingly active players in the export market are Japanese companies, such as Toshiba and Hitachi. The lack of new-build opportunities domestically means that export markets have become essential to maintain their production capabilities, again with technology sales accompanied by a financial package. Like Russia, this effort encompasses proposals in countries that currently don’t have programs (e.g. Lithuania and Turkey) as well as projects under development in more developed nuclear countries such as Bulgaria and the UK. The revised Japanese New Growth Strategy includes an explicit statement that the Government will actively support the export of nuclear power.⁶⁴ In the future, China and South Korea might also provide state or quasi-state financing for reactor export projects to support their domestic industries. Such concessionary state financing is seldom on offer for competing exports of renewable and distributed generators or of energy efficiency.

The following section provides a country-by-country overview of potential newcomer countries.

Under Construction

In the **United Arab Emirates** (UAE), construction is ongoing at the Barakah nuclear project, 300 km west of Abu Dhabi, where there are now three, soon to be four reactors, being built. At the time of the contract signing in December 2009, with Korean Electric Power Corp., the Emirates Nuclear Energy Corp (ENEC), said that “the contract for the construction, commissioning

⁶² 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 5 May 2015.

⁶³ Steve Kidd, “The world nuclear industry – is it in terminal decline?”, *NEI*, 6 October 2014, see <http://www.neimagazine.com/opinion/opinionthe-world-nuclear-industry-is-it-in-terminal-decline-4394815/>, accessed 7 June 2015.

⁶⁴ Satoru Koyama, “The Role of Export Credits in NPP Financing”, Nippon Export and Investment Insurance (NEXI), September 2013, see http://www.oecd-nea.org/ndd/workshops/wpne/presentations/docs/3_1_KOYAMA_2013_09_19_OECD_Seminer.pdf, accessed 14 July 2014.

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”.⁶⁵

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.⁶⁶ However, it is unclear what other financing sources will be needed for the project, as it is reported that the cost of the project has risen significantly, with the total cost of the plant including infrastructure and finance now expected to be about US\$32 billion,⁶⁷ with others putting the cost of the project at US\$40 billion.⁶⁸

In July 2010, a site-preparation license and a limited construction license were granted for four reactors at Barakah, 53 kilometers from Ruwais.⁶⁹ The application is based on the safety analysis prepared for South Korea’s Shin-Kori units 3 and 4, the “reference plant”, which is also still under construction. A tentative schedule published in late December 2010, and not publicly altered since, suggests that Barakah-1 will 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, and on Barakah-3 on 24 September 2014. Construction of unit 4 is expected to be launched in 2015. In March 2015, ENEC stated that Barakah-1 is 69 percent complete and filed an application for the operating license for Barakah-1 and -2. First fuel loading is expected in 2016.⁷⁰

There is little independent information about the progress of construction. An International Advisory Board (IAB) for the UAE program, chaired by former IAEA Director General Hans Blix, said of construction in October 2013 that “unit 1 is progressing on schedule—overall progress is on target although construction is slightly behind”.⁷¹ The IAB also noted that problems with the falsification of parts that have been reported in the Korean nuclear sector have also been detected at Barakah. While the Federal Authority for Nuclear Regulation (FANR) stated that there was a low risk suspected parts had been installed, they also note that “the potential risks for the future is not well understood at this stage” and the IAB responded that it would “appreciate further

⁶⁵ ENEC, “UAE Selects Korea Electric Power Corp, as Prime Team as Prime Contractor for Peaceful Nuclear Power”, 27 December 2009, see <http://www.enec.gov.ae/media-centre/news/content/uae-selects-korea-electric-power-corp.-as-prime-team-as-prime-contractor-fo>, accessed February 2015.

⁶⁶ Sang-Baik Kim, Jan-Horst Keppler, “Case Studies On Financing And Electricity Price Arrangements—The Barakah Nuclear Power Plants, The United Arab Emirates”, Organisation for Economic Development and Co-operation (OECD), Nuclear Energy Agency (NEA), Nuclear Development Division, OECD NEA Workshop on Electricity Prices and Nuclear New Build, Paris, 19 September 2013, see http://www.oecd-nea.org/ndd/workshops/wpne/presentations/docs/4_2_KIM_%20Barakah%20presentation.pdf, accessed 25 June 2015.

⁶⁷ World Nuclear Association (WNA), “Country Profile—UAE”, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Arab-Emirates/>, accessed February 2015.

⁶⁸ *Business Korea*, “Nuclear Power Korea Builds Nuclear Reactor in United Arab Emirates”, 20 May 2014, see <http://www.businesskorea.co.kr/article/4728/nuclear-power-korea-builds-nuclear-reactor-united-arab-emirates#sthash.FVVVoXWp.xqt8U0nj.dpuf>, accessed February 2015.

⁶⁹ *ArabianBusiness.com*, “ENEC Welcomes Regulator’s License Approval”, 11 July 2010.

⁷⁰ ENEC, “ENEC Submits Operating License Application to FANR for Barakah Units 1 & 2”, 26 March 2015, see <http://www.enec.gov.ae/media-centre/news/content/enec-submits-operating-license-application-to-fanr-for-barakah-units-1>, accessed 7 June 2015.

⁷¹ IAB, “Eighth Semi-Annual report 2014”, UAE Nuclear Program, Undated, see http://www.uaeiab.ae/download.php?f=publications/IAB_Semi_Annual%20Report_English_2014.pdf, accessed 7 June 2015.

reports on the faulty components' issue".⁷² In the following, ninth semi-annual IAB report, based on meetings held in March 2014, it is stated that "to date there has not yet been a case of CFSI [Counterfeit, Fraudulent and Suspect Items] concerning equipment of materials supplied or installed at the BNPP [Barakah Nuclear Power Plant]".⁷³

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 two 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. In February 2012, Russian state-owned bank Vneshekonombank (VEB), and the Belarusian commercial bank Belvneshekonombank signed an agreement to implement the Russian export credit facility. 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.⁷⁴ The project assumes the supply of all fuel and repatriation of spent fuel for the life of the plant. The fuel is to be reprocessed 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 2018.⁷⁵ However, these dates were revised and when construction was started it was stated that the reactors will not be completed until 2018 and 2020.⁷⁶ In March 2015, Atomstroyexport admitted the plant would cost 1,433.7 billion Rubles compared to the forecast from 2014 of 840 billion Rubles. At exchange rates of March 2015, when the Ruble was valued at about half the level of 2014, this equates to an original cost estimate of US\$13 billion, increasing by 71 percent to US\$22.9 billion.

The project is the focus of international opposition and criticism, with formal complaints from the Lithuanian government⁷⁷ and Belarus has been found to be in non-compliance with some of its obligations concerning the construction of the Ostrovets NPP (Nuclear Power Plants), according to the meeting of the Parties of the Espoo Convention.⁷⁸ The extent of international opposition to the project was reported in *Nuclear Intelligence Weekly (NIW)*, where it said that during the IAEA's general conference, "a slick presentation from the major government players in the

⁷² Ibidem.

⁷³ IAB, "Ninth Semi-Annual report 2014", International Advisory Board for the UAE nuclear program, undated, see http://www.uaeiab.ae/download.php?f=publications/IAB_Annual_%20Report_2014_EN.pdf, accessed 7 June 2015.

⁷⁴ *Nuclear Intelligence Weekly (NIW)*, "Belarus, Aided by Russia and Broke, Europe's Last Dictatorship Proceeds With NPP", 28 September 2012.

⁷⁵ V.V. Kulik, Deputy Minister, Ministry of Natural Resources and Environmental Protection of the Republic of Belarus, Letter to the European Commission, dated 9 August 2011.

⁷⁶ WNN, "Ostrovets plant meets construction safety rules", 7 November 2014.

⁷⁷ Bloomberg, "Lithuania Urges Belarus to Halt Nuclear Project on Safety Issues", 20 August 2013, see <http://www.bloomberg.com/news/2013-08-20/lithuania-urges-belarus-to-halt-nuclear-project-on-safety-issues.html>, accessed 10 June 2014.

⁷⁸ United Nations Economic Commission for Europe (UNECE), "Parties to UNECE treaties adopt declaration on applying environmental assessment procedures to nuclear energy issues", Press Release, 13 June 2014.

Belarussian nuclear program did little to impress international experts and diplomats.”⁷⁹ The trade journal also reported domestic criticism of the project on the grounds of the signing of contracts with a Russian company of poor reputation and that no detailed economic justification of the plant had been presented. The Government had projected electricity costs from the plant in the order of US\$45/MWh, which is significantly lower than similar projects being proposed in other countries, for example in Jordan.

Contracts Signed

In **Turkey**, two projects are being developed, but rather than proceeding with a single builder and design, the Government has decided to undertake at least two different reactor designs and at least two different sets of contractors.

Akkuyu

The first project, on the southern coast, is at Akkuyu, which is to be built under a Build-Own-Operate- (BOO) model by Rosatom of Russia. An agreement was signed in May 2010 for four VVER1200 reactors, with construction originally expected to start in 2015, but now delayed until at least 2016, and to cost US\$20–25 billion for 4.8 GW. 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 will be sold at a guaranteed price for the first 15 years, with the rest to be sold on the market, where the average wholesale electricity price for 2010 was US\$93.8/MWh. The electricity price within the PPA (excluding value added tax) is reported to be US\$123.5/MWh, with a possibility to increase the price up to US\$153.3/MWh to ensure the payback of the project.⁸⁰ Furthermore, the fixed price of the PPA is above the feed-in tariffs being offered for renewables, as the prices for 10 years for hydro and wind are US\$73/MWh, geothermal US\$105/MWh, and solar US\$103 /MWh.⁸¹

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, a delay of about 18 months from an earlier planned start-up date. However, further delays are likely as there have been problems with the Environmental Impact Assessment (EIA), which when submitted in July 2013 was rejected by the Ministry of Environment. However, when it was eventually approved in December 2014, it was said that the commissioning of the first unit was likely to be in 2021.⁸² In

⁷⁹ *NIW*, “Belarus—A chilled Reception in Vienna”, 27 September 2014.

⁸⁰ Marco Cometto, “Financing the Akkuyu NPP in Turkey”, OECD/NEA, Nuclear Development Division, as presented at OECD/NEA Workshop on Electricity price and Nuclear New Build, 19 September 2013, see http://www.oecd-nea.org/ndd/workshops/wpne/presentations/docs/4_1_Cometto_Akkuyu.pdf, accessed 14 July 2014.

⁸¹ Chadborne and Parke, “Turkey Moves to Boost Renewable Energy; new feed-in tariffs and other incentives for renewable energy”, January 2011, see http://www.chadbourne.com/Turkey_Renewable_Energy_projectfinance/, accessed 14 July 2014.

⁸² *WNN*, “Akkuyu project EIA gets ministry approval”, 1 December 2014.

January 2015, both the Chamber of Turkish Engineers and Architects (TMMOB)⁸³ and Greenpeace started legal proceedings against the approval, claiming that the Agency had insufficient qualified staff to make the decision and that there were no clear waste management plans or nuclear liability arrangements.⁸⁴ As a result of these domestic developments and financing problems, it was reported in March 2015 that the completion will now occur only in 2022⁸⁵ at an estimated budget for the two units of US\$22 billion. However, site preparation work started in April 2015.⁸⁶

Sinop

The other project is at Sinop, on the northern coast, where the latest project proposal is for 4.4 GW using the ATMEA reactor design. If completed this would be the first reactor of this design, jointly developed by Mitsubishi and AREVA. The estimated cost of the project is US\$22 billion and involves a consortium of Mitsubishi, AREVA, GDF-Suez, and Itochu, who between them will own 51 percent of the project, with up to 49 percent owned by Turkish companies including the State-owned electricity generating company (EÜAS). The ongoing problems with the financial viability of AREVA will affect its ability to invest in the project. According to GDF-Suez, the consortium will have a 20-year power purchase agreement for 100 percent of its output.⁸⁷ Construction is currently expected to start in 2017.⁸⁸ In April 2015, Turkish President Erdogan approved parliament's ratification of the intergovernmental agreement with Japan.⁸⁹

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 will be needed to take the electricity to Istanbul and Ankara. Reports at the end of 2014 suggested that the project would be further delayed, by up to two years—the fourth delay in two years. This has led to extreme frustration with the bidders, with company saying of the process: “They’re basically at the point where no one believes them any more.”⁹⁰ It is suggested that a final decision from the international consortium will be taken in 2016.

Third Plant Project

In December 2014, Westinghouse announced that it was starting talks with the Chinese State Nuclear Power Technology Corporation (SNPTC) and Turkey's Electricity Generation Company over a possible third nuclear project. However, as has been noted by the Deputy Undersecretary

⁸³ *Turkish Weekly*, “Chamber to sue state over abrupt green light to Turkey's first nuclear plant”, 3 January 2015, see <http://www.turkishweekly.net/2015/01/03/news/chamber-to-sue-state-over-abrupt-green-light-to-turkey-s-first-nuclear-plant/>, accessed 7 June 2015.

⁸⁴ *NIW*, “Briefs—Turkey”, 9 January 2015.

⁸⁵ *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 25 March 2015.

⁸⁶ *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 7 June 2015.

⁸⁷ *NIW*, “GDF Suez's Newbuild Strategy – Partners Needed”, 31 October 2014.

⁸⁸ *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 7 June 2015.

⁸⁹ *WNN*, “Ground broken for Turkey's first nuclear power plant”, 15 April 2015, op.cit.

⁹⁰ *NIW*, “Weekly Review”, 27 September 2015.

for the Turkish Ministry of Energy and National Resources, “having three different projects with three different technologies is not sound.”⁹¹

Further problems for the development of nuclear power in Turkey have been identified including the updating of nuclear liability laws and the establishment of the necessary legal and regulatory frameworks.⁹² Industry analysts have concluded that “Turkey hasn’t come close to establishing a viable regulator and remains more focused on securing a good financial deal”.⁹³

Plans and Projects

Lithuania had two large RBMK (Chernobyl-type) reactors at Ignalina, which were shut down in 2004 and 2009 as part of the agreement to join the European Union. Since then there have been ongoing attempts to build a replacement with neighboring countries. The most recent proposal was confirmed in 2012 when the Government, along with its partners in Estonia and Latvia, chose Hitachi together with its Hitachi-GE Nuclear Energy Ltd. unit as a strategic investor and technology supplier to construct a nuclear plant by the end of 2020.⁹⁴ In May 2012, the percentage breakdown of the initially US\$6.5 billion project was announced with a 20 percent ownership for Hitachi, and 38 percent for Lithuania, while Estonia would get 22 percent and Latvia 20 percent.⁹⁵

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.⁹⁶ 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”.⁹⁷ However, in January 2013, the Minister set up a Working Group on the energy development in the country, which concluded in April 2013 that the development of the nuclear new-build project could be continued under the condition of the involvement of regional partners, the availability of a strategic investor and “the use of the most modern and practically tested nuclear technology”.⁹⁸

In March 2014, in response to the situation in Ukraine, the seven parties represented in the Lithuanian Parliament signed an agreement on strategic priorities through 2020. This included the construction of a liquefied natural gas (LNG) plant, the synchronization of the grid with other EU countries, and that the nuclear project to be implemented “in accordance with the terms and

⁹¹ NIW, “Akkuy EIA Approved: A New Consortium Emerges”, 1 December 2014.

⁹² NIW, “Turkey’s Second Project Totters Forward”, 25 April 2014.

⁹³ NIW, “Newbuild—The Collapse of the Public Technology Tender”, 25 April 2014.

⁹⁴ Bloomberg, “Lithuania Seeking Lower Electricity Prices at New Nuclear Plant”, 15 February 2012, see <http://www.bloomberg.com/news/2012-02-15/lithuania-seeking-lower-electricity-prices-at-new-nuclear-plant.html>, accessed 10 June 2013.

⁹⁵ NIW, “Lithuania”, 11 May 2012.

⁹⁶ Reuters, “Lithuanians send nuclear plant back to drawing board”, 15 October 2012.

⁹⁷ NIW, “Lithuania—Prospective PM Wants to Scrape Visaginas”, 9 November 2012.

⁹⁸ Ministry of Energy of Lithuania, “Working Group’s Conclusions for Preparation of Proposals Regarding Cost-Effective and Consumers-Favorable Self-Provision with Power and Other Energy Resources”, 25 April 2013, unofficial translation, distributed by the Ministry, see http://www.enmin.lt/lt/nauijenos/Conclusions_of_the_Working_Group2.pdf, accessed 7 June 2015.

conditions of financing and participation improved in cooperation with partners”.⁹⁹ In April 2014, the Prime Minister said that the project might proceed but that it was dependent on the answers to 80 questions submitted to Hitachi, which included questions on the costs of the project, the price of electricity and the capabilities of synchronizing with the Western electricity grid. The Energy Minister, Jaroslav Neverovich, said there is a good chance the projects will proceed.¹⁰⁰ In July 2014 the Lithuania Energy Ministry and Hitachi signed an agreement to set up a joint venture for the construction of the Visaginas nuclear power plant. However, as of June 2015, further agreements with other partners, namely Estonia and Latvia, had yet to be signed.¹⁰¹

In November 2011, the **Bangladesh** Government’s press information department said that it would sign a deal with the Russian Government for two 1000 MW units to be built by 2018 at a cost of US\$2 billion.¹⁰² Since then, while it is said negotiations have been ongoing, the start-up date was postponed, and the price has risen. In January 2013, Deputy Finance Minister of Russia Sergey Storchak and Economic Relations Division (ERD) Secretary of Bangladesh Abul Kalam Azad signed the agreement on the Extension of State Export Credit for financing the preparatory stage work for the nuclear power plant at Rooppur (or Ruppur).¹⁰³ The deal was only for US\$500 million¹⁰⁴ and will only cover the site preparatory work.¹⁰⁵ In October 2013, a ceremony was held for the formal start of the preparatory stage,¹⁰⁶ with formal construction then expected to begin in 2015. At the time of the ceremony, the cost of construction was revised upwards and it was suggested that each unit would cost US\$1.5–2 billion.¹⁰⁷ These cost estimates tripled in April 2014, when a senior official at the Ministry of Science and Technology was quoted as suggesting the price was more likely to be US\$6 billion.¹⁰⁸ In Russia, it is expected that the total cost of the project is more likely to be around US\$10 billion¹⁰⁹, the cost of similar deals in Belarus and Hungary. However, falls in the value of the Ruble are likely to affect the overall cost of the project. It is expected that Bangladesh will be responsible for 10 percent of the project with the rest of the financing in the form of a loan from Russia. In June 2014, the Cabinet Committee on Government

⁹⁹ Ministry of Energy of Lithuania, “Lithuanian Parliamentary Parties Reached an Agreement Regarding the Key Strategic Energy Projects”, 31 March 2014.

¹⁰⁰ *Baltic Course*, “Lithuania waiting for Hitachi’s answers to nearly 80 questions concerning NPP”, 2 April 2014.

¹⁰¹ *The Lithuanian Tribune*, “Lithuanian energy minister expects new N-plant talks to speed up after Estonia forms new government”, 12 March 2015, see

<http://en.delfi.lt/nordic-baltic/lithuanian-energy-minister-expects-new-n-plant-talks-to-speed-up-after-estonia-forms-new-government.d?id=67412324#ixzz3Vls6GcfQ>, accessed 24 March 2015.

¹⁰² *Bloomberg*, “Bangladesh to Sign Deal With Russia to Build Nuclear Power Plant”, 2 November 2011.

¹⁰³ Energy Bangla, “Bangladesh, Russia sign nuclear power pact”, 17 January 2013.

¹⁰⁴ All dollar (equivalent) amounts are expressed in U.S. dollars unless indicated otherwise. However, the year’s dollars are not always clear in the original references.

¹⁰⁵ *The Star*, “Russia to lend \$1.5B to Bangladesh to build nuclear power station, buy arms”, 15 January 2013.

¹⁰⁶ *BBC*, “Bangladesh nuclear power plant work begins”, 2 October 2013.

¹⁰⁷ Bangladesh Awami League, “PM Sheikh Hasina inaugurates Rooppur Power Plant”, see <http://www.albd.org/index.php/en/updates/news/281-pm-sheikh-hasina-inaugurates-rooppur-power-plant>, accessed 25 March 2015.

¹⁰⁸ *The Independent* (of Bangladesh), “Roopur N-plant cost to double”, 7 April 2014, see http://www.theindependentbd.com/index.php?option=com_content&view=article&id=210774:roopur-n-plant-cost-to-double&catid=129:frontpage&Itemid=121, accessed 25 March 2015.

¹⁰⁹ *Moscow Times*, “Rosatom to Build Bangladesh’s First Nuclear Power Plant”, 3 October 2013.

Purchase approved a US\$190 million procurement contract with Atomstoyexport for the preconstruction work, with the start of actual construction expected for 2016.¹¹⁰

On 4 May 2015, the Government approved a draft of “The Nuclear Power Plant Law, 2015”.¹¹¹ The Minister for Science and Technology, Yeafesh Osman, stated that the actual budget would not yet be under discussion. “As for now, we are trying to understand the components of construction.”¹¹² On 4 June 2015, Bangladesh’s Finance Minister, AMA Muhith, recalled the target of 2 GW operational by 2022 and 4 GW by 2030.¹¹³

“The quest for setting up a nuclear power plant in Bangladesh’s Rooppur is even older than the country’s independence”, a recent book review of “Nuclear Power & Rooppur” by Abdul Matin noted.¹¹⁴ It remains to be seen whether the country has moved much closer to the goal.

Jordan has been encouraging the development of nuclear power for some decades and has discussed possible projects with Atomic Energy Canada Limited (AECL), GDF-Suez, AREVA, and Korea Electric Power Corporation (KEPCO). In May 2010, three consortia were shortlisted: the proposed designs were the ATMEA-1 (from a consortium of AREVA and Mitsubishi Heavy Industries (MHI), as projected in Turkey), EC6 (from AECL), and the AES-93 (from Rosatom). However, on 30 May 2012, the Jordanian parliament approved a recommendation to shelve the program, as it was said it would “drive the country into a dark tunnel and will bring about an adverse and irreversible environmental impact”. The parliament also recommended suspending uranium exploration until a feasibility study is done.¹¹⁵ Prior to the vote, the Parliament’s Energy Committee had published a report accusing the Jordanian Atomic Energy Commission (JAEC) of deliberately “misleading” the public and officials over the program by “hiding facts” related to costs.¹¹⁶ The JAEC responded by saying it wouldn’t be able to produce a full evaluation until the start of construction of the plant.¹¹⁷

Despite the parliamentary opposition, in October 2013, JAEC announced that Rosatom was the preferred bidder. The value of the engineering, procurement and construction contract is said to be US\$10 billion for the two 1000 MW units.¹¹⁸ It is suggested that Jordan will cover 50.1 percent

¹¹⁰ NIW, “News Briefs”, 6 June 2014.

¹¹¹ *The Daily Star*, “Cabinet okays Rooppur nuclear power plant draft”, 4 May 2015, see <http://www.thedailystar.net/country/cabinet-okays-rooppur-nuke-power-plant-draft-80446>, accessed 7 June 2015.

¹¹² *The Daily Star*, “Nuke power plant cost up three times”, 17 May 2015, see <http://www.thedailystar.net/frontpage/nuke-power-plant-cost-three-times-82738>, accessed 7 June 2015.

¹¹³ *The Daily Star*, “No new in energy”, 5 June 2015, see <http://www.thedailystar.net/backpage/no-new-energy-92401>, accessed 7 June 2015.

¹¹⁴ *The Daily Star*, “Decoding Rooppur...”, 18 May 2015, see <http://www.thedailystar.net/book-reviews/decoding-rooppur-83116>, accessed 7 June 2015.

¹¹⁵ *Jordan Times*, “Deputies vote to suspend nuclear project”, 30 May 2012, see <http://jordantimes.com/Deputies+vote+to+suspend+nuclear+project-48497>, accessed March 2015.

¹¹⁶ Ibidem.

¹¹⁷ *Monitor Global Outlook*, “Jordan clings on to nuclear ambitions, despite delays”, 10 January 2014, see <http://monitorglobaloutlook.com/news-story/jordan-clings-on-to-nuclear-ambitions-despite-delays/>, accessed July 2014.

¹¹⁸ It remains unclear what the US\$10 billion would actually cover, as the construction of two units would cost rather twice that amount.

of the contract, with Rosatom covering 49.9 percent and therefore being an investor and operator of the plant.¹¹⁹ In September 2014, JAEC and Rosatom signed a two-year development framework for a project, which will cost under US\$10 billion with electricity costs US\$0.10/kWh. It is now envisaged the earliest that construction start would be 2019,¹²⁰ which would make completion by the original objective of 2021¹²¹, impossible and even the revised dates of 2023 highly unlikely. In March 2015, an inter-government agreement was signed on co-operation in the construction and operation of the plant, with a construction agreement expected to be signed in 2016.¹²² As with other countries in the region, water is a critical factor and affects choices in the energy sector. 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”.¹²³ There has been uncertainty about where the plant would be located; current plans are to site the reactor at Al-Amra.¹²⁴

Poland planned the development of a series of nuclear power stations in the 1980s and started construction of two VVER1000/320 reactors in Żarnowiec on the Baltic coast, but both construction and further plans were halted following the Chernobyl accident. 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 plan.¹²⁵ The Programme was subject to a Strategic Environmental Assessment (SEA), which was also approved in January 2014. In April 2014, Greenpeace started legal procedures against the Assessment, alleging its public participation process was inadequate. The SEA drew around 60,000 submissions, a majority coming from neighboring Germany. The plan includes proposals to build 6 GW of nuclear power with the first reactor starting up by 2024. The reactor types under consideration include AREVA’s EPR, Westinghouse’s AP1000, and Hitachi/GE’s Advanced Boiling Water Reactor (ABWR).

In January 2013, the Polish utility PGE [Polska Grupa Energetyczna] had selected Australian consulting firm Worley Parsons 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.¹²⁶ The proposed US\$13–19 billion project was at the time to start with site selection in 2016 with construction scheduled to

¹¹⁹ *Construction Week*, “Jordan seeks Russian help to go nuclear”, 11 March 2014, see <http://www.constructionweekonline.com/article-27022-jordan-seeks-russian-help-to-go-nuclear/#.U0VKGahdXD8>, accessed 14 July 2014.

¹²⁰ *NIW*, “Briefs—Jordan”, 18 April 2014.

¹²¹ *NIW*, “Newbuild—Jordan and Russia Move Closer on Newbuild Plans”, 26 September 2014.

¹²² *WNN*, “Russia and Jordan agree \$10 billion construction project”, 25 March 2015, see <http://world-nuclear-news.org/NN-Russia-and-Jordan-agree-10-billion-construction-project-25031501.html>, accessed 25 March 2015.

¹²³ *Mining.com*, “Water shortages may end Jordan’s nuclear power hopes”, *oilprice.com*, 18 June 2013, see <http://www.mining.com/web/water-shortages-may-end-jordans-nuclear-power-hopes/>, accessed 11 June 2014.

¹²⁴ *NIW*, “Briefs—Jordan”, 14 November 2014.

¹²⁵ Ministerstwo Gospodarki, “Polish Nuclear Power Programme”, January 2014. Apparently, an updated version of the Program was published in the Polish Monitor MP on 24 June 2014.

¹²⁶ *NIW*, “Briefs—Poland”, 8 February 2013.

begin in 2019.¹²⁷ A number of vendors, including AREVA, Westinghouse, and GE-Hitachi, are all lobbying Warsaw aggressively.¹²⁸ 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 UK in July 2014. The timetable was that PGE expects to make a final investment decision on the two plants by early 2017.¹²⁹ Final design and permits for the first plant were expected to be ready in 2018, allowing construction start in 2020.

However, in April 2014, it was reported that PGE had cancelled its contract with Worley Parsons to research potential sites. It was thought that this would delay the process by at least two years, with the Supreme Audit Office suggesting that there was a high risk of further delays or that the plant wouldn't be completed at all.¹³⁰ In May 2015, the deputy Japanese METI [Ministry of Economics, Trade and Industry] minister visited Poland and assured his Polish counterparts that Japanese companies would be "very interested" in participating in the country's first nuclear power plant project.¹³¹

An independent critical assessment stated in late May 2015: "At this point, it is central to highlight that neither the Polish administration, nor PGE have announced so far any realistic or even detailed financing plan for the NPPs' scheme."¹³²

A decision by the Prime Minister of **Vietnam** of July 2011 states 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 2030.¹³³ In October 2010, Vietnam signed an intergovernmental agreement with Russia's Atomstroyexport to build the Ninh Thuan-1 nuclear power plant, using 1200 MW VVER reactors. Construction was slated to begin in 2014, with the turnkey project being owned and operated by the state utility Electricity of Vietnam (EVN), and with operations projected to begin in 2020.¹³⁴ In April 2013, the Song Da Corporation stated that it expected to

¹²⁷ *Economist*, "Polish Energy, Going nuclear", 31 January 2014, see <http://www.economist.com/blogs/easternapproaches/2014/01/polish-energy>, accessed July 2014.

¹²⁸ *NIW*, "Potential and Existing Global Nuclear Newbuild Projects", 25 April 2014.

¹²⁹ *NucNet*, "Amec Wins USD 430 Million Contract To Support Polish New-Build", 9 July 2014, see <http://www.nucnet.org/all-the-news/2014/07/21/amec-wins-usd-430-million-contract-to-support-polish-new-build>, accessed 7 June 2015.

¹³⁰ *Reuters*, "Poland's nuclear project pushed back at least another two years: sources", 14 April 2015, see <http://uk.reuters.com/article/2015/04/14/uk-poland-energy-nuclear-idUKKBN0N512M20150414>, accessed April 2015.

¹³¹ *WNN*, "Japanese interest in Poland's first nuclear plant", 6 May 2015, see <http://www.world-nuclear-news.org/NN-Japanese-interest-in-Polands-first-nuclear-plant-06051501.html>, accessed 7 June 2015.

¹³² Marcin Harembki, "Plan for Nuclear Power in Poland vs. Nuclear Energy Project Application", 21 May 2015.

¹³³ Vuong Huu Tan, "Challenges for New Comers in Regulating Nuclear Security", Director, Vietnam Agency for Radiation and Nuclear Safety, as presented at IAEA Senior Regulators' Meeting, 25 September 2014, see http://www-ns.iaea.org/downloads/coordination/snr-reg-meeting-2014/II-11%20Vietnam_Challenges%20for%20printing.pdf, accessed 17 March 2015.

¹³⁴ *Global Energy Magazine*, "Japan and Russia to Build Ninh Thuan Nuclear Power Plants for Vietnam", 3 November 2010.

start construction in the next 2–3 years,¹³⁵ but further delays were announced in January 2014, with a revised expectation that construction would begin in 2017 and therefore startup only in 2023.¹³⁶ However, once again the project has been delayed; first concrete is now unlikely to take place until 2019.¹³⁷ Rosatom has confirmed that Russia's Ministry of Finance is prepared to finance at least 85 percent of this first plant, and that Russia will supply the new fuel and take back spent fuel for the life of the plant. An agreement for up to US\$9 billion finance was signed in November 2011 with the Russian government's state export credit bureau, and a second US\$0.5 billion agreement covered the establishment of a nuclear science and technology center.¹³⁸

Like Turkey, Vietnam has also signed an intergovernmental agreement with Japan for the construction of a second nuclear power plant in Ninh Thuan province, with two reactors projected to come on line in 2024–25. The agreement calls for assistance in conducting feasibility studies for the project, low-interest and preferential loans, technology transfer and training of human resources, and cooperation in the waste treatment and stable supply of materials for the whole life of the project. In July 2011, the government issued a master plan detailing plans for Ninh Thuan-1 and -2 including a total of eight 1000 MWe-class reactors, one coming on line each year 2020–27 and then two more by 2029 at another central location. EVN is currently to be the sole investor in the reactors.¹³⁹ In May 2013, the Government set up a National Council for Atomic Energy, which is designed to identify the strategies and priorities for the development of nuclear power.¹⁴⁰

The delay in the ordering of the new nuclear units is not of concern due to a slower than expected increase in electricity demand, according to the Director General of the Atomic Energy Agency.¹⁴¹ However, other analysts have suggested that the slowdown in demand has given Vietnam another reason to abandon its nuclear development program altogether.¹⁴² Nguyen Khac Nhan, who has taught nuclear engineering at the Grenoble Institute of Technology in France and who has advised French state utility EDF for three decades, is convinced: “The nuclear power projects will most certainly be stopped.”¹⁴³

In 2012, the IAEA suggested that in 2013 the Kingdom of **Saudi Arabia** might start building its first nuclear reactor.¹⁴⁴ This confident prediction was based on the fact that in April 2010 a

¹³⁵ *Investvine*, “Vietnam prepares for nuclear power”, 13 April 2013.

¹³⁶ *WNN*, “Vietnamese delay confirmed”, 28 January 2014, see <http://www.world-nuclear-news.org/NP-Vietnamese-delay-confirmed-2801141.html>, accessed 14 July 2014.

¹³⁷ *NIW*, “News Brief”, 30 January 2015.

¹³⁸ *WNA*, “Nuclear Power in Vietnam”, Updated February 2015, see http://world-nuclear.org/info/vietnam_inf131.html, accessed 17 March 2015.

¹³⁹ *Nucleonics Week (NW)*, “Vietnam might require investors to set up fund for closure costs”, 11 January 2013.

¹⁴⁰ *WNN*, “New nuclear development council for Vietnam”, 9 May 2013.

¹⁴¹ *NIW*, “News Brief”, 30 January 2015.

¹⁴² *Vietnam.net*, “Nuclear power plans delayed as electricity demand lower than predicted”, 2 March 2015, see <http://english.vietnamnet.vn/fms/science-it/124198/nuclear-power-plans-delayed-as-electricity-demand-lower-than-predicted.html>, accessed 17 March 2015.

¹⁴³ *Asahi Shimbun*, “Anti-nuclear activists soldier on in nuclear energy powerhouse”, 28 April 2015, see http://ajw.asahi.com/article/forum/politics_and_economy/southeast_asia/AJ201504280004, accessed 7 June 2015.

¹⁴⁴ 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 5 May 2012.

royal decree said: “The development of atomic energy is essential to meet the Kingdom's growing requirements for energy to generate electricity, produce desalinated water and reduce reliance on depleting hydro-carbon resources.”¹⁴⁵ The King Abdullah City for Atomic and Renewable Energy (KA-CARE) was set up in Riyadh 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 would be planned to be online in ten years and then two more per year until 2030. However, the KA-CARE nuclear proposal has still not been approved by the country's top economic board, then headed by the late King Abdullah, and in March 2013, it was reported that a KA-CARE official has said that a tender is now unlikely for 7–8 years. In November 2013, it was nonetheless suggested that the project would be put back on track faster than this, with a suggestion that KA-CARE could bring forward proposals for new-build in 2015.¹⁴⁶

Hashim Yamani, president of the King Abdullah City for Atomic and Renewable Energy has said: “Recently, however, we have revised the outlook together with our stakeholders to focus on 2040 as the major milestone for long-term energy planning in Saudi Arabia.”¹⁴⁷ No reason was given for the delay or when the first nuclear and solar plants would be operational.

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 specific development occurred for several decades. In October 2006, the Minister for Energy announced that a 1,000 MW reactor would be built, but this was later expanded to four reactors by 2025, with the first one coming on line in 2019. In early 2010, a legal framework was adopted to regulate and establish nuclear facilities; however, an international bidding process for the construction was postponed in February 2011 due to the political situation. Since then there have been various attempts and reports that a tender process would be restarted, all of which have come to nothing. In February 2015, Rosatom and Egypt's Nuclear Power Plant Authority signed an agreement that would lead to the construction and financing of two reactors and possibly two additional ones, at as yet unspecified site. However, Rosatom highlighted the “need to prepare for signing two intergovernmental agreements—one on nuclear power plant construction and one on financing”.¹⁴⁸ A long way to go yet.

¹⁴⁵ *World Politics Review*, “Saudi Arabia's Nuclear Ambitions Part of Broader Strategy”, 16 June 2011, see <http://www.worldpoliticsreview.com/articles/9186/saudi-arabias-nuclear-ambitions-part-of-broader-strategy>, accessed May 2015.

¹⁴⁶ *NIW*, “Briefs—Saudi Arabia”, 15 November 2014; and Ali Ahmad and M.V. Ramana, “Too costly to matter: Economics of nuclear power for Saudi Arabia”, *Energy Journal*, 2014.

¹⁴⁷ *Reuters*, “Saudi Arabia's nuclear, renewable energy plans pushed back”, 19 January 2015, see <http://www.reuters.com/article/2015/01/19/saudi-nuclear-energy-idUSL6N0UY2LS20150119>, accessed 8 June 2015.

¹⁴⁸ Rosatom, “Russia Helps Egypt To Explore Opportunities Of Nuclear Power Plant Construction”, 10 February 2015, see <http://www.rosatom.ru/en/presscentre/news/5e972b804741f759a754ffed5d96ec92>, accessed 8 June 2015.

Generation III Reactors—Why the Delays and Cost Overruns?

Introduction

In the late 1990s, the nuclear industry began to talk about a Nuclear Renaissance. This would be driven by a new generation of nuclear designs, termed Generation III+, that would solve the three key problems of safety, cost and buildability that were seen as behind nuclear power's steep ordering decline. The central claim was based on the premise that the existing designs had become too complex as a result of adding new safety systems to old designs. It was claimed that with a fresh eye, the design could be simplified but would be safer, cheaper, and easier to build. Construction costs of US\$1,000/kW were forecast, a level that would make nuclear competitive with gas, and construction times of four years or less were also expected (see previous WNISRs). The promise that nuclear power could be the cheapest option reignited interest in nuclear power in a number of key markets. In particular President Bush's attempt in 2002 and Prime Minister Blair's attempt in 2005 to re-launch nuclear ordering in the U.S. and the UK, respectively, were powerful endorsements of these new designs in two of the world's most prestigious markets.

The promoters' claims of low costs quickly proved unrealistic and when analyses based on actual commercial proposals turned up, with builders bearing most or all of the price risk, prices increased sharply and continually. By 2013, the expected cost had increased 8-fold. There is little sign of prices stabilizing and lessons from the Fukushima disaster will, as they emerge, be likely to drive prices even higher. These price increases were well documented in previous editions of the WNISR and prices are not the main focus of this analysis. The claims for greater safety are also not directly addressed.

Rather, this chapter focuses on the claim the designs would be easier to build. Despite its being nearly 20 years since a Nuclear Renaissance was mooted, none of the new designs is yet in service. By May 2015, 18 reactors of designs claimed to meet Generation III+ criteria were under construction.¹⁴⁹ Only two were still on time and the rest were two to nine years late. So on the face of it, the claims that these designs would be easier to build appear no better based than the cost claims are unsubstantiated. Eight reactors are of the Toshiba/Westinghouse AP1000 (Advanced Passive) design, six are of the Rosatom AES-2006 design, and four use the AREVA European Pressurized Water Reactor (EPR) (see Table 3). This chapter identifies what specific problems have been experienced leading to these delays to determine how far these problems are soluble—for example loss of expertise and capability resulting from the long period of low orders—and how far they are generic to the new designs.¹⁵⁰

The analysis also examines two other pillars to the “renaissance” not specific to Generation III+ designs; standardization and use of generic regulatory safety reviews. For more than 40 years, standardization has been promoted by many in the nuclear industry as a way to reduce

¹⁴⁹ In May 2015, first concrete was poured for a new Chinese design, Hualong One, which has also been offered for export markets, including Argentina, Pakistan and Europe. This design is claimed to meet Generation III+ criteria.

¹⁵⁰ For a fuller account of the problems suffered at each of the sites see Steve Thomas, “Construction Delays at Generation III+ Nuclear Power Plants”, July 2015, see <http://www.psiru.org/re#B1FAF33>, accessed 1 July 2015.

construction times and costs, reduce design issues, and accelerate industry “learning”. The use of generic design reviews was meant to resolve all design safety issues before construction started. It was claimed that in the past, regulators gave overall, in-principle approval of the design, but when the details emerged, construction was sometimes interrupted because the detailed design did not meet the regulator’s requirements. Of the six countries building Generation III+ designs, only the USA has opted for this approach, although the UK has also adopted this policy for its proposed reactors.

The evidence base for buildability is still relatively small. Twelve of the 18 reactors are in China, Russia or Belarus—countries where independent, reliable information is often not available, so the record of problems suffered is unlikely to be complete. Six of the reactors had, by mid-2015, been under construction for only about two years or less. Nevertheless, with few orders in prospect, it is important to evaluate the limited data available.

Generation III+ designs were seen as transitional technologies until Generation IV designs became available. If Generation III+ reactors fail, the future for the nuclear industry appears bleak. Generation III+ was seen as a last chance for light water technology and, as discussed in the next chapter on Advanced Nuclear Reactors, small modular reactors or radical new reactor designs, known as Generation IV, are decades away from being commercially deployable, if ever.

What is Generation III+?

Nuclear plants are commonly divided into four generations. There are no clear definitions of what determines what design generation a given reactor design fits into. Generation I designs are the prototype and early nuclear orders, for example, the UK’s “Magnox” gas-cooled reactors. Generation II includes the vast majority of operating reactors ordered from the mid-60s to about 1990. Generation III designs began to emerge from the mid-80s onwards, learning from the Three Mile Island accident. A number of Generation III designs were developed. However, the only orders placed were the eight placed for the Advanced Boiling Water Reactor (ABWR), developed by General Electric (GE), Hitachi and Toshiba and the six for the Rosatom AES-91 and AES-92 designs. The ABWR is being upgraded and upgraded versions have been submitted to the U.S. and UK regulatory bodies for review. The Rosatom AES-91 and AES-92 were designed, as their name implies, in the 1990s and had some of the features that characterize the latest designs, such as a core-catcher and some passive safety characteristics and formed the basis for AES-2006.

Two other designs usually categorized as late Generation II are particularly relevant to this analysis. The Framatome N4 design (four reactors built) and the Siemens “Konvoi” (three built) formed the basis for the AREVA EPR. The Westinghouse AP600, usually seen as Generation III, was a more radical departure from previous practice than the others, being much smaller than its predecessors and relying on “passive safety”. It received generic design approval from the U.S. safety authorities but was never offered for sale. However, it was scaled up to about 1,150 MW to create the AP1000.

Generation III+ reactors were developed or significantly modified after the Chernobyl disaster. They also now include the added requirements of being able to withstand aircraft impact resulting from the terrorist attack of 11 September 2001 (the 9/11 attack). The AP1000, EPR, and

AES-2006 have received orders, whilst another four—GE-Hitachi¹⁵¹ Economic Simplified Boiling Water Reactor (ESBWR), Hitachi-GE, and Toshiba updated versions of the ABWR and the Mitsubishi Advanced Pressurized Water Reactor (APWR)—are undergoing generic review by the U.S. and/or U.K. safety authorities.

The World Nuclear Association (WNA) claims that: “Newer advanced reactors [Generation III+] now being built have simpler designs which reduce capital cost. They are more fuel efficient and are inherently safer.”¹⁵² In more detail, it lists some of the design characteristics of which the most relevant to this analysis are:

- a standardized design for each type to expedite licensing, reduce capital cost and reduce construction time,
- a simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets,
- further reduced possibility of core melt accidents,
- substantial grace period, so that following shutdown the plant requires no active intervention for (typically) 72 hours,
- resistance to serious damage that would allow radiological release from an aircraft impact.

The WNA lists some additional possible characteristics including: “The greatest departure from most designs now in operation is that many incorporate passive or inherent safety features which require no active controls or operational intervention to avoid accidents in the event of malfunction, and may rely on gravity, natural convection or resistance to high temperatures.” And “A feature of some new designs is modular construction. The means that many small components are assembled in a factory environment (offsite or onsite) into structural modules weighing up to 1,000 tonnes, and these can be hoisted into place. Construction is speeded up.”

These possible design characteristics do reveal the diversity of the reactors claimed to be design Generation III+. The EPR and AES-2006 appear to be upgraded versions of earlier commercial designs, while AP1000 is a more radical departure. Westinghouse claims: “The AP1000 PWR is the safest and most economical nuclear power plant available in the worldwide commercial market-place.”¹⁵³ On modularization, Westinghouse claims: “Factory-built modules can be installed at the site in a planned construction schedule of three years—from first concrete pour to fuel load.”¹⁵⁴

Price rises occur throughout the period from project announcement to operation. For example, in 2003, the French Industry Ministry estimated that construction costs for an EPR would be just over €1 billion (US\$1.2 billion) per reactor. The price tag had tripled by the time the contract was

¹⁵¹ In 2006, Toshiba ended its partnership with GE and Hitachi, and began to market its own version of the ABWR in competition with Hitachi and GE. Hitachi and GE formed two joint ventures, GE-Hitachi with 80 percent GE for the USA and Hitachi-GE (80 percent Hitachi) for non-U.S. markets. Only GE-Hitachi markets the ESBWR.

¹⁵² WNA, “Advanced Nuclear Power Reactors”, Updated May 2015, see <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Advanced-Nuclear-Power-Reactors/>, accessed 21 May 2015.

¹⁵³ Westinghouse, “AP1000 Nuclear Power Plant”, see <http://www.westinghousenuclear.com/New-Plants/AP1000-PWR>, accessed 23 May 2015.

¹⁵⁴ Westinghouse, “AP1000PWR—Construction”, see <http://www.westinghousenuclear.com/New-Plants/AP1000-PWR/Construction>, accessed 23 May 2015.

signed for the Flamanville plant in 2007, and by 2012, the estimated cost had reached €8.5 billion (US\$10.6 billion) (see also WNISR2013, Table 2¹⁵⁵).

Standardization and Generic Design Reviews

The first characteristic listed by the WNA for Generation III+ designs talks of “a standardized design for each type to expedite licensing, reduce capital cost and reduce construction time.”¹⁵⁶ For more than 40 years, the nuclear industry has been claiming standardizing designs would reduce costs and improve performance. Intuitively, there would appear to be significant advantages to standardization. However, full-scale standardization has never happened. Even the French nuclear program of 58 reactors, often portrayed as fully standardized, was actually subject to continual design changes with the 58 orders split between three designs split into a total of seven variants. This begs the questions, why has standardization not happened so far, and will it be feasible now?

Generic design reviews also seem an intuitively sensible way to reduce the risk of construction delays. This would be an exhaustive review of the design and once complete, the reactor design would have approval for future projects and, for example, in the USA, the Nuclear Regulatory Commission (NRC) grants design approvals with a 15-years validity. However, whilst this has been the policy since 1992, it has not really been tested. Without standardization, it is difficult to see how generic design approval could be credible. Experience shows even relatively limited design changes can have implications for the whole plant, so any significant change to the approved design ought to re-open the process of design approval.

Causes of Construction Delays

Complexity

Westinghouse claimed its AP1000 design had 50 percent fewer valves, 35 percent fewer pumps, 80 percent less pipe, 80 percent fewer heating, ventilating, and cooling units, 45 percent less seismic building volume, and 70 percent less cable than a standard PWR.¹⁵⁷ AREVA claimed that a “guiding design principle” for its EPR design was “simplifying system design.”¹⁵⁸

Other Causes of Delay

When delays occur, they are seldom attributed to complexity although often, it seems likely that complexity is one of the root causes. The most commonly cited causes of delay are: design issues;

¹⁵⁵ WNISR, “Olkiluoto and Flamanville”, 30 July 2013, see, http://www.worldnuclearreport.org/World-Nuclear-Report-2013.html#olkiluoto_and_flamanville, accessed 21 May 2015.

¹⁵⁶ WNA, “Advanced Nuclear Power Reactors”, Updated May 2015, see <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Advanced-Nuclear-Power-Reactors/>, accessed 21 May 2015.

¹⁵⁷ Regis Matzie, “The AP1000 Reactor Nuclear Renaissance Option”, Tulane Engineering Forum, 26 September 2003, see http://www2.lakelandcc.edu/nora/events/iuser/faculty/images/members/AP1000_percent202.pdf, accessed 24 February 2015.

¹⁵⁸ Robert C. Twilley, “EPR development—An evolutionary design process”, AREVA, *Nuclear News*, April 2004, see <http://www2.ans.org/pubs/magazines/nn/docs/2004-4-3.pdf>, accessed 23 May 2015.

shortage of skilled labor; quality control issues; supply chain issues; poor planning either by the utility or equipment suppliers; shortage of finance; and public opposition.

The role of public opposition in delaying construction is frequently overstated and there is no evidence that construction of any of the Generation III+ plants has been delayed by public opposition. At least in the U.S., this reflects the nuclear industry's successful efforts to restrict meaningful public access to judicial or regulatory proceedings and to rule that unresolved safety issues cannot be raised. While obtaining finance is clearly now one of the major hurdles to building new nuclear plants, this is much more likely to occur before construction starts. Again, there is no evidence that shortage of finance has delayed construction apart from the plants under construction in Russia. The Fukushima disaster did delay ordering in some markets, for example China, but there is no evidence that any of the delays at the Generation III+ plants resulted directly from lessons drawn of the catastrophe in Japan.

Design Issues

A frequent problem has been that detailed design is worked out by the vendor only during construction. If producing the final detailed design proves difficult, for example, or if the regulator is not satisfied with the detailed design, this can delay construction. A notable example of this was the Instrumentation & Control (I&C) System for the EPR. In 2009, the safety regulatory authorities for Finland, France, and the UK issued a joint statement expressing concern about the adequacy of the safety systems (those used to maintain control of the plant if it goes outside normal conditions), and their independence from the control systems.¹⁵⁹ This was eventually resolved in all three countries but with a different solution for each and only after up to five years of effort to produce designs that would satisfy the national regulator.

Delays can also be caused by designs that meet regulatory requirements but do not function as specified. A particular example has been the reactor coolant pumps (RCPs) for the AP1000 to be supplied by Curtiss-Wright. Curtiss-Wright acknowledged that it “failed to meet deadlines for shipping RCPs from the U.S. to AP1000 plant sites in China and that it had to ship pumps back from the Sanmen and Haiyang sites in China for modification.”¹⁶⁰

Shortage of Skilled Labor, Loss of Expertise

The low ordering rate for new nuclear power plants over the past 30 years has meant that there has been little demand for skilled construction workers, so the workforce has aged and its skills have not been utilized. Re-building a skilled workforce cannot be done quickly, requiring basic education as well as experience. Until the flow of orders is more established and the job prospects secure, the incentives for workers to undergo such training will be weak. For both the first orders for EPRs, the pouring of the concrete base-mat had to be re-done because of errors. Particularly for France, where EDF, the owner and site engineer had already built 58 PWRs, it seems reasonable to assume this was due to loss of expertise at diverse levels of craft labor and management. This is not surprising, since the French vendor's last construction start before

¹⁵⁹ Health and Safety Executive's Nuclear Directorate (HSE's ND), French Nuclear Regulator (ASN) and Finnish Radiation and Nuclear Safety Regulator (STUK), “Joint Regulatory Position Statement on the EPR Pressurised Water Reactor—Release No V4 22/10/2009”, 2 November 2009, see <http://www.hse.gov.uk/press/2009/hse221009.htm>, accessed 21 May 2015.

¹⁶⁰ NW, “AP1000 reactor pump issue brings plant design change: Westinghouse”, 6 November 2014.

Olkiluoto-3 dates back to 1991—long enough for a whole generation of craftsmen and managers to have retired and their transmission of experience therefore to have been lost.

Supply Chain Issues

Here we are dealing with poor quality of equipment or delays in delivery rather than unavailability of equipment, which is dealt with under “poor planning”. The error by AREVA in the fabrication of the pressure vessels for Flamanville and the two reactors for Taishan in China is one of the most serious failures to date (see below).

Poor Planning

The dearth of orders has also led to a loss of project planning expertise in utilities, project engineers and regulatory bodies. The history of construction at the Olkiluoto-3 site has been littered with accusations of failures of planning by the utility, the vendor and the regulatory authority.

First-Of-A-Kind Problems

There is frequent mention of first-of-a-kind (FOAK) issues and, intuitively, it might be expected that the first time a design is built, problems will arise that will not affect subsequent units. For this analysis, these problems generally fall into one of the other categories, such as poor planning, supply chain issues or loss of skills. For example, if construction is delayed because new procedures have to be approved by the regulator, this must be counted as poor planning.

Experience at Construction Sites

EPR

While the guiding principle for the EPR was said to be “simplifying system design”, it seems clear they were unable to do this. This was confirmed in the Roussely report—a 2010 inquiry into the problems facing the EPR, commissioned by the French government and chaired by the Honorary President of EDF, François Roussely. This found that:

The resulting complexity of the EPR, arising from the choice of design, specifically the level of power, the containment, the core catcher and the redundancy of the security systems is certainly a handicap for its construction and therefore its cost. These factors explain, in part, the difficulties encountered in Finland or in Flamanville.¹⁶¹

Also in 2010, Anne Lauvergeon, then CEO of AREVA, told its shareholders: “Safety has a cost, 15 percent for EPR compared with generation 2.”¹⁶² While AREVA does claim on its website the

¹⁶¹ François Roussely, “Future of the French civilian nuclear industry”, Honorary President of EDF Group, Translated by the Institute for Energy and Environmental Research, Takoma Park, Maryland, see <http://www.psr.org/nuclear-bailout/resources/roussely-report-france-nuclear-epr.pdf>, accessed 13 February 2015.

¹⁶² Areva, “Q4 2009 AREVA CI Earnings Presentation”, Transcript, 4 March 2010.

use of passive features in the EPR¹⁶³, elsewhere it said it had chosen “an evolutionary path with an emphasis on active safety features”.¹⁶⁴

There are three EPR construction projects. Olkiluoto-3 (Finland) was started in 2005 and expected to come on-line in 2009 at a cost of €3 billion (US\$3.6 billion). By 2015, completion was not expected before 2018 at a cost (not revised since 2012) of €8.5 billion (US\$9.5 billion). Flamanville-3 (France) was started in 2007 and expected in-line in 2012 at a cost of €3.2 billion (US\$4.7 billion). By 2015, completion was not expected before 2017 at a cost of €8.5 billion (US\$9.5 billion). Taishan-1 & -2 (China) units started construction in 2009 and 2010 when they were both due on-line in 2014. In 2015, completion was expected in 2016 but no reliable cost information has been published.

For both the Olkiluoto and Flamanville, problems emerged at the start with the pouring of the base mat and from then on quality control problems particularly with welds, were a recurring problem. There were delays due to difficulties meeting regulatory requirements for aircraft protection at the Olkiluoto site and for both Flamanville and Olkiluoto meeting requirements for redundancy in the Instrumentation & Control System. The latter problem emerged in 2009 when a joint regulatory statement by the Finnish, French and UK (which was carrying out a generic design review) regulators expressed their concerns.¹⁶⁵ Subsequently the U.S. regulator, which was also carrying out a generic review, also stated its reservations.

The issue was resolved in a little over three years in France, and there is no evidence this added significantly to the delays for Flamanville. For Olkiluoto the issues took five years to sort out, and AREVA and the customer, Teollisuuden Voima Tyj (TVO), have claimed this caused significant delays. The generic approval process for EPR in the USA was suspended in 2015 before the U.S. regulator had given approval for the proposed instrumentation & control design. It is not clear whether the Chinese regulator had any issues with this part of the plant. It appears that different instrumentation & control system designs were implemented in all three construction projects and the designs that were different again would have been required for the UK and USA.

Potentially the most serious problem was made public in April 2015 when it was admitted that there had been manufacturing errors in the tops and bottoms of the Reactor Pressure Vessel (RPV) fabricated at AREVA's Le Creusot plant in 2006. This affected the Flamanville and Taishan projects, while the Olkiluoto parts had been supplied by another firm. Three more reactor tops and bottoms were fabricated soon after (for the two UK Hinkley Point reactors and the subsequently abandoned Calvert Cliffs project in the USA) and suffer from the same issue of too high a carbon content in the steel. By mid-2015, investigations were under way to determine what needed to be done. There appeared to be three options: the regulator could rule that the deviation from required specification was acceptable and no further action needed; repairs could be carried out; or the projects could be abandoned because it is no longer feasible to access the parts requiring repair.

¹⁶³ Areva, “EPR Reactor: The very high power reactor (1,650MWe)”, see <http://www.AREVA.com/EN/global-offer-419/epr-reactor-one-of-the-most-powerful-in-the-world.html>, accessed 23 May 2015.

¹⁶⁴ Robert C. Twilley, “EPR development—An evolutionary design process”, AREVA, *Nuclear News*, April 2004.

¹⁶⁵ HSE's ND (UK), ASN (France) and STUK (Finland), “Joint Regulatory Position Statement on the EPR Pressurised Water Reactor—Release No V4 22/10/2009”, 2 November 2009, see <http://www.hse.gov.uk/press/2009/hse221009.htm>, accessed 13 February 2015.

For Taishan, it was not until 2014 that reliable reports confirmed construction delays although there is little information on what is behind delays now acknowledged to be more than two years. The reports in 2014 suggested that the main problem from then on were that, instead of being the third and fourth EPRs to be completed, Taishan will now be the first-of-a-kind and will need to carry out extra tests on novel components and test acceptance and start-up procedures. The emergence of the pressure vessel issue in April 2015 puts the entire project in doubt.¹⁶⁶

At about the same time the full extent of AREVA's financial difficulties became apparent when it announced annual losses of nearly €5 billion (US\$5.5 billion) for 2014. AREVA and its Finnish customer TVO were in the midst of a legal battle over who would pay about €3 billion (US\$3.2 billion) in cost overruns, and AREVA had few credible prospects for EPR orders other than a long-delayed project in India (Jaitapur) and Hinkley Point C. By mid-2015, the French government and the two publicly controlled companies AREVA and Électricité de France (EDF) were still discussing how to save AREVA. It may be that this combination of issues will mean that the solution for AREVA will involve abandoning attempts to sell the EPR.

AP1000

The AP1000 is a scaled-up version of the AP600; the latter received regulatory approval from the U.S. authorities in 1999 but was clearly uneconomic and never found a customer. The AP1000 designed was submitted to the Nuclear Regulatory Commission (NRC) in 2002. Given that it was portrayed as just a scaled-up version of an already approved design, it was assumed regulatory approval would be quick. However, the process involved multiple design revisions and it was not until 2011 that a final design was approved. This was a strategically important victory for the Westinghouse AP1000, by then owned by Toshiba of Japan, over the AREVA EPR, because China had signaled that it expected that subsequent reactor orders for China would be for AP1000.

The first orders for the AP1000 were for two units at each of the Sanmen and Haiyang sites in China. Construction of these units started in 2009-10 with completion expected in 2013-15. Four further orders for AP1000 for the USA, two each for the Summer and Vogtle sites, started construction in 2013 with then expected completion in 2016-18. These are likely to be the only fruit of President George W. Bush's 2010 nuclear program and of subsidies estimated to rival or exceed construction costs.¹⁶⁷

By 2015, the Chinese plants were running 18–36 months late, while the U.S. plants, after only two years of construction, late by two years or more. Unlike Taishan, where reports of problems only emerged after 4–5 years of construction, reports of problems emerged after two years in 2011 with the reactor coolant pumps a particularly long-running issue. By May 2015, Westinghouse and its Chinese partner, State Nuclear Power Technology Corporation, claimed that the problems had been solved after five years of multiple failed endurance tests. This is far from the first time that Westinghouse has made such claims.¹⁶⁸ While this appears to have been the major problem,

¹⁶⁶ For a 4-page briefing on the issue see Yves Marignac, "Fabrication Flaws in the Pressure Vessel of the EPR Flamanville-3", WISE-Paris, 12 April 2015, see <https://dl.dropboxusercontent.com/u/25762794/20150412Fabrication-Flaws-EPR-Flamanville-v3.pdf>, accessed 6 June 2015.

¹⁶⁷ Doug Koplow, "Still Not Viable Without Subsidies", Earth Track, February 2011, see <http://earthtrack.net/documents/nuclear-power-still-not-viable-without-subsidies>, accessed 20 June 2015.

¹⁶⁸ *NIW*, "Testing Winds Down for AP1000 RCPs", 8 May 2015.

there have been a number of other issues such as design issues (squib valves), poor documentation, and quality issues. Like Taishan, there are increasing concerns about commissioning tests and acceptance criteria.

Westinghouse claims the problems with the reactor coolant pumps emerged early enough for them to be avoided for the U.S. orders, which will use a different manufacturing process for the impellers. For the U.S. plants, there has been a large number of problems in the factories of the module suppliers, especially Chicago Bridge & Iron (CB&I). From the beginning of 2013 to 1 May 2015, the pumps' vendor CB&I had had to inform the NRC of 65 failures "to comply with the Atomic Energy Act (AEA) of 1954, as amended, or other NRC regulations."¹⁶⁹

A senior executive with CB&I said: "The suppliers really struggled understanding the exact nature of what we wanted, how to stand up [nuclear quality assurance] programs. Getting suppliers up the learning curve on what was expected in terms of quality and how that process had to work was quite difficult".¹⁷⁰

AES-2006

The development of the AES-2006 is more complex than that of EPR or AP1000, partly because, while Rosatom is the umbrella organization for all the major Russian nuclear companies, there appears to be considerable overlap between different subsidiaries. There are two major nuclear design companies, Moscow Atomenergoproekt and Saint-Petersburg Atomenergoproekt, which generally have their own distinctive versions of the same basic design, including AES-2006. A third design company, Nizhniy Novgorod Atomenergoproekt, exists but does not seem to be as important as the other two. Rosatom presents the successive versions of the VVER (the Russian version of the PWR) as a smooth evolution with Rosatom emphasizing the additional safety features that each successive model included.¹⁷¹ There were two early post-Chernobyl designs, AES-91/V-428 (Saint-Petersburg Atomenergoproekt) exported to China and AES-92/V-412 (Moscow Atomenergoproekt) exported to India. The reactor was essentially the same as its predecessor, VVER-1000/V-320), but with added safety systems including a core-catcher and some passive safety systems. Both models are still being offered, for example to markets like Jordan where the extra output of the AES-2006 would be difficult to accommodate.

The AES-2006 comes in two versions, V-392M designed by Moscow Atomenergoproekt with two units under construction at Novovoronezh, and V-491, designed by Saint-Petersburg Atomenergoproekt and under construction at the Leningrad, Belarus, and the Baltic sites, although work at the Baltic site was suspended in 2013 and appears unlikely to restart. It is not clear which versions would be exported to the numerous export orders Rosatom claims but on which construction has not started, such as Turkey and Vietnam. There are differences between the two variants in terms of their passive safety systems.

Work on a successor design, VVER-TOI/V-520 developed by Moscow Atomenergoproekt and based on V-392M, quickly started and by 2010, it was said the new design would be available

¹⁶⁹ U.S.NRC, "Part 21 Reports", Updated 22 May 2015, see <http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/>, accessed 22 May 2015.

¹⁷⁰ NW, "US experiences nuclear construction challenges, progress: industry", 29 August 2013.

¹⁷¹ Rosatom, "The VVER today", Updated 11 March 2015, see http://www.rosatom.ru/en/resources/b6724a80447c36958cface920d36ab1/brochure_the_veer_today.pdf, accessed 11 March 2015.

from 2012, although by 2015 no orders had been placed. VVER-TOI was expected to be 20 percent cheaper and could be built in 40 months.

First concrete was poured for the reactors sited in Russia from 2008–10 and these reactors are where substantive experience exists. The major reported incident was the collapse of the steel structures for a containment build at the Leningrad site in 2011. It was only in 2014 that first reports of delays emerged and by 2015, all four reactors were 3–4 years late. However, a January 2015 report from Russia’s Audit Chamber seemed to put the blame squarely on shortage of funds.¹⁷² Whether there are other construction issues is difficult to tell. Two reactors using an older design at the Rostov site were ordered at about the same time as the AES-2006s; one of these was completed on time and the other appears close to schedule. It may be that this indicates more deep-seated issues at Novovoronezh and Leningrad than just shortage of capital.

Comparison of the EPR and AP1000

The record of AES-2006 seems somewhat better than that of EPR and AP1000, but the lack of detailed information on the AES-2006 projects and the lack of transparency of the regulatory system means it is difficult to draw strong conclusions on the buildability of the AES-2006 compared to AP1000 and EPR.

In terms of delays, the record of AP1000 and EPR appears comparably bad. The delays at the Chinese AP1000 and EPR sites are similar to each other, and the delays at the U.S. AP1000 sites are similar to those incurred at a comparable stage for EPR. Both designs have suffered a serious design issue that has delayed construction. The instrumentation & control system for EPR caused delays because of problems persuading the regulators of its adequacy. The reactor coolant pump issue was somewhat different, with the problem being that the pump simply did not meet the design standard.

However, the pattern of construction problems seems somewhat different. For EPR, there was a succession of quality problems with sitework at both European sites, while the AP1000 suffered serious quality issues at the module suppliers’ facilities, especially those of CB&I.

Conclusions

The promise that Generation III+ designs would be simpler and therefore easier to build appears not to have been fulfilled. Real costs have increased significantly compared to their predecessors suggesting the attempt to reduce complexity was not a success. The attempt to reduce sitework by shifting the workload to factories through modularized design also does not seem to have had the desired effect, and seems to simply have shifted the quality issues from site to module factories.

Standardization has not happened, and all three designs have seen significant and continuing design changes. The reality may be that nuclear technology is simply not mature enough to standardize yet and there is still a continuing flow of design changes driven by experience of operating plants and technical change that it would be foolish to ignore. The rate of ordering may also be too low for standardization to be feasible. If vendors are receiving only a handful of orders per decade, it seems to make little sense to standardize. Without standardization, the process of

¹⁷² NIW, “Auditor Report Illuminates Rosatom’s Financial Challenges”, 23 January 2015.

generic design review does not appear feasible. It may make sense to review a design in detail before it is built, but if the design is not standardized, this process may need to be carried out for every project.

The “Nuclear Renaissance” appears, in retrospect, to have been a last chance for light water reactor technology. Given the failure to reduce costs—and there are few who would forecast costs are going to go down at all, much less decline to the levels originally claimed—and the apparent failure to reduce the incidence of construction overruns, the future looks bleak for light water technology. There is considerable momentum to the Chinese and Russian programs, but unless costs fall, even these countries will have to think again. If the nuclear industry is to have a future, it can only be through new technologies such as Generation IV designs or Small Modular Reactors. Both of these options are many years from being commercially available.

Table'3: Summary'of'Status'of'Generation'III+'Construction'Projects

Plant	Country	Technology	Construction Start	Completion Date at Construction Start	Completion date in May 2015	Forecast Cost at Construction Start	Latest Forecast Cost
Olkiluoto>3'	Finland'	EPR'	5/05'	5/09'	Late'2018 ^{173'}	€3>3.2bn'	€8.5bn'
Flamanville>3'	France'	EPR'	12/07'	5/12'	2017 ^{174'}	€3.2bn'	€8.5bn'
Taishan>1'	China'	EPR'	11/09'	2/14'	12/15'	€4bn ^{175'}	'
Taishan>2'	China'	EPR'	4/10'	8/14'	2016'	€4bn'	'
Sanmen>1'	China'	AP1000'	4/09'	8/13'	Mid'2016'	US\$1940/kW ^{176'}	20%'over'budget'
Sanmen>2'	China'	AP1000'	12/09'	8/14'	6/16'	US\$1940/kW'	20%'over'budget'
Haiyang>1'	China'	AP1000'	9/09'	5/14'	3/16'	US\$1940/kW'	20%'over'budget'
Haiyang>2'	China'	AP1000'	6/10'	2/15'	9/16'	US\$1940/kW'	20%'over'budget'
Summer>2'	USA'	AP1000'	3/13'	3/16'	6/19 ^{177'}	US\$5.2bn'	US\$6.2bn ^{178'}
Summer>3'	USA'	AP1000'	11/13'	11/18'	6/20'	US\$5.2bn'	US\$6.2bn'
Vogtle>3'	USA'	AP1000'	3/13'	4/16'	2 nd 'q'2019 ^{179'}	US\$6.65bn'	US\$8.15bn ^{180'}

[illegible]

¹⁷³NIW, "Finland's 'Near-Decade Delay' at OL3", 5 September 2014.

¹⁷⁴NIW, "Knock-On Effects From Flamanville Delay", 21 November 2014.

¹⁷⁵Associated Press, "AP Interview: 'AREVA's 'US\$11.9 billion' (€8 billion)' deal' could 'spark' more 'sales' in 'China'", 28 November 2007.

¹⁷⁶NIW, "New AP1000s See Rising Costs, Component Delays", 31 October 2011.

¹⁷⁷*Business Wire*, "Fitch: 'SCE&G' Updated 'Nuclear' Cost 'Estimate' Captured 'in' Current 'Negative' Rating 'Outlook'", 17 March 2015, see

<http://www.businesswire.com/news/home/20150317006289/en/Fitch>SCEG>Updated>Nuclear>Cost>Estimate>Captured#.VQxLCtI8a70>, 'accessed' 23'May'2015.'

178'Ibidem.'

¹⁷⁹NIW, "Weekly Roundup—Vogle Delayed Another 18 Months", 30 January 2015.

¹⁸⁰Wall Street Journal (WSJ), "Nuclear Power Firms Feel Squeeze", 5 March 2015, see <http://www.wsj.com/articles/nuclear-power-firms-feel-squeeze-1425591380>, accessed 22 May 2015.

Vogtle>4'	USA'	AP1000'	11/13'	1/18'	2 nd q'2020 ^{181'}	US\$6.65bn'	US\$8.15bn'
Plant	Country	Technology	Construction Start	Completion Date at Construction Start	Completion date in May 2015	Forecast Cost at Construction Start	Latest Forecast Cost
Leningrad>2>1'	Russia'	AES>2006'	10/08'	2013'	2016 ^{182'}	'	'
Leningrad>2>2'	Russia'	AES>2006'	4/10'	2015'	2018'	'	'
Novovoronezh>2>1'	Russia'	AES>2006'	6/08'	2013'	2016 ^{183'}	'	'
Novovoronezh>2>2'	Russia'	AES>2006'	7/09'	2014'	2018'	'	'
Belarusian>1'	Belarus'	AES>2006'	11/13'	2018 ^{184'}	2018 ^{185'}	US\$6.5bn'	US\$11.45bn ^{186'}
Belarusian>2'	Belarus'	AES>2006'	4/14'	2020'	2020 ^{187'}	US\$6.5bn'	US\$11.45bn'

Source: IAEA-PRIS, see <http://www.iaea.org/PRIS/home.aspx>, accessed 15 May 2015, unless noted otherwise.

^{181'}NIW, "Weekly Roundup", p.1, '30'January'2015.'

^{182'}NIW, "Weekly Roundup", p.1, '20'February'2015.'

^{183'}WNN, '23'April'2015.'

^{184'}NIW, "Fast Tracking Newbuild With First Concrete Pour", '8'November'2013.'

^{185'}Belta News Agency, "Construction of first, second units of Belarusian nuclear station on schedule", '25'February'2015, 'see' http://www.atom.belta.by/en/belaes_en/view/construction-of-first-second-units-of-belarusian-nuclear-station-on-schedule>5056/, 'accessed'22'May'2015.'

^{186'}Atomstroyexport, "The total investment in the development of the Belarusian NPP site in 2015 is planned to increase up to 14.337 billion Russian rubles", 'Press Release', '5'March'2015, 'see' <http://www.atomstroyexport.ru/wps/wcm/connect/ase/eng/journalists/press/9e84aa00478814e2b1d9f36578d50f5d>, 'accessed'23'May'2015.'

^{187'}Belta News Agency, "Construction of first, second units of Belarusian nuclear station on schedule", '25'February'2015, 'see' http://www.atom.belta.by/en/belaes_en/view/construction-of-first-second-units-of-belarusian-nuclear-station-on-schedule>5056/, 'accessed'23'May'2015.'

Advanced Nuclear Reactors—The Story of the SMR

“SMRs Could Be The Way Forward For Europe, Conference Told”

NucNet,
16 June 2015¹⁸⁸

One reaction to the decline of nuclear power from the nuclear industry and other proponents has been to advocate what it terms “advanced reactors”. The underlying presumption is that the slowdown of nuclear power is a result of the kind of reactors that are operated or constructed, and if new kinds of reactors are constructed, then nuclear power will be revived. Accordingly, “advanced reactors” are held out as an answer to one or more of the problems—such as poor economics, generation of radioactive waste, linkage to nuclear weapons, and potential for severe accidents—confronting nuclear power. Many “advanced reactor” designs are held out as solving all of the problems. In the past decade, the overwhelming focus of this effort has been on what are called Small Modular Reactors (SMRs).¹⁸⁹

History

The idea of small reactors is not new and a belief in the power of small nuclear reactors to energize different communities that were not currently served by atomic energy dates back to the 1950s and 1960s, but the early experiments were mostly failures.¹⁹⁰ Nevertheless, the AEA and other organizations foresaw a large expansion of small nuclear reactors, with one analyst projecting that during the 1980s, over 160 nuclear reactors with capacities of 300 MW or less would be constructed in 44 developing countries.¹⁹¹ None of those reactor projects materialized.

The second wave of interest in SMRs came about in the 1980s, as utilities in the United States had stopped ordering nuclear reactors. The U.S. Department of Energy (DOE) observed new interest in small and medium size reactors and in more advanced reactor concepts other than those marketed today.”¹⁹² In 1983, the AEA launched a new study on what it termed Small and Medium Power Reactors with “the objective of surveying the available designs, examining the major factors influencing the decision making processes in Developing Countries and thereby arriving at an estimate of the potential market”.¹⁹³ The AEA received descriptions of 23 design concepts

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¹⁸⁸ NucNet, “SMRs Could Be The Way Forward For Europe, Conference Told”, 16 June 2015, see <http://www.nucnet.org/allTheNews/2015/06/16/srmsCouldBeTheWayForwardForEuropeConferenceTold>, accessed 2 June 2015.

¹⁸⁹ The acronym SMR is also used to mean small and medium sized reactor” by the AEA. For the AEA, a “small” reactor is one having electrical output less than 300 MWe and a “medium” reactor is one having a power output between 300 and 700 MWe.

¹⁹⁰ M.V. Ramana, “The Forgotten History of Small Nuclear Reactors”, *IEEE Spectrum*, May 2015, see <http://spectrum.ieee.org/energy/nuclear/the-forgotten-history-of-small-nuclear-reactors>, accessed 24 May 2015.

¹⁹¹ James Lane, “The Impact of Oil Price Increases on the Market for Nuclear Power in Developing Countries”, IAEA Bulletin, 1974, 16, no. 1–2.

¹⁹² Office of Program Support, “Nuclear Energy Cost Database”, U.S. Department of Energy (DOE), 1988.

¹⁹³ AEA, “Small and Medium Power Reactors—Project Initiation Study, Phase 1”, International Atomic Energy Agency, Vienna, 1985.

but noted that these “had varying levels of readiness and proveness”.¹⁹⁴ As of 1987, 19 of these 23 were reported as have documented “readiness and proveness” and the IAEA concluded that SMRs “could play an important role in the 90ies and beyond” and reported that several countries had “expressed their particular interest in these reactors”.¹⁹⁵ In 1991, the Nuclear Development Committee of the Nuclear Energy Agency (NEA) claimed that “there is now considerable interest arising in small reactor types”.¹⁹⁶ The 1990s came, but the SMRs did not play the important role that was envisioned for them; with the exception of the VVER-440, no reactor that was included in the IAEA’s list of 23 was ever constructed.

The most recent, and current, wave of interest in SMRs dates back to the early 2000s. The problem, as laid out in 2002 by three analysts from the IAEA’s Department of Nuclear Energy, was that “quite simply, over the last 15 years, nuclear power has been losing market share badly in a growing world electricity capacity market”.¹⁹⁷ Their diagnosis: “The main reason for this stalemate is that we, in all our doings, continue to rely on nuclear technology developed in the 1950s, which had its roots in military applications which cannot exclude absolutely the possibility of a severe accident and which has reached its limits from an economic point of view.”¹⁹⁸ As the way forward, these analysts suggested developing innovative new reactor designs, chiefly of the SMR variety.

United States

“The problem I have with SMRs is not the technology, it’s not the deployment—it’s that there’s no customers.”

Danny Roderick, President and CEO of Westinghouse
February 2014¹⁹⁹

Thanks to its strong belief in SMRs, the DOE (U.S. Department of Energy) has been funding research and development of such reactors since the 1990s. In 2000, the United States Congress provided one million dollars to the DOE “to undertake a study to determine the feasibility of and issues associated with the deployment of... small reactors”.²⁰⁰ The DOE’s Office of Nuclear Energy published such a report in May 2001, which conducted an overview of nearly ten SMR designs and concluded:

¹⁹⁴ L.V. Konstantinov and J. Kupitz, “The Status of Development of Small and Medium Sized Reactors”, *Nuclear Engineering and Design*, 1988.

¹⁹⁵ Ibidem, 9.

¹⁹⁶ NEA, “Small and Medium Reactors: Status and Prospects”, OECD, Paris, 1991.

¹⁹⁷ V. Mourogov, K. Fukuda, and V. Kagramanian, “The Need for Innovative Nuclear Reactor and Fuel Cycle Systems: Strategy for Development and Future Prospects”, *Progress in Nuclear Energy*, 2002.

¹⁹⁸ Ibidem.

¹⁹⁹ Anya Litvak, “Westinghouse Backs off Small Nuclear Plants”, *Pittsburgh Post-Gazette*, 1 February 2014, see <http://www.post-gazette.com/business/2014/02/02/Westinghouse-backs-off-small-nuclear-plants/stories/201402020074>, accessed 3 February 2014.

²⁰⁰ DOE, “Report to Congress on Small Modular Nuclear Reactors”, Office of Nuclear Energy, May 2001; and Senate, “Congressional Record”, S7900, 19 July 2001.

The most technically mature small modular reactor (SMR) designs and concepts have the potential to be economical and could be made available for deployment before the end of the decade, provided that certain technical and licensing issues are addressed.²⁰¹

None of the SMR designs were available for deployment by the end of that decade. In 2012, the DOE established a cost-share funding opportunity aimed at commercializing SMR technology, with an initial funding level of US\$452 million over five years to cover costs associated with research and development, design certification, and licensing. Separately, DOE also funded research and development under an “Advanced” SMR program.

The two SMR designs that were selected by the DOE for funding were mPower and NuScale. Both are light water reactors, but with an integral design, in which the steam generators are located in the same pressurized vessel as the reactor core. The former is being developed by Babcock & Wilcox, while the latter is being developed by NuScale Power and has received investment from Fluor Corporation. After the DOE had provided it US\$111 million in funding,²⁰² Babcock & Wilcox (B&W) decided to slash its spending on SMRs in April 2014, from about US\$80 million/year to less than US\$15 million/year.²⁰³ For at least the prior year B&W had been trying to find other companies willing to invest in mPower or customers willing to enter into a contract for an mPower reactor, but in April 2014 a B&W spokesperson admitted that “neither of those things have happened”.²⁰⁴

NuScale, for its part, has continued with the development of its reactor design. In its annual report submitted to the U.S. Securities and Exchange Commission for the fiscal year that ended on 31 December 2014, Fluor Corporation offered some details about funding under the DOE’s Small Modular Reactor Licensing Technical Support Program:

This cost-sharing award requires NuScale to use the DOE funds to cover first-of-a-kind engineering costs associated with small modular reactor design development and certification. The DOE is to provide cost reimbursement for up to 43 percent of qualified expenditures incurred during the period from June 1, 2014 to May 31, 2019. The Cooperative Agreement also provided for reimbursement of pre-award costs incurred from September 18, 2013 to May 31, 2014, which were recognized in the second quarter of 2014... NuScale expenses included in the determination of segment profit were \$46 million, \$53 million, and \$63 million for 2014, 2013 and 2012, respectively. NuScale expenses for 2014 are reported net of qualified reimbursable expenses of \$38 million.²⁰⁵

Another vendor that had applied for DOE funding was Westinghouse, which had long pushed the concept of SMRs. In parallel with developing the AP600 and AP1000 designs, Westinghouse led a

²⁰¹ Ibidem.

²⁰² John Downey, “Three Takeaways from Babcock & Wilcox’s Latest Earnings”, *Charlotte Business Journal*, 26 February 2015, see <http://www.bizjournals.com/charlotte/blog/energy/2015/02/three-takeaways-from-babcock-wilcox-s-latest.html?page=all>, accessed 8 May 2015. In its March 2015 filing with the U.S. Securities and Exchange Commission, B&W stated “At this time, the latest extension to the Cooperative Agreement [Small Modular Reactor Licensing Technical Support Program] has expired and the DOE funding has been suspended.”; see <http://services.corporate-ir.net/SEC.Enhanced/SecCapsule.aspx?c=236851&fid=10100075>, accessed 24 May 2015.

²⁰³ WNN, “Funding for mPower Reduced”, 14 April 2014, see <http://www.world-nuclear-news.org/C-Funding-for-mPower-reduced-1404141.html>, accessed 24 May 2015.

²⁰⁴ Jason Ruiter, “Babcock & Wilcox Cuts Investment in mPower”, *NewsAdvance.com*, 14 April 2014, see http://www.newsadvance.com/news/local/babcock-wilcox-cuts-investment-in-mpower/article_d7998d52-c3d3-11e3-8fbb-0017a43b2370.html, accessed 25 May 2015.

²⁰⁵ Fluor Corporation, “Form 10-K—Annual Report pursuant to section 13 or 15 (d) of the securities exchange Act of 1934—For the Fiscal Year ended December 31, 2014”, 11 February 2015, see <http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9MjcMTY3fENoaWxkSUQ9LTF8VHlwZT0z&t=1>, accessed 25 May 2015.

large international team in the development of the International Reactor Innovative and Secure (IRIS) design. The design started its life as the Safe Transportable Autonomous Reactor–Light Water design in 1999 and received funding under the DOE’s Nuclear Energy Research Initiative (NERI) program.²⁰⁶ For a decade, a series of papers and conference talks extolled the virtues of the IRIS design, including its safety, its applicability to developing countries, and economic competitiveness.²⁰⁷ According to its filings with the NRC in 2009, Westinghouse was “hoping to submit a design for review by the third quarter of 2012”.²⁰⁸ That was not to be and in 2010, Westinghouse withdrew from the IRIS consortium. In early 2011, it introduced a new SMR design, the Westinghouse SMR, which had an output of 225 MWe, downsized from the IRIS’s 335 MWe. According to a Westinghouse official, this reduction was based on “market observations”, which included the fact that “incremental base load additions typically range from 200 to 300 MWe” and “coal [plant] retirements average 150 to 250 MWe”.²⁰⁹ After unsuccessfully submitting this new design for DOE funding in both 2012 and 2013, Westinghouse “reprioritized staff devoted to SMR development” (i.e., stopped working on the SMR) and decided to focus its efforts on the AP1000 reactor and “gaining new decommissioning contracts”.²¹⁰ Explaining this decision, Danny Roderick, president and CEO of Westinghouse, announced: “The problem I have with SMRs is not the technology, it’s not the deployment—it’s that there’s no customers.... The worst thing to do is get ahead of the market”.²¹¹

For all the public advertising, there is no evidence that SMRs will be constructed in the United States anytime soon. One indicator is the fact that although there have been many claims over the past decade that SMRs would soon be certified for construction, no vendor has even submitted an application. As with plans for SMR deployment at scale, the licensing schedule has been slipping continuously.

In October 2008, for example, an NRC official projected that NuScale would submit an application for design certification in early 2010 and that review would be completed by early 2015. The same presentation also projected that the Pebble Bed Modular Reactor would be submitting an application and be certified in the same time period (early 2010 to early 2015); that the Hyperion reactor (currently Gen4 Energy) would submit an application by the beginning of 2012 and be certified by end of 2015; and that the Toshiba 4S would submit an application in mid-2009 and be

²⁰⁶ Mario D. Carelli, “The Exciting Journey of Designing an Advanced Reactor”, *Nuclear Engineering and Design*, May 2009.

²⁰⁷ Mario Carelli et al., “The Design and Safety Features of the IRIS Reactor”, *Nuclear Engineering and Design*, 230, no. 1–3, 2004; see also, A. Finnicum, D.J. Kumagai, and Y. Maioli, “IRIS Simplified LERF Model”, at American Nuclear Energy Symposium, Miami (Florida) USA, 2004; and Gonçalves Orlando João Agostinho Filho, “INPRO Economic Assessment of the IRIS Nuclear Reactor for Deployment in Brazil”, *Nuclear Engineering and Design* 241, no. 6, 2011.

²⁰⁸ Phil Chaffee, “Bechtel Joins B&W’s Small Modular Reactor Project”, *Uranium Intelligence Weekly*, 19 July 2010.

²⁰⁹ Nick Shulyak, “Westinghouse Small Modular Reactor: Taking Proven Technology to the Next Level”, International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) Dialogue Forum on Nuclear Energy Innovations, Common User Considerations for Small and Medium-sized Nuclear Power Reactors, Vienna, Austria, 10 October 2011.

²¹⁰ Heba Hashem, “Westinghouse: Taking Care of Business”, *Nuclear Energy Insider*, 12 February 2014, see <http://analysis.nuclearenergyinsider.com/small-modular-reactors/westinghouse-taking-care-business>, accessed 25 May 2015.

²¹¹ Anya Litvak, “Westinghouse Backs off Small Nuclear Plants”, *Pittsburgh Post-Gazette*, 1 February 2014, see <http://www.post-gazette.com/business/2014/02/02/Westinghouse-backs-off-small-nuclear-plants/stories/201402020074>, accessed 3 February 2014.

certified by mid-2013.²¹² To be fair, there was a caveat attached to these projections: “Schedules depicted for future activities represent nominal assumed review durations based on submittal time frames in letters of intent from prospective applicants. Actual schedules will be determined when applications are docketed.”

Clearly none of these projections materialized. Nevertheless, even in 2009, the NRC’s “Advanced Reactors” webpage stated that the Commission expected “to receive applications for staff review and approval of some of these [small light-water reactor (LWR) and non-LWR] designs as early as Fiscal Year 2011”.²¹³ In 2010, the Chief Executive Officer (CEO) of Hyperion Power (currently Gen4 Energy) told Bloomberg News that the company intended to apply for a license “within a year”.²¹⁴

So far, the NRC has received no license applications for SMRs. Indeed, when explaining the reduction in its 2015 budget request—\$1,032 million, down by 3 percent relative to 2014—the NRC reportedly said that “the decrease is due to a decreasing workload for its New Reactors and Fuel Facilities business lines”.²¹⁵ One can take that as a commentary on NRC’s expectation that SMR license applications will be slow in coming, at best.

Russia

Although the Russian nuclear establishment seems mainly interested in selling its standard pressurized water reactors, it has a number of SMR designs under development. Among the SMRs that Russia is developing, the KLT-40S, which is based on the design of reactors used in the small fleet of nuclear-powered icebreakers that Russia has operated for decades, will likely be the first one to be deployed. The KLT-40S is to be deployed on a ship and therefore called the Floating Point Unit (FPU) design. In October 2002, the power module for this design was approved by a joint decision of Russia Minatom, “Rosenergoatom” Concern, and Russian Shipbuilding Agency.²¹⁶ The construction of two such reactor modules for the Akademik Lomosoov plant was completed in 2009.²¹⁷ Construction of Akademik Lomonosov, the first prototype ship based on the FPU design, began in April 2007 at the Sevmash Arctic military shipyard, but this contract was canceled and construction was transferred to the JSC Baltic Shipyard in Saint Petersburg in February 2009. The project was re-launched in June 2010, and construction of the on-shore infrastructure in Vilyuchinsk started in September 2010.²¹⁸ At that time, the ship was expected to be delivered to Vilyuchinsk in the Kamchatka region of Russia’s Far East, followed by grid connection in late 2012

²¹² Edward Baker, “NRC’s Advanced Reactor Program”, 16 October 2008, see <http://web.mit.edu/ans/www/documents/seminar/F08/baker.pdf>, accessed 19 May 2015.

²¹³ NRC, “Advanced Reactors”, 4 November 2009, see <http://www.nrc.gov/reactors/advanced.html>, accessed 4 August 2010.

²¹⁴ Jeremy van Loon and Alex Morales, “Miniature Nuclear Plants Seek Approval to Work in U.S.”, *Bloomberg News*, 17 May 2010, see <http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aNWxvJD2xhZ8>, accessed 19 May 2015.

²¹⁵ WNN, “US Budget Request Reflects Nuclear Commitments”, 3 February 2015, see <http://www.world-nuclear-news.org/NP-US-budget-request-reflects-nuclear-commitments-0302157.html>, accessed 19 May 2015.

²¹⁶ IAEA, “Status Report for Advanced Nuclear Reactor Designs - Report 73”, Vienna, 4 January 2011.

²¹⁷ WNN, “Reactors Ready for Floating Plant”, 7 August 2009, see http://www.world-nuclear-news.org/NN-Reactors_ready_for_first_floating_plant-0708094.html, accessed 19 May 2015.

²¹⁸ Alexandr Nikitin and Leonid Andreyev, “Floating Nuclear Power Plants”, Bellona Foundation, Oslo, 2011.

or early 2013.²¹⁹ In 2011, it was reported that the project was “delayed by [a minimum of] 1.5 years due to financial difficulties”.²²⁰ By late that year the Baltic Shipyards “found itself on the verge of bankruptcy. Workers had gone unpaid for months.”²²¹ The situation seems to have eased, and in the update from October 2014, the shipyard promised delivery in September 2016.²²² The World Nuclear Association, on the other hand, expects commercial operations only in December 2019.²²³ Associated with these lengthy delays is an enormous cost increase: from an original estimate of 9 billion rubles (\$140 million) in 2006 to 37 billion rubles (\$740 million) as of 2015.²²⁴

South Korea

South Korea has been developing the System-Integrated Modular Advanced Reactor (SMART) for nearly two decades. The project to develop an SMR was launched by the Korea Atomic Energy Research Institute (KAERI) in 1996.²²⁵ The result was the SMART design, which has received extensive Korean government and industry support. In 2010, a consortium consisting of Korea Electric Power Corporation, POSCO, STX Heavy Industries, Daewoo, Iljin, and Samchang pledged to contribute 100 billion won (about US\$83 million) to complete design work on the SMART.²²⁶ Like other SMRs, the SMART has also been long delayed. In 1998, KAERI projected that licensing activities will be done by 2004, on the basis of “close cooperation between the licensing body and the reactor developer”.²²⁷ This was not to be. Only in July 2012 did the Nuclear Safety and Security Commission issue a Standard Design Approval for SMART, making it the first licensed land based SMR of LWR design (not including the designs from the 1950s and 1960s). This early start, however, hasn’t helped, and the reactor has not received any orders so far. KAERI did, however, sign a Memorandum of Understanding with Saudi Arabia’s King Abdullah City for Atomic and Renewable Energy (KA-CARE) in March 2015 to “conduct a three-year preliminary study to review the feasibility of constructing SMART reactors in Saudi Arabia”.²²⁸

²¹⁹ Thomas Young, “Isolated Criticality: Russia’s Floating Nuclear Power Plants, Concepts and Concerns”, *NTI* (Nuclear Threat Initiative), 5 November 2010, see <http://www.nti.org/analysis/articles/russias-floating-nuclear-power-plants/>, accessed 19 May 2015.

²²⁰ Gary Peach, “Newbuild Slows but Only Slightly”, *NIW*, 24 October 2011.

²²¹ Gary Peach, “Floating Reactors — Strategic Advantage, or Bad Idea?”, *NIW*, 2 March 2012.

²²² Charles Digges, “Russia Announces yet Newer Delivery Date for First Floating Nuclear Power Plant”, *Bellona.org*, 28 October 2014, see <http://bellona.org/news/nuclear-issues/nuclear-russia/2014-10-russia-announces-yet-newer-delivery-date-first-floating-nuclear-power-plant>, accessed 19 May 2015.

²²³ WNA, “Akademik Lomonosov 2”, WNA Reactor Database, 2015, see <http://world-nuclear.org/NuclearDatabase/reactordetails.aspx?id=27570&rid=A0D78EB7-B62A-48FF-9D78-21A8E4534D90>, accessed 24 May 2015.

²²⁴ Charles Digges, “New documents show cost of Russian floating nuclear power plant skyrockets”, *Bellona*, 25 May 2015, see <http://bellona.org/news/nuclear-issues/2015-05-new-documents-show-cost-russian-nuclear-power-plant-skyrockets>, accessed 18 June 2015.

²²⁵ Kyoo Hwan Bae et al., “Safety Evaluation of the Inherent and Passive Safety Features of the Smart Design”, *Annals of Nuclear Energy*, 2001.

²²⁶ WNN, “Consortium Pledges Cash for Smart Reactor”, 18 June 2010, see http://www.world-nuclear-news.org/C-Consortium_pledges_cash_for_SMART_reactor-1806107.html, accessed 24 June 2015.

²²⁷ Moon Hee Chang and Si-hwan Kim, “Approach for SMART Application to Desalination and Power Generation”, IAEA, in Advisory Group Meeting on Materials and Equipment for the Coupling Interfaces of Nuclear Reactors with Desalination and District Heating Plants, vol. IAEA-TECDOC-1056, Vienna, 1998.

²²⁸ WNN, “Saudi Arabia Teams up with Korea on SMART”, 4 March 2015, see <http://world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html>, accessed 19 May 2015.

China

China has pursued multiple SMR designs but the most advanced of these, and the one currently under construction, is the High Temperature Reactor (HTR) that it has developed since the 1970s. In turn, the Chinese design was based on the prior failed German effort to commercialize the technology.²²⁹

Before China embarked on this effort, South Africa set up a major program to develop a commercial HTR called the Pebble Bed Modular Reactor (PBMR). The PBMR differed from the German design in that its design avoided the use of a heat exchanger (also called steam generator) to convert heat produced by the reactor into steam; the steam is then used to drive a turbine to generate electricity. Instead, the PBMR design involved circulating the helium that is used to cool the reactor directly through a turbine. This feature was highly touted by the company as being one of the many “unique and patented technological innovations, which make it [PBMR] particularly competitive”.²³⁰ South Africa appears to have been so confident of its technology that it did not even try to construct a pilot scale reactor, going directly to a commercial scale plant.

In 2005, South Africa and China signed a Memorandum of Understanding (MoU) in order to cooperate on the technology, even though the two countries were considered as competitors. The PBMR CEO justified the MoU by arguing that “having two plants completed in the same timeframe will bring technical understanding for follow-on applications that can only enhance the future of the technology”.²³¹ At that time, PBMR optimistically projected construction beginning in 2007 and that “the first commercial PBMR modules will be available from 2013.”²³² But in 2010, after spending over 7 billion Rand (nearly US\$1 billion), the government announced that it was mothballing the project “after the programme failed to find private investors or customers abroad.”²³³

China, on the other hand, started with the pilot scale HTR-10 reactor that was developed by the Institute of Nuclear and New Energy Technology of Tsinghua University. HTR-10 reached its criticality in 2000, achieved full power operation, and began to supply power to the grid in 2003.²³⁴ Soon after the HTR-10 attained criticality, in 2001, the high-temperature gas cooled reactor pebble-bed module (HTR-PM) project was launched.²³⁵ The development of this reactor became a high priority under the “Chinese Science and Technology Plan” for the period 2006–2020.

In February 2008, the implementation plan and the budget for the HTR-PM project was approved by the State Council of China. The HTR-PM received final approval from China’s cabinet and its

²²⁹ Steve Thomas, “The Pebble Bed Modular Reactor: An Obituary”, *Energy Policy*, (39, no. 5), 2011.

²³⁰ Tom Ferreira, “South Africa’s Nuclear Model”, *IAEA Bulletin*, June 2004.

²³¹ *Engineering News*, “SA and China Team up to Develop Nuclear Technology”, 24 June 2005, see <http://www.engineeringnews.co.za/article/sa-and-china-team-up-to-develop-nuclear-technology-2005-06-24>, accessed 24 May 2015.

²³² *Ibidem*.

²³³ *Mail & Guardian*, “SA Mothballs Pebble Bed Modular Reactor Project”, 17 September 2010, see <http://mg.co.za/article/2010-09-17-sa-mothballs-pebble-bed-modular-reactor-project/>, accessed 19 May 2015.

²³⁴ Sheng Zhou and Xiliang Zhang, “Nuclear Energy Development in China: A Study of Opportunities and Challenges”, *Energy*, 35, no. 11, 2010; 4282–88.

²³⁵ Zuoyi Zhang et al., “Current Status and Technical Description of Chinese 2 × 250 MWth HTR-PM Demonstration Plant”, *Nuclear Engineering and Design*, 2009.

national energy bureau around two weeks before the Fukushima accidents.²³⁶ However, in the aftermath of Fukushima, all nuclear construction was frozen. In December 2012, construction of HTR-PM commenced in China's eastern Shandong province.²³⁷ It is scheduled to be connected to the grid in 2017.

India

The main new SMR design that India has been developing since the 1990s is the Advanced Heavy Water Reactor (AHWR).²³⁸ Indian officials have marketed this design for a while with a message about its potential for “utilization of thorium on a large scale”.²³⁹ Thorium has been a long-standing interest of the Department of Atomic Energy (DAE) in India, which has considerable thorium resources. Besides thorium, the design that had been developed since the 1990s involved the use of large quantities of plutonium as fuel.²⁴⁰ In 2009, the Chairman of the Atomic Energy Commission announced that India had made an export version of this design called the AHWR-LEU, which will dispense with any plutonium use as input and use LEU (low enriched uranium) instead. This modified design is advertised as possessing “intrinsic proliferation resistant features”.²⁴¹

The AHWR has also been repeatedly delayed. In 2003, the director of the Bhabha Atomic Research Centre in Mumbai announced at a meeting of the Indian Nuclear Society that the AHWR's “construction is proposed to be started within 2 years time”.²⁴² Speaking to the Indian Science Congress in 2007, Atomic Energy Commission Chairman Anil Kakodkar promised: “We will start the construction on the AHWR sometime this year”.²⁴³ That hasn't happened, but in December 2014, the DAE informed the Indian Parliament that the reactor is likely to be functional by 2020.²⁴⁴

One reason for the delay is that the DAE would like to build the AHWR—a design that has never been built anywhere in the world—in the Visakhapatnam campus of the Bhabha Atomic Research

²³⁶ Keith Bradsher, “China Building Nuclear Reactors With Radically Different Design”, *New York Times*, 24 March 2011, see <http://www.nytimes.com/2011/03/25/business/energy-environment/25chinanuke.html>, accessed 24 April 2012.

²³⁷ NucNet, “China Begins Construction Of First Generation IV HTR-PM Unit”, *The Communications Network for Nuclear Energy and Ionising Radiation*, 7 January 2013, see <http://www.nucnet.org/all-the-news/2013/01/07/china-begins-construction-of-first-generation-iv-htr-pm-unit>, accessed 10 January 2013.

²³⁸ R. K. Sinha and Anil Kakodkar, “Advanced Heavy Water Reactor”, *Nu-Power* (13, no. 3), 1999.

²³⁹ R. K. Sinha and Anil Kakodkar, “Design and Development of the AHWR—the Indian Thorium Fuelled Innovative Nuclear Reactor”, *Nuclear Engineering and Design*, 2006.

²⁴⁰ Sinha and Kakodkar, “Advanced Heavy Water Reactor”, *Nu-Power*, 1999.

²⁴¹ K. L. Ramkumar, “Th-LEU Fuel in AHWR to Enhance Proliferation Resistance Characteristics”, IAEA 3rd Technical Meeting on Options to incorporate intrinsic proliferation resistance features to Nuclear Power Plants with innovative Small Modular Reactors, Vienna, Austria, 15 August 2011.

²⁴² B. Bhattacharjee, “An Overview of R&D in Fuel Cycle Activities of AHWR”, Indian Nuclear Society (INS), Nuclear Fuel Cycle Technologies: Closing the Fuel Cycle Conferences, INS Annual Conference (INSAC), Kalpakam, December 2003.

²⁴³ *The Frontier Star*, “India To Begin Construction Of Advanced Heavy Water Reactor”, 4 January 2007.

²⁴⁴ *Press Trust of India (PTI)*, “Advanced Heavy Water Reactor Likely to Be Functional by 2020”, *Zee News*, 17 December 2014, see http://zeenews.india.com/news/india/advanced-heavy-water-reactor-likely-to-be-functional-by-2020_1516207.html, accessed 19 May 2015.

Centre.²⁴⁵ The city of Visakhapatnam has a population of 1.7 million according to the 2011 Census. Such siting is considered significant because it is intended as “relevant for future next generation reactors that will meet the further enhanced safety requirements for locating them in close proximity to population centers”.²⁴⁶

Argentina

In February 2014, Argentina’s National Atomic Energy Commission (CNEA) started construction of the CAREM-25 reactor.²⁴⁷ SMR enthusiasts around the world welcomed the event.²⁴⁸ CAREM is a pressurized water reactor with a gross electrical output of 27 MWe.

Like other reactors around the world, CAREM has been significantly delayed. The reactor has been in development since the 1980s with an original design output of 15 MWe.²⁴⁹ Construction of the reactor was scheduled to begin in 2001.²⁵⁰ By 2009, CAREM developers promised that “preparation of the site facilities” was going well enough “to start the construction during the second half of 2010” and that was “expected to be finished by the end of 2014”.²⁵¹ When construction started, CNEA announced that the reactor is currently scheduled to begin cold testing in 2016 and receive its first fuel load in the second half of 2017.²⁵² The reactor has not received authorization from the country’s regulator for the various forthcoming steps, including fuel loading.²⁵³

Conclusion

For decades, small modular reactors have been held out as holding great promise for expanding nuclear power into various new markets. Remarkably similar claims have been made by the nuclear industry in multiple countries. Nowhere have these claims come true. Although a few small reactors were constructed in the first round of nuclear construction, most countries quickly progressed from those to larger sizes, primarily because of the hope that through economies of

²⁴⁵ T. S Subramanian, “Radiation Fears Unfounded’: Interview with R.K. Sinha, Chairman of the Atomic Energy Commission”, *Frontline*, 20 June 2012.

²⁴⁶ Government of India, “National Report to the Convention on Nuclear Safety—Fifth Review Meeting of Contracting Parties, April 2011”, August 2010, see

<http://www.aerb.gov.in/AERBPortal/pages/English/t/documents/CNS2011.pdf>, accessed 25 June 2015.

²⁴⁷ WNN, “Construction of CAREM Underway”, 10 February 2014, see <http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html>, accessed 23 May 2015.

²⁴⁸ Will Davis, “Argentina Carries Torch for SMR Construction”, *ANS Nuclear Cafe*, 13 February 2014, see <http://ansnuclearcafe.org/2014/02/13/carem-25-carries-torch-for-smr-construction/>, accessed 23 May 2015.

²⁴⁹ *Agence France Presse (AFP)*, “Atomic Power for Poor”, *Herald*, 11 November 1987.

²⁵⁰ Jorge H. Barón, Jorge E. Núñez McLeod, and Selva S. Rivera, “Risk-Oriented Safety Evaluation of the CAREM-25 Prototype Reactor”, *Nuclear Technology*, 1 May 2001.

²⁵¹ H. Boado Magan et al., “CAREM Prototype Construction and Licensing Status”, IAEA, Proceedings of an International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century, Vienna, Austria, 27–30 October 2009, see http://www-pub.iaea.org/MTCD/Publications/PDF/P1500_CD_Web/htm/topic5.htm, accessed 26 June 2015.

²⁵² WNN, “Construction of CAREM Underway”, 10 February 2014, see <http://www.world-nuclear-news.org/NN-Construction-of-CAREM-underway-1002144.html>, accessed 24 June 2015.

²⁵³ A.I. Lazarte et al., “Adopted Licensing Scheme for the Argentinean Modular Reactor CAREM-25”, Latin American Regional IRPA (International Radiation Protection Association) Congress on Radiation Protection and Safety, Buenos Aires, Argentina, 14–16 April 2015.

scale they would manage to lower their generation costs to a stage where they could compete with other cheaper sources of electricity, such as coal. Although that hope was never really fulfilled, and large reactors are finding it extremely difficult to compete economically without extensive government support, and sometimes even with such support, the nuclear industry today and supporting governments around the world are placing their hopes on what is sometimes called economies of serial production as well as promises of quicker construction periods. The history so far offers little evidence that such hopes will be realized but the nuclear industry practices a selective kind of remembrance, choosing to forget or not emphasize earlier failures.²⁵⁴

The second lesson from the history of small reactors is that, as with large reactors, construction schedules and commercialization dates keep getting pushed back. This feature is even more commonly seen with reactor designs that feature what are termed novel or innovative features, as exemplified by the case of the South African PBMR.²⁵⁵ Although we have not discussed large reactors that are deemed advanced, these problems also afflict them. For example, a recent study by the French Institut de Radioprotection et de Sûreté Nucléaire (IRSN) of so-called Generation IV reactor designs concluded that “the SFR [Sodium-cooled Fast Reactor] system [is] the only one of the various nuclear systems considered by GIF [Generation IV International Forum] to have reached a degree of maturity compatible with the construction of a Generation IV reactor prototype during the first half of the 21st century; such a realization, however, requires the completion of studies and technological developments mostly already identified”.²⁵⁶ This is a remarkable statement because GIF is considering a very wide variety of reactor designs, under six different categories. What is also worth remembering is that past history shows that SFRs are expensive, are capable of undergoing severe accidents, and have operational problems.²⁵⁷

A third problem with SMRs is that as evidence of the multiple problems associated with nuclear power becomes clearer to the publics around the world, there is socially generated pressure to alleviate if not eliminate these problems, including radioactive waste generation, linkage with nuclear weapons, and risk of catastrophic accidents. But none of the SMR designs so far can address all these problems simultaneously; indeed, attempts to tackle one of them can make other problems worse.²⁵⁸

²⁵⁴ Benjamin Sovacool and M.V. Ramana, “Back to the Future: Small Modular Reactors, Nuclear Fantasies, and Symbolic Convergence”, *Science, Technology, & Human Values*, 40, no. 1, 2015.

²⁵⁵ Steve Thomas, “The demise of the pebble bed modular reactor”, *Bulletin of the Atomic Scientists*, 22 June 2009, see <http://thebulletin.org/demise-pebble-bed-modular-reactor>, accessed 26 June 2015.

²⁵⁶ IRSN, “Review of Generation IV Nuclear Energy Systems”, 27 April 2015, see http://www.irsn.fr/EN/newsroom/News/Pages/20150427_Generation-IV-nuclear-energy-systems-safety-potential-overview.aspx, accessed 24 May 2015.

²⁵⁷ International Panel on Fissile Materials (IPFM), “Fast Breeder Reactor Programs: History and Status”, Princeton University, 2010.

²⁵⁸ M. V. Ramana and Zia Mian, “One Size Doesn’t Fit All: Social Priorities and Technical Conflicts for Small Modular Reactors”, *Energy Research & Social Science*, 2 June 2014.

Fukushima—A Status Report

Over four 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 and subsequent events. The Japanese Government and the Tokyo Electric Power Company (TEPCO) have been pursuing a decommissioning program, but the progress has not gone smoothly. This chapter summarizes the current onsite and offsite conditions of the Fukushima accident aftermath as of mid-2015.

Onsite challenges

Decommissioning

In June 2013, the Ministry of Economy, Trade and Industry (METI) and TEPCO revised the “Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4”,²⁵⁹ originally established in December 2011. In the 2013 edition, concrete plans for fuel debris removal from each plant and the construction of an international study system were added. The first phase (an approximately two-year period up to the start of spent nuclear fuel removal from the spent fuel pool of unit 4) has been completed, and the program is in its second phase (an approximately 10-year period up to the start of fuel debris removal from reactor pressure vessels). Fuel debris removal is planned at unit 1 and unit 2 in the first half of FY2020, and at unit 3 in the second half of FY2021. The third phase (a 30-40-year period up to the end of decommissioning) is planned to begin in December 2021.

Current Status of Each Reactor

Figure 18 shows each unit's appearance as of November 2014²⁶⁰ compared to the situation in the immediate aftermath of March 2011. The reactor building of unit 1 has been entirely covered in order to reduce the dispersion of radioactivity to the environment; the roof had been damaged by the hydrogen explosion during the accident. In May 2015, the removal of the cover began, in order to allow for debris to be cleaned up before starting the unloading of spent fuel from the storage pool.²⁶¹

The decommissioning of unit 2 has not progressed beyond the preparation stage because of high radiation levels. Although a hydrogen explosion did not occur in unit 2, it is highly contaminated with radioactive substances.²⁶²

²⁵⁹ METI, “Announcement of the Revised Version of the Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4”, 27 June 2013, see http://www.meti.go.jp/english/press/2013/0627_01.html, accessed 12 May 2015.

²⁶⁰ METI, “Current Status of Fukushima Daiichi Nuclear Power Station”, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/hairo_osensui/befor_after.html, accessed 12 May 2015.

²⁶¹ TEPCO, “Dismantling of reactor building cover for unit 1”, (in Japanese), see <http://www.tepco.co.jp/decommission/planaction/removal-reactor/index-j.html>, accessed 22 May 2015.

²⁶² On 20 May 2015, TEPCO reported about the performance outcome of the venting operation of unit 2 at the time of the accident; the outcome had not been clarified until then. They concluded that venting operation of the unit 2 had most likely failed. It can be assumed that the pressure vessel was not damaged because of the pressure decrease caused by the “fortunate” damage of the pressure suppression chamber; TEPCO, “TEPCO

The top of the reactor building of unit 3 was significantly damaged by a hydrogen explosion at the time of the accident. However, debris removal has been finished and preparations are under way for spent fuel removal from the storage pool. The removal of debris from the spent fuel pool using a remote controlled crane, and decontamination work on the floor, are being implemented.

Figure 18: Fukushima Units 1 – 4 in March 2011 and in November 2014



Source: METI website "Current Status of Fukushima Daiichi Nuclear Power Station", 2015

There was no fuel in the reactor of unit 4, but a hydrogen explosion occurred in the reactor building because of the flow, through a shared piping system, of hydrogen from unit 3. As of December 2014, all spent nuclear fuel had been taken out from the pool after removing the building's debris in the pool and constructing a facility for spent fuel removal.²⁶³

Continuing high levels of radiation in the plant are causing delays in the decommissioning work. As of November 2014, the highest reading at a measuring point outside the power station was 2.4 mSv/h²⁶⁴. Very high radiation levels, up to several Sv/h, have been measured inside each of the reactor buildings.²⁶⁵

reports latest findings of technical inquiry into how accident at Fukushima unfolded", 20 May 2015, see http://www.tepco.co.jp/en/press/corp-com/release/2015/1250927_6844.html, accessed 26 May 2015.

²⁶³ METI, "Portal Site of Decommissioning and Contaminated Water Countermeasures", (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/hairo_osensui/, accessed 12 May 2015.

²⁶⁴ TEPCO, "Survey map of the entire power station site (on November 7)", 28 November 2014, see <http://www.tepco.co.jp/en/nu/fukushima-np/f1/surveymap/images/f1-sv2-20141128-e.pdf>, accessed 12 May 2015.

²⁶⁵ TEPCO, "Air dose rates in the buildings", 22 March 2013, see <http://www.tepco.co.jp/en/nu/fukushima-np/f1/surveymap/images/f1-sv3-20130322-e.pdf>, accessed 12 May 2015.

Spent Fuel Management

As the potential risks of the spent nuclear fuel in the cooling pools became clear, METI and TEPCO have been implementing countermeasures on an ongoing basis. About half of the spent nuclear fuel that was in the ground-level common storage pool in March 2011, located behind the four reactors, was removed during step 1 and it has been transferred to a temporary dry storage facility newly established on site²⁶⁶.

**Table 4: Spent Fuel Storage in Reactor Pools and Dry Cask Storage Facility
(as of 22 December 2014)**

Storage place	Number of stored fuel assemblies				Removal rate [%]
	Fresh fuel	Spent fuel	Total	As of 11 March 2011	
Unit 1	100	292	392	392	0.0
Unit 2	28	587	615	615	0.0
Unit 3	52	514	566	566	0.0
Unit 4	0	0	0	1535	100.0
Dry cask storage facility	0	0	0	408	100.0
Total	180	1393	1573	3516	55.3

**Table 5: Spent Fuel Storage Away From Reactor (Pool and Temporary Dry Storage)
(as of 22 December 2014)**

Storage place	Number of stored fuel assemblies				Storage rate [%]
	Fresh fuel	Spent fuel	Total	Storage capacity	
Dry Cask storage Temporary facility	0	1412	1412	2930	48.2
Common storage pool	24	6702	6726	6799	98.9

Note: A portion of the fresh fuel of unit 4 (180 assemblies) was transported to a storage pool in unit 6.

Source: TEPCO, "Storage situation of spent fuel (as of December 22, 2014)", 25 December 2014.

²⁶⁶ TEPCO, "Installation work of dry cask temporary storage facility at the Fukushima Daiichi nuclear power plant", 28 June 2012, (in Japanese), see http://www.pref.fukushima.lg.jp/download/1/setumeityoushukai_120628_2.pdf, accessed 12 May 2015.

TEPCO and the Government are planning to move the spent fuel of units 1–3 to the space emptied in the common pool,²⁶⁷ but has recently delayed the schedule for units 1 and 2 to April 2020–March 2021, and for unit 3 to April 2017–March 2018.²⁶⁸ At present, as indicated before, all 1,535 spent fuel assemblies from unit 4 have been moved to the common pool (See Table 4 and Table 5).^{269,270}

The Inside of Reactor Vessels and Fuel Debris

The investigation in the core and preparations for fuel debris extraction are now finally beginning. Schematic views of units 1–3 and the parameters of each reactor are shown in Annex 3.²⁷¹

TEPCO started an investigation in the containment vessel of unit 1 using a robot and detected a radiation level of 10 Sv/h²⁷², but the robot malfunctioned and stopped on the first day of operation on 12 April 2015.²⁷³

An International Research Institute for Nuclear Decommissioning (IRID) was established in August 2013 by Japanese research organizations, reactor vendors and component makers, and electric power companies to perform research and development for decommissioning. Development work on fuel debris measurement technology using cosmic rays is being carried out.^{274,275} As a result of the measurements on unit 2 using this new method, its meltdown was confirmed for the first time. Until then, the meltdown of unit 2 had only been inferred from simulations.

²⁶⁷ The government and TEPCO medium- and long-term measures meeting, “Points of medium- and long-term roadmap progress”, 22 October 2012, (in Japanese), see http://www.tepco.co.jp/nu/fukushima-np/roadmap/images/t121022_01-j.pdf, accessed 12 May 2015.

²⁶⁸ *Asahi Shimbun*, “Japan delays nuclear fuel removal schedule for Fukushima plant”, 12 June 2015, see <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201506120098>, accessed 5 July 2015.

²⁶⁹ TEPCO, “Storage situation of spent fuel (as of December 22, 2014)”, 25 December 2014, (in Japanese), see http://www.meti.go.jp/earthquake/nuclear/pdf/141225/141225_01_3_5_05.pdf, accessed 12 May 2015.

²⁷⁰ Of these 50 casks, 20 are designed for storage use only (9 casks are already in use and 11 casks will be added) and 30 casks are designed for both transport and storage. Each of those 30 dual-purpose casks can store 69 assemblies containing 12 tons of fuel that have been cooled for 18 years or more. The temporary storage area is about 100 x 60 meters and the facility can store 50 casks (space for an extension for 15 more casks is available).

²⁷¹ METI, “Progress Status and Future Challenges of the Mid-and-Long-Term Roadmap toward the Decommissioning of TEPCO’s Fukushima Daiichi Nuclear Power Station Units 1-4 (Outline)”, 29 January 2015, see <http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/pdf/20150129-e.pdf>, accessed 12 May 2015.

²⁷² TEPCO, “Development of internal investigation technology in the reactor containment vessel (Operated on April 10)”, 13 April 2015, (in Japanese), see http://www.tepco.co.jp/nu/fukushima-np/handouts/2015/images/handouts_150413_02-j.pdf, accessed 12 May 2015.

²⁷³ TEPCO, “Internal investigation of the reactor containment vessel for the Fukushima Daiichi Nuclear Power Station Unit 1”, 12 April 2015, (in Japanese), see http://www.tepco.co.jp/cc/press/2015/1249672_6818.html, accessed 12 May 2015.

²⁷⁴ IRID, “Cosmic-ray Muon Technology To Image Debris Inside Fukushima Dai-ichi Reactors -Can image debris as small as 30-cm size”, 27 March 2015, see http://irid.or.jp/wp-content/uploads/2015/03/20150327_e.pdf, accessed 12 May 2015.

²⁷⁵ Mitsubishi Research Institute, Inc., “The Accomplishment Report of the Conceptual Study of Innovative Approach for Fuel Debris Retrieval and Feasibility Study of Essential Technologies”, 9 April 2015, see <http://en.dccc-program.jp/2015/04/09/?p=401>, accessed 12 May 2015.

Contaminated Water Management^{276,277}

The presence and continuous generation of large quantities of contaminated water, defined here as water containing radioactive substances, is delaying remediation work onsite.²⁷⁸

(1) The large amount of contaminated sea and fresh water used to cool the reactors:

Large quantities of contaminated water have already accumulated in tanks, and adding new fresh water as coolant for debris would further increase the amount of contaminated water. Therefore, METI and TEPCO installed the Multi-nuclides Removal System (Advanced Liquid Processing System: ALPS) to purify and circulate the water without using additional water. According to METI and TEPCO, the system can reduce the concentration of 62 nuclides in the contaminated water to levels below the concentration limits for environmental monitoring area of the power plant.²⁷⁹ However, its operation rate has been low because of technical problems and human errors.²⁸⁰

(2) The leakage of contaminated water from the storage tanks: A large number²⁸¹ of contaminated water storage tanks, many of them bolted rather than welded makeshift containers, are installed onsite. Leakages of contaminated water from the tanks are frequent and shortage of space for installing more tanks is becoming evident. In August 2013, it was revealed that approximately 300 tons of contaminated water had leaked and that the maximum radiation level detected near the storage tanks was 6.0 mSv/h.²⁸² The Nuclear Regulatory Authority (NRA) considered this a serious problem and officially rated the leakage at Level 3 on the International Nuclear and Radiological Event Scale (INES).²⁸³ It was pointed

²⁷⁶ METI, "Progress of major contaminated water measures", in the Portal Site of Decommissioning and Contaminated Water Countermeasures (in Japanese), see

http://www.meti.go.jp/earthquake/nuclear/hairo_osensui/#shinchoku, accessed 12 May 2015.

²⁷⁷ TEPCO "Status of the Fukushima Daiichi Nuclear Power Station", January 2014, see

http://www.tepco.co.jp/en/decommision/planaction/images/140127_01.pdf, accessed 12 May 2015.

²⁷⁸ In the latest review, the IAEA advises that the improvement of contaminated water management for decontamination facilities, storage tanks and ground water analysis are necessary. METI, "Receiving the Final Report of the Third IAEA Review on Plans towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4", 14 May 2015, see

http://www.meti.go.jp/english/press/2015/0514_01.html, accessed 24 May 2015.

²⁷⁹ TEPCO, "Overview of the Multi-nuclide Removal Equipment (ALPS) at Fukushima Daiichi Nuclear Power Station", 29 March 2013, see http://www.tepco.co.jp/en/nu/fukushima-np/handouts/2013/images/handouts_130329_01-e.pdf, accessed 12 May 2015.

²⁸⁰ Fukushima Daiichi Decommissioning and Decontamination Engineering Company, "Current status of decommissioning and contaminated water measures of the Fukushima Daiichi Nuclear Power Plant", 1 December 2014, (in Japanese), see

http://www.nrmc.jp/report/detail/_icsFiles/afieldfile/2014/12/17/j7.pdf, accessed 12 May 2015.

²⁸¹ The total capacity of the contaminated water storage tank became 800,000 tons in March 2015. When it is presumed that one tank has 1,000 tons capacity, the total number is 800 tanks. If contaminated water increases 400t every day, one tank will be needed per 2.5 days; see TEPCO, "Expansion of water storage tank (measures for preventing leakage of contaminated water)", (in Japanese), see

http://www.meti.go.jp/earthquake/nuclear/hairo_osensui/09.html; and Decommissioning and

Contaminated Water Measures Local Arrangement Meeting, "Management list for the problems, Countermeasures for contaminated water of Fukushima Daiichi Nuclear Power Plant of Tokyo Electric Power Company", 19 May 2014, (in Japanese), see

http://www.meti.go.jp/earthquake/nuclear/pdf/140519/140519_01f.pdf, both accessed 12 May 2015.

²⁸² TEPCO, "Leakage of contaminated water in H4 tank area", 27 August 2013, (in Japanese), see

<http://www.nsr.go.jp/data/000051222.pdf>, accessed 12 May 2015.

²⁸³ NRA, "Leakage from contaminated water storage tank in the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company (draft)", 21 August 2013, (in Japanese), see

<http://www.nsr.go.jp/data/000047627.pdf>, accessed 12 May 2015.

out that TEPCO's lax management of the work environment was one of the contributors to this problem. Many workers have been hired with illegal contracts due to a serious labor shortage.²⁸⁴ On 24 February 2015, TEPCO issued a press release stating that the source of high radiation levels in one of its drains came from a puddle of rainwater that had accumulated on the rooftop of unit 2.²⁸⁵ The drain leads to open seawater. It was thus suspected that contaminated water may have leaked into the sea, although TEPCO found "no increase in radioactivity" in the seawater in the area.²⁸⁶

(3) Inflow of groundwater: Groundwater from the nearby mountain is flowing into the basements of the plant buildings and mixing with contaminated water.²⁸⁷ METI and TEPCO are preparing a Ground Water Bypass System that will change the water path to prevent it from flowing into the power plant buildings. A similar system (subdrain) existed, but was destroyed during the earthquake²⁸⁸. TEPCO is also preparing a Frozen Soil Wall, in which the ground would be frozen around pipes filled with circulating refrigerant (Length: approx. 1,500 m, Volume of frozen soil: approx. 70,000 m³, Depth: 30 m).²⁸⁹ About 400 m³/day of water is added to the plant as cooling water, but at the same time, about 400 m³/day of groundwater is flowing into the building basements. Therefore, 800m³/day of water in total has to be circulated and decontaminated, and then 400m³/day of water is removed and stored in the tanks and an equivalent amount is re-injected into the reactor vessels.²⁹⁰ To reduce the burden of managing and securing space for the increasing number of storage tanks, METI and TEPCO are planning to release decontaminated water to the ocean to reduce the required storage capacity for contaminated water. However, this water includes tritium, which ALPS cannot remove and fishery cooperatives in Fukushima Prefecture have been blocking the plan for fear of losses caused by harmful rumors.²⁹¹ In this way, as distrust of government and

²⁸⁴ *Toyokeizai Online*, "Fukushima nuclear power plant contaminated water, illegal labor behind tank leakage", 11 December 2013, (in Japanese), see <http://toyokeizai.net/articles/-/26064>, accessed 12 May 2015.

²⁸⁵ TEPCO, "Radiation monitor alarm of gutter drainage in the site of Fukushima Daiichi Nuclear Power Plant", by the Explanatory materials for Fukushima Prefecture Fisheries Federation union president meeting, 25 February 2015, (in Japanese), see http://www.tepco.co.jp/nu/fukushima-np/handouts/2015/images/handouts_150225_05-j.pdf, accessed 12 May 2015.

²⁸⁶ TEPCO, "Analysis of seawater in the port, near the outlet and seawall", 26 February 2015, (in Japanese), see http://www.tepco.co.jp/nu/fukushima-np/f1/smp/2015/images/2tb-east_15022601-j.pdf, accessed 1 May 2015.

²⁸⁷ TEPCO insists that there has been no serious radioactive materials increase based on the results of seawater sampling in the harbor. See TEPCO, "Detailed analysis result of Fukushima Daiichi port: inside of the gulf, water outlet and shore protection area (seawater sampling points)", 26 April 2015, (in Japanese), see http://www.tepco.co.jp/nu/fukushima-np/f1/smp/2015/images/2tb-east_15042601-j.pdf, accessed 12 May 2015.

²⁸⁸ Subdrains are wells installed around each reactor building for pumping up groundwater. Although TEPCO is planning to release the contaminated water from these recovered subdrains, the company is facing strong objection from the Fukushima Fishery Association. TEPCO, "Groundwater pump-up by Subdrain or Groundwater drain", see <http://www.tepco.co.jp/en/decommission/planaction/sub-drain/index-e.html>; and Kahoku Shinpo, "Fukushima Daiichi' Restart of discussion for subdrain issue with Fukushima Fishery Association", 1 May 2015, (in Japanese), see http://www.kahoku.co.jp/tohokunews/201505/20150501_63033.html, both accessed 27 May 2015.

²⁸⁹ TEPCO, "Land-side Impermeable Wall (Frozen Soil Wall)", Undated, see <http://www.tepco.co.jp/en/decommission/planaction/landwardwall/index-e.html>, accessed 12 May 2015.

²⁹⁰ Nuclear Emergency Response Headquarters Council for the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station, "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4", 27 June 2013, see http://www.meti.go.jp/english/press/2013/pdf/0627_01.pdf, accessed 12 May 2015.

²⁹¹ *Reuters*, "Nuclear power plant contaminated water treatment has been cornered: Underground storage proposed as a countermeasure for tritium release", 2 April 2015, (in Japanese), see <http://jp.reuters.com/article/idJPL3N0WW06U20150401>, accessed 12 May 2015.

TEPCO and concerns about the social impact are strong, discussions for the solution based on scientific arguments have not deepened.²⁹²

The Chairman of Japan's nuclear regulator NRA had “harsh words” for TEPCO's contaminated water management. TEPCO “has failed to manage [contaminated water] properly,” said Shunichi Tanaka, at a regularly scheduled meeting on 3 June 2015. “It lacks a strategic approach in addressing the contaminated water issue.”²⁹³

Offsite challenges

Evacuation problem

The evacuation zones around the plant have been changed several times and they have become more complex, while the total designated contaminated area itself has been in general shrinking due to decontamination efforts and natural radiation decline.^{294,295} Figure 37 (see Annex 4) shows this situation.²⁹⁶ Currently, there are three kinds of zones, according to the Ministry of the Environment (MOE).²⁹⁷ According to the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the number of evacuees from Fukushima prefecture as of January 2015 is about 120,000 (vs. 164,000 at the peak in June 2013). Among these evacuees, over 79,000 people (more than half of the total evacuees) were forced to evacuate from the evacuation zones (Difficult to Return Zone: 24,000 people; Restricted Residence Zone: 23,000 people; Zone in preparation for the lifting of the evacuation order: 32,000 people); and the rest evacuated voluntarily.²⁹⁸

Because evacuation has been prolonged, low morale among the evacuees has become widely prevalent. About 3,200 people have died for reasons related to the evacuation such as decreased

²⁹² According to TEPCO, the tritium concentration of contaminated water is estimated at 1-5 million Bq/l. Incidentally, before the Fukushima accident, the legal release limit was 22 trillion Bq/year, and the measurement results level was 1-2 trillion Bq/year for Fukushima Daiichi site. See TEPCO, “Tritium in Fukushima Daiichi Nuclear Power Station”, 28 February 2013, (in Japanese), see http://www.tepco.co.jp/nu/fukushima-np/handouts/2013/images/handouts_130228_08-j.pdf, accessed 12 May 2015; and Japan Nuclear Energy Safety Organization, “Operational Status of Nuclear Facilities in Japan—2011 Edition”, October 2011, see <http://www.nsr.go.jp/archive/jnes/atom-library/unkan/e-unkanhp2/e-unkanhp2-2011/book1/#page=1>, accessed 12 May 2015.

²⁹³ *Asahi Shimbun*, “NRA rebukes TEPCO for failure to contain radioactive Fukushima water”, 4 June 2015, see <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201506040105>, accessed 5 July 2015.

²⁹⁴ Fukushima Prefecture, “History of the Evacuation Instruction”, 31 March 2012 or earlier, (in Japanese), see <https://www.pref.fukushima.lg.jp/download/1/01240331.pdf>, accessed 12 May 2015.

²⁹⁵ Fukushima Prefecture, “Conceptual diagram of the evacuation area”, 1 April 2012, (in Japanese), see https://www.pref.fukushima.lg.jp/uploaded/library/141001_suiizu.pdf, accessed 12 May 2015.

²⁹⁶ MOE, “Progress on Off-site Cleanup Efforts in Japan”, April 2015, see http://josen.env.go.jp/en/pdf/progressseet_progress_on_cleanup_efforts.pdf?150406, accessed 12 May 2015.

²⁹⁷ 1) Difficult to Return Zone (RED): areas where annual radiation exposure levels exceed 50 mSv (off-limit in general, lodging is prohibited); 2) Restricted Residence Zone (YELLOW): areas with annual radiation exposure level from 20 to 50 mSv (entry permitted, business partially allowed, lodging is prohibited in general); 3) Zone in preparation for the lifting of the evacuation order (GREEN): areas with annual radiation exposure level lower than 20 mSv (access permitted, business allowed, lodging is prohibited in general).

²⁹⁸ Nuclear victims life support team, “Situation of the evacuation area”, 28 January 2015, (in Japanese), see http://www.mext.go.jp/b_menu/shingi/chousa/kaihatu/016/shiryo/_icsFiles/afiedfile/2015/01/28/1354739_3_1.pdf, accessed 12 May 2015.

physical condition or suicide (“earthquake-related deaths”). Among these, about 1,800 people (more than half) are from Fukushima prefecture.²⁹⁹

The Reconstruction Agency is conducting the Residents Intention Survey on a regular basis in municipalities affected by the Fukushima nuclear disaster. According to the survey, many local residents—among the younger generation in particular—are progressively giving up on going back to their homes. According to a survey of Tomioka city residents conducted in October 2013, 49 percent of the residents had given up on going back to their homes and 31% had not decided yet.³⁰⁰

Decontamination Waste³⁰¹

The MOE has set the threshold standard of waste generated by the decontamination process at 8,000 Bq/kg.³⁰² This means that decontamination waste with levels lower than this standard is considered “safe” and can be disposed of as ordinary household or industrial waste by local governments, while the Government will take charge of the waste with levels above the limit to be disposed of as “designated waste.”

According to the MOE, exposure levels of waste disposal workers handling incineration ash containing 8,000 Bq/kg of radioactivity are estimated to be lower than 1 mSv/year (0.78mSv/year).³⁰³ Furthermore, exposure levels of residents living near disposal sites for waste with more than 8,000 Bq/kg are estimated to be lower than 1mSv/year by a substantial margin.

Decontamination waste is not limited to the waste from evacuation zones in Fukushima prefecture (waste generated by the tsunami, demolition waste from disaster-damaged houses, and garbage from disaster-damaged house cleanup). Since radioactivity spread over a wider area, decontamination waste is also being generated outside Fukushima prefecture (incineration ash, rice straw, compost, sewage sludge, etc.). According to MOE's estimation, as of December 2014, the total amount of decontamination waste in 12 prefectures including Fukushima Prefecture exceeded 157,000 tons.³⁰⁴

²⁹⁹ Reconstruction Agency, Cabinet Office (Disaster Management), Fire and Disaster Management Agency, “The death toll of the earthquake-related deaths in the Great East Japan Earthquake (as of September 30, 2014)”, 26 December 2014, (in Japanese), see http://www.reconstruction.go.jp/topics/main-cat2/sub-cat2-1/20141226_kanrenshi.pdf, accessed 12 May 2015.

³⁰⁰ Reconstruction Agency, “Tomioka -city, Residents intention survey results (preliminary version)”, 17 October 2015, (in Japanese), see http://www.reconstruction.go.jp/topics/main-cat1/sub-cat1-4/ikoucyousa/20141017_ikouchousa_tomioka.pdf, accessed 12 May 2015.

³⁰¹ MOE, Radioactive waste and contaminated waste processing information site, “The Designated Waste”, (in Japanese), see http://shiteihaiki.env.go.jp/radiological_contaminated_waste/designated_waste/, accessed 12 May 2015.

³⁰² The value is the sum of the amounts of radioactive Cesium 134 and Cesium 137; see MOE, “The rules for the enforcement of the special measures law concerning radioactive material contamination”, page 9, (in Japanese), see <http://www.env.go.jp/press/files/jp/18815.pdf>, accessed 23 May 2015.

³⁰³ In Japan, the radiation exposure dose limit (excluding natural radiation and medical exposure) for a member of the general public is set at 1mSv/year in reference to the recommendation of the International Commission on Radiological Protection (ICRP).

³⁰⁴ Each prefecture's amount: Iwate (475.6 tons), Miyagi (3,324.10 tons), Yamagata (2.7 tons), Fukushima (129,669.20 tons), Ibaraki (3,532.80 tons), Tochigi (13,526.30 tons), Gunma (1,186.70 tons), Chiba (3,687.00 tons), Tokyo (981.7 tons), Kanagawa (2.9 tons), Niigata (1,017.90 tons), Shizuoka (8.6 tons).

In Fukushima Prefecture, transportation of decontamination waste to centralized temporary storage facilities has begun.³⁰⁵ Waste is also being stored temporarily in incineration plants and sewage treatment plants. As for the final waste disposal sites, MOE has announced a policy to select a site in each prefecture. However, this policy is facing strong oppositions from local residents. For example, when MOE explained about the importance and safety of the designated final waste disposal site for the first time to residents of Niigata Prefecture on 5 April 2015, residents strongly criticized the plan and the risks.³⁰⁶

Radiation Exposure and Health Impact

From the results of studies on butterflies³⁰⁷ and wild birds³⁰⁸, effects of the radioactivity released from the Fukushima accident are becoming clear. Although precise effects on human health from the Fukushima accident have yet to be published in peer-reviewed studies, independent studies in Germany indicate increased infant mortality and decreased numbers of live births in 2011 following the accident.³⁰⁹

In addition, the 2014 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) Report on Fukushima has estimated that the collective dose to the Japanese people from the exposures following Fukushima will be 48,000 person-Sievert.³¹⁰ According to independent radiation expert Ian Fairlie, in terms of fatal cancers, the UNSCEAR estimate implies (via the Linear No-Threshold Theory) that in future about 5,000 people in Japan will die from Fukushima's fallout, if a conventional fatal cancer risk of 10 percent per person-Sievert is applied.³¹¹

In a report of a thyroid cancer survey in which several children were diagnosed with thyroid cancer, the authors concluded that it is too early to link those cases to the Fukushima accident.³¹²

³⁰⁵ Fukushima prefecture, "About the transportation of removed soil to an interim storage facility", (in Japanese), see <http://www.pref.fukushima.lg.jp/site/portal/yuso.html>, accessed 12 May 2015.

³⁰⁶ Kahoku Shinpo, "Final disposal site construction, It's alibi-making", 6 April 2015, (in Japanese), see http://www.kahoku.co.jp/tohokunews/201504/20150406_11009.html, accessed 12 May 2015.

³⁰⁷ Atsuki Hiyama et al., "Spatiotemporal abnormality dynamics of the pale grass blue butterfly: three years of monitoring (2011–2013) after the Fukushima nuclear accident", *BMC Evolutionary Biology* 2015, see <http://www.biomedcentral.com/1471-2148/15/15/abstract>, accessed 12 May 2015.

³⁰⁸ Kaori Murase et al., "Scientific Reports 5 Effects of the Fukushima Daiichi nuclear accident on goshawk reproduction", see <http://www.nature.com/srep/2015/150324/srep09405/pdf/srep09405.pdf>, accessed 12 May 2015.

³⁰⁹ Alfred Koerblein, "Infant mortality in Japan after Fukushima", 10 January 2013, see http://www.strahlentelex.de/Infant_mortality_in_Japan_after_Fukushima.pdf, accessed 26 June 2015.

³¹⁰ UNSCEAR, "UNSCEAR 2013 Report—Volume I—Report to the General Assembly—Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami", April 2014, see http://www.unscear.org/docs/reports/2013/13-85418_Report_2013_Annex_A.pdf, accessed 26 June 2015.

³¹¹ Ian Fairlie, "New UNSCEAR Report on Fukushima: Collective Doses", 2 April 2014, see <http://www.ianfairlie.org/news/new-unscear-report-on-fukushima-collective-doses/>, accessed 26 June 2015.

³¹² Regarding the usage of ultrasonography for finding thyroid cancer in infants, specialists have been concerned about the phenomenon of the "screening effect", the asymptomatic diseases being found at higher than expected frequency by large-scale testing. Syunichi Yamashita, "Ultrasonography examination of thyroid for infants in Fukushima prefecture", 12 February 2014, (in Japanese), see http://www.kantei.go.jp/saigai/senmonka_g62.html, accessed 25 May 2015.

In March 2015, Fukushima Prefecture released an interim report of the evaluation meeting by experts regarding thyroid cancer examinations that targeted young persons aged 0–18 years old at the time of the Fukushima accident. According to this report, among the ~300,000 subjects examined, malignant (or suspected to be malignant) cells were found in 110 people, and 86 people were officially diagnosed with thyroid cancer. However the report stated that 70 percent (41 out of 62) of the young persons whose external doses were estimated from medical questionnaires³¹³ were exposed to less than 1mSv (effective dose). The maximum exposure was estimated as 2.2 mSv.³¹⁴ For this reason, the report's authors stated that a conclusion could not be reached on whether or not the results were caused by radioactivity from Fukushima as they were small compared to those in the case of, for example, the Chernobyl accident.

Cost of the Fukushima Accident

The Japanese Government has not provided a comprehensive total accident cost estimate. However, it can be estimated that it already reached 10 trillion yen (US\$100 billion) just by using the limited available information (see below). If we include other economic impacts, such as food export³¹⁵ and tourism³¹⁶, the cost estimate would increase.³¹⁷

1) Costs for bringing the accident under control and decommissioning: TEPCO reported that the total cost for bringing the accident under control and decommissioning was about 992.7 billion yen (US\$9.9 billion) for the 4-year period since the beginning of the accident.³¹⁸ Besides, the company revealed that the loss from other nuclear power plants (shutdown of Fukushima Daiichi 5 and 6 as well as Fukushima Daini 1-4, and cancelation of the construction of Fukushima Daiichi 7 and 8) was almost 389.2 billion yen (US\$3.8 billion).

2) Decontamination cost: In 2013, MOE estimated the decontamination cost as 2.5 trillion yen (US\$25 billion) and the interim storage facilities cost as 1.1 trillion yen (US\$11 billion)³¹⁹.

3) Cost of compensation for damages: TEPCO has to compensate not only for the damages to buildings but also for emotional distress damages following evacuation and relocation.³²⁰

³¹³ Fukushima prefecture, "What is the basic investigation of residents health investigation?", (in Japanese), see <http://fukushima-mimamori.jp/basic-survey/>, accessed 12 May 2015.

³¹⁴ Fukushima Prefecture, "Prefectural health survey, the thyroid test (prior inspection)" Summary (Preliminary), 24 March 2015, (in Japanese), see <http://www.pref.fukushima.lg.jp/uploaded/attachment/107580.pdf>, accessed 12 May 2015.

³¹⁵ The import restrictions on Japanese foods of each country are gradually being removed, but some restrictions still remain; see Japan External Trade Organization (JETRO), "Special feature: Influence of the Great East Japan Earthquake on international business", see <http://www.jetro.go.jp/world/shinsai.html>, accessed 25 May 2015.

³¹⁶ The number of tourists visiting Japan is finally increasing now; Japan National Tourism Organization (JNTO), "Number of foreign visitors to Japan (April 2015 estimation)", April 2015 (in Japanese), see http://www.jnto.go.jp/jpn/news/press_releases/pdf/20150520_1.pdf, accessed May 2015.

³¹⁷ Committee on Lessons Learned from the Fukushima Nuclear Accident for Improving Safety and Security of U.S. Nuclear Plants; Nuclear and Radiation Studies Board; Division on Earth and Life Studies; National Research Council, "Lessons Learned from the Fukushima Nuclear Accident for Improving Safety of U.S. Nuclear Plants", 2014, see <http://www.nap.edu/catalog/18294/lessons-learned-from-the-fukushima-nuclear-accident-for-improving-safety-of-us-nuclear-plants>, accessed 12 May 2015.

³¹⁸ TEPCO, "Settlement of account briefing materials (Second Quarter, March 2015)", 31 October 2014, (in Japanese), see <http://www.tepco.co.jp/ir/tool/setumei/pdf/141031setsu-j.pdf>, accessed 1 May 2015.

³¹⁹ NDF and TEPCO, "New Comprehensive Special Business Plan", December 27 2013, (in Japanese), see http://www.tepco.co.jp/cc/press/betu14_j/images/140115j0102.pdf, accessed 12 May 2015.

According to the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF), cost of compensation for damages is estimated at 6.1 trillion yen (\$61 billion) at the moment³²¹.

By financing from the NDF, TEPCO has been able to avoid bankruptcy. The latest business results of TEPCO from March 2015 report an “ordinary” profit of 208 billion yen (US\$2 billion), a 105 percent increase over the previous fiscal year, but also an expenditure of 616.2 billion yen (US\$6.1 billion) for nuclear damage compensation, which is reported as “special loss”. On the other hand, TEPCO obtained grants of 887.7 billion yen (US\$8.8 billion) from NDF as an extraordinary gain.³²² NDF was established by the financing of the government and all Japanese electric power companies; in other words, Japanese citizens are supporting TEPCO indirectly through their payments of taxes and electric bills.

³²⁰ TEPCO, “Guidance of compensation items”, (in Japanese), see http://www.tepco.co.jp/fukushima_hq/compensation/guidance/index-j.html, accessed 12 May 2015.

³²¹ NDF and TEPCO, “New Comprehensive Special Business Plan”, Authorized at 15 January 2014, (in Japanese), see <http://www.ndf.go.jp/gyomu/tokujikei/kaitei20150415.pdf>, accessed 12 May 2015.

³²² TEPCO, “Highlight of Business Performance”, 28 April 2015, (in Japanese), see <http://www.tepco.co.jp/ir/kojin/highlight-j.html>, accessed 25 May 2015.

Nuclear Power vs. Renewable Energy Deployment

“Rising long-term natural gas prices, the high capital costs of new coal and nuclear generation capacity, state-level policies, and cost reductions for renewable generation in a market characterized by relatively slow electricity demand growth favor increased use of renewables.”

U.S. Energy Information Administration
April 2015³²³

Introduction

There is a growing realization that the power sector is in a period of profound transformation. This is driven by a variety of factors, but one of the most powerful is the greater deployment of renewable energy to mitigate climate change and exploit increasing economic competitiveness. This is altering and in general lowering the market prices for electricity, and as much of the new renewable capacity is not owned by the incumbent power companies, it is reducing their market share. In competitive markets, it further reduces their electricity sales at the most profitable times. These and other factors are leading to lower share prices, lower profits and lower credit ratings for the large traditional power companies.

As described in more detail in other sections of the report, the largest nuclear operator in the world, the French state-controlled EDF, is still struggling with massive debts and increasing operating costs. This situation is likely to get worse, as an April 2015 note from credit-rating agency Moody's pointed out that the share of domestic electricity volumes that EDF sells under a regulated tariff will significantly decrease in the coming years, from 84 percent to 50 percent by 2016. This will further affect the utility's profitability. In consequence Moody's is downgrading EDF's rating from Aa3 to A1 with a negative outlook (see Annex 5 for definitions of credit rating).³²⁴

Some European electricity companies are responding by rebranding and restructuring in an attempt to remain relevant under the new market conditions. E.ON, owner of four of the remaining nine operating nuclear reactors in Germany, announced in December 2014 that it would split the company into two, with one maintaining the name E.ON to focus on renewables, efficiency, distribution networks, and customer solutions, while the existing generating assets would go to a new company called Uniper.³²⁵ Rheinisch-Westfälisches Elektrizitätswerk (RWE) is adopting a similar agenda but without the split. GDF Suez announced in April 2015 a rebranding, changing its name to ENGIE, with a statement of intent that “we have one conviction: the energy model of tomorrow will be in 3D: Decarbonized, thanks to the development of renewable

³²³ U.S. EIA, “Annual Energy Outlook 2015 With Projections to 2040”, April 2015.

³²⁴ Moody's, “Moody's downgrades EDF to A1; negative outlook”, 16 April 2015.

³²⁵ E.ON, “Our Strategy: 'Empowering customers. Shaping markets.'”, Undated, see <https://www.eon.com/en/about-us/strategie.html>, accessed 14 June 2015.

energies, Digitized, by deploying intelligent networks, and Decentralized.”³²⁶ While it remains to be seen what this really means for a company that owns and operates seven reactors in Belgium through Electrabel, owns stakes in the Chooz and Tricastin plants in France (1,208 MW—the equivalent of one nuclear reactor), has signaled its interest in taking a share of AREVA’s reactor maintenance business, and owns as well as considerable fossil fuel capacity, it is a remarkable statement of intent if taken at face value.

The deployment of renewable energies at scale is also particularly affecting the economic and operational efficiency of large, centralized power stations, usually coal and nuclear plants, which are most suited to operate continuously (“baseload” capacity). Those power stations that cannot rapidly react to the resultant changing prices and/or demand will increasingly have to continue to generate when they are no longer needed or when they are operating at a loss. As solar or wind power have no fuel costs, they are able to produce power at lower cost and therefore will enter the market, unless obstructed, whenever they are able to generate. Therefore an efficient system increasingly needs highly flexible complementary sources—whether decentralized storage, biogas, waste combustion, dispatchable renewables, or conventional micro-power plants—to complement renewables, i.e. capacity that can rapidly and efficiently alter its output. Consequently, the development of renewables, as the system is currently configured, tends to be to the detriment of nuclear power and other base-load generators, which are said to be uncompetitive and “structurally disadvantaged”.³²⁷ UBS, the largest Swiss bank, says of large-scale power plants that they will become “the dinosaur of the future energy system: Too big, too inflexible; not even relevant for backup power in the long run”.³²⁸

The escalation in the growth of renewables is forecasted by an increasing number of financial analysts and investors. There now seems to be a general recognition that the falling production costs of renewable energy technologies, particularly solar photovoltaics (PV), coupled with the expected falling costs of electricity storage, will accelerate the transformation of the power sector. UBS, in a report published in June 2015, stated: “We believe solar will eventually replace nuclear and coal, and [be] establish[ed] as the default technology of the future to generate and supply electricity.”³²⁹ An important driver is the realization that solar PV will increasingly be deployed without subsidy, unlike the technology cost curves for nuclear power. In an increasing number of locations, solar systems are producing power at lower prices than consumers are paying (retail price); according to Morgan Stanley, even without subsidies solar can move to a commercially viable position by 2020 across all major European countries.³³⁰ However, solar is not just competing with the retail price of electricity, in some market environments, it is now undercutting conventional power generation costs. In March 2014, the Texas utility Austin Energy signed a purchase agreement for PV power for “just below” US\$5c/kWh. The media was wondering then whether this is “the cheapest solar ever”.³³¹ Half a year later, Georgia Power reported over 5,000 MW worth of bids from 56 companies for a 515 MW target. The winning

³²⁶ ENGIE.com, “Ideas are now reality”, see <http://engie.com/en/>, accessed 11 June 2015.

³²⁷ Citi Research, “Evolving Economics of Power and Alternative Energy—The Age of Renewables is Beginning – A Levelised Cost of Energy Perspective”, 23 March 2014.

³²⁸ UBS, “Will solar, batteries and electric cars re-shape the electricity system?”, 20 August 2014.

³²⁹ Ibidem.

³³⁰ Morgan Stanley, “Solar Power and Energy Storage—More Disruption ahead for Utilities”, 29 July 2014.

³³¹ *GreenTechMedia*, “Cheapest Solar Ever? Austin Energy Buys PV From SunEdison at 5 Cents per Kilowatt-Hour”, 10 March 2014, see <http://www.greentechmedia.com/articles/read/Cheapest-Solar-Ever-Austin-Energy-Buys-PV-From-SunEdison-at-5-Cents-Per-Ki>, accessed 14 June 2015.

projects came in at an *average* of US\$0.065/kWh for 515 MW worth.³³² Another half-year later, Austin Energy was offered 1.3 GW of PV power bid at below US\$0.04/kWh.³³³ Similar trends are seen on the international scale. In January 2015, the winning bid in Dubai for the construction of a new solar plant was US\$0.0584/kWh (€51/MWh).³³⁴ In all cases, the PV bids came in cheaper than electricity produced by natural gas plants.

The falling technology costs and system changes are likely to be reinforced as a result of renewed attention to the decarbonization of the energy sector in the run up to and following the United Nations Framework Convention on Climate Change (UNFCCC) summit in Paris in December 2015. The leaders of the G7 committed themselves to the need to “decarbonize the global economy in the course of this century.”³³⁵ Within the framework of the UN, countries will submit their carbon mitigation plans known as the Intended Nationally Determined Contributions (INDCs). These are likely to include the emissions reduction targets for 2030, as has already been seen from China, the EU and the United States, and outline the sector strategies for how these will be met. As of mid-2015, regardless of the UN process, 164 countries had adopted at least one type of renewable energy target, up almost four-fold from 2005.³³⁶

The changing landscape of the power sector and in particular, the move away from nuclear power and the graphic growth in renewables, is shown in the following section.

Investment

According to data published by Bloomberg New Energy Finance (BNEF) and United Nations Environment Programme (UNEP), global investment in renewable energy—excluding large hydro—was US\$270 billion in 2014—a significant increase (+17 percent) from the previous year’s US\$231 billion, close to the all-time record of US\$278 billion in 2011, and four times the 2004 total of US\$45 billion³³⁷, as illustrated in Figure 19. Of this, the largest section of funding was for asset financing, which required US\$170 billion of investment, 10% higher than the previous year. The second largest category was investment into small distributed capacity—projects of less than 1 MW, predominantly rooftop solar. This saw US\$73.5 billion committed in 2014, up 34 percent. Capacity additions are growing faster than these investment totals, because prices are rapidly falling.

³³² *GreenTechMedia*, “Georgia Is the Latest State to Procure Dirt-Cheap Solar Power”, 15 October 2014, see <http://www.greentechmedia.com/articles/read/how-cheaply-can-georgia-power-buy-solar-for-6.5-cents>, accessed 14 June 2015.

³³³ S. Lacey, “Cheapest Solar Ever: Austin Energy Gets 1.2 Gigawatts of Solar Bids for Less Than 4 Cents”, *GreenTechMedia*, 30 June 2015, see www.greentechmedia.com/articles/read/cheapest-solar-ever-austin-energy-gets-1.2-gigawatts-of-solar-bids-for-less, accessed 30 June 2015. The U.S. solar prices are net of a 30% Federal Investment Tax Credit that drops to 10% after 2016, but many observers expect prices to fall more.

³³⁴ *The National*, “UAE beats renewables cost hurdle with world’s cheapest price for solar energy”, 18 January 2015, see <http://www.thenational.ae/business/energy/uae-beats-renewables-cost-hurdle-with-worlds-cheapest-price-for-solar-energy>, accessed 14 June 2015.

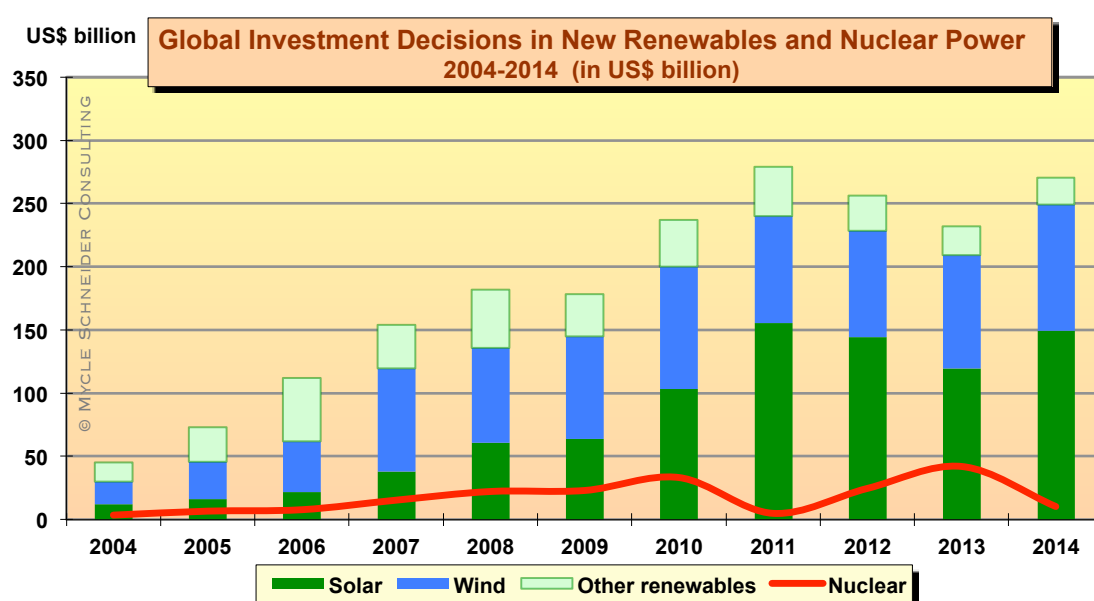
³³⁵ *The Guardian*, “G7 leaders agree to phase out fossil fuel use by end of century”, 8 June 2015, see <http://www.theguardian.com/world/2015/jun/08/g7-leaders-agree-phase-out-fossil-fuel-use-end-of-century>, accessed 14 June 2015.

³³⁶ International Renewable Energy Agency, “Renewable Energy Target Setting”, June 2015.

³³⁷ UNEP, “Global Trends in Renewable Energy Investment”, Frankfurt School, UNEP Collaboration Centre for Climate and Sustainable Energy Finance and BNEF, April 2015.

Figure 19 also compares the annual investment decisions for the construction of new nuclear compared to renewable energy excluding large hydro since 2004. The year 2014 saw a sharp drop in new nuclear investment, with construction starting on only three units, which were the Barakah-3 in the UAE, Belarus-2 in Belarus and the Carem reactor in Argentina. This compares to 10 construction starts in 2013 and 15 in 2010. In the absence of comprehensive, publicly available investment estimates for nuclear power by year, the total projected investment costs³³⁸ have been included 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. In other words, actual nuclear investment would be much lower than illustrated in this exercise. However, despite all these uncertainties, it is clear that over this period the investment in nuclear construction decisions is about an order of magnitude lower than that in renewable energy.

Figure 19: Global Investment Decisions in Renewables and Nuclear Power 2004–14



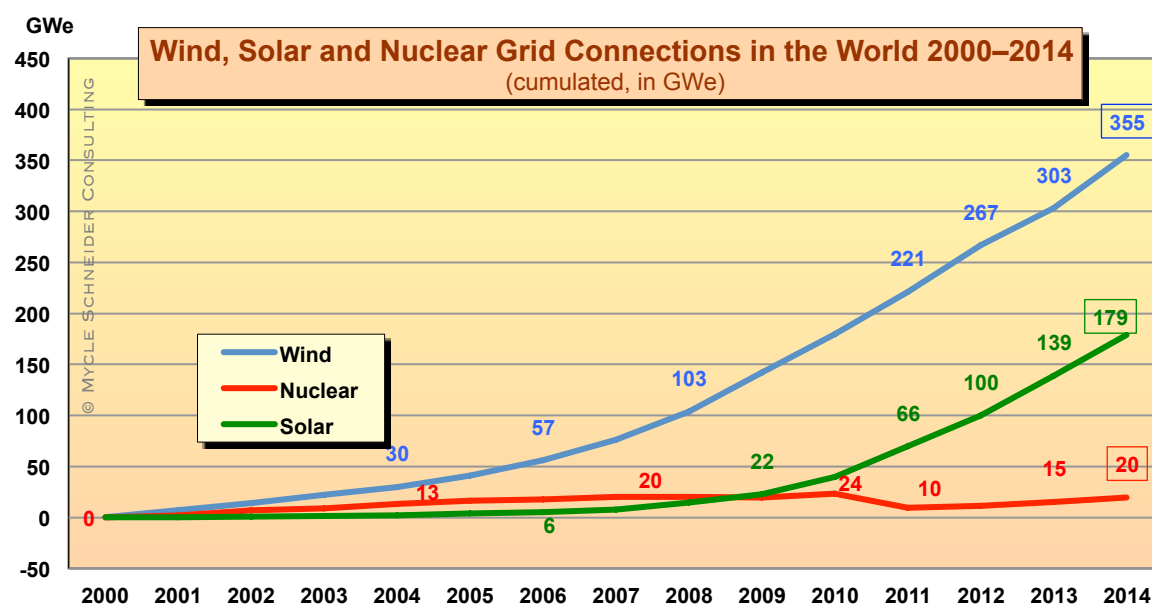
Sources: FS-UNEP 2015 and WNISR original research

Installed Capacity

Globally renewable energy continues to dominate new capacity additions. As the FS-UNEP [Frankfurt School-United Nations Environment Programme] Report points out, renewables excluding large hydro accounted for 49 percent of new capacity in 2014 and consequently they now account for 15.2 percent of the total.

³³⁸ On the basis of publicly available estimates at the time of construction start.

Figure 20: Wind, Solar and Nuclear, Capacity Increases in the World 2000–2014



Sources: WNISR, BP Statistical Review 2015

This included 49 GW for new wind power (up from 34 GW added in 2013) and 46 GW of solar PV (up from 40 GW added in 2013).³³⁹ BP figures indicate an increase in 2014 over the previous year of 52 GW in wind power and 40 GW of solar.³⁴⁰ Figure 20 shows the changing capacity in renewable energy and nuclear since 2000 and highlights the massive growth in renewables compared to new capacity for nuclear power, which has remained largely static.

These figures illustrate the extent to which renewables have been deployed at scale since the new millennium, an increase in capacity of 355 GW for wind and of 180 GW for solar, compared to the stagnation of nuclear power capacity, which over this period increased by only 20 GW (including all reactors in LTO).

Electricity Generation

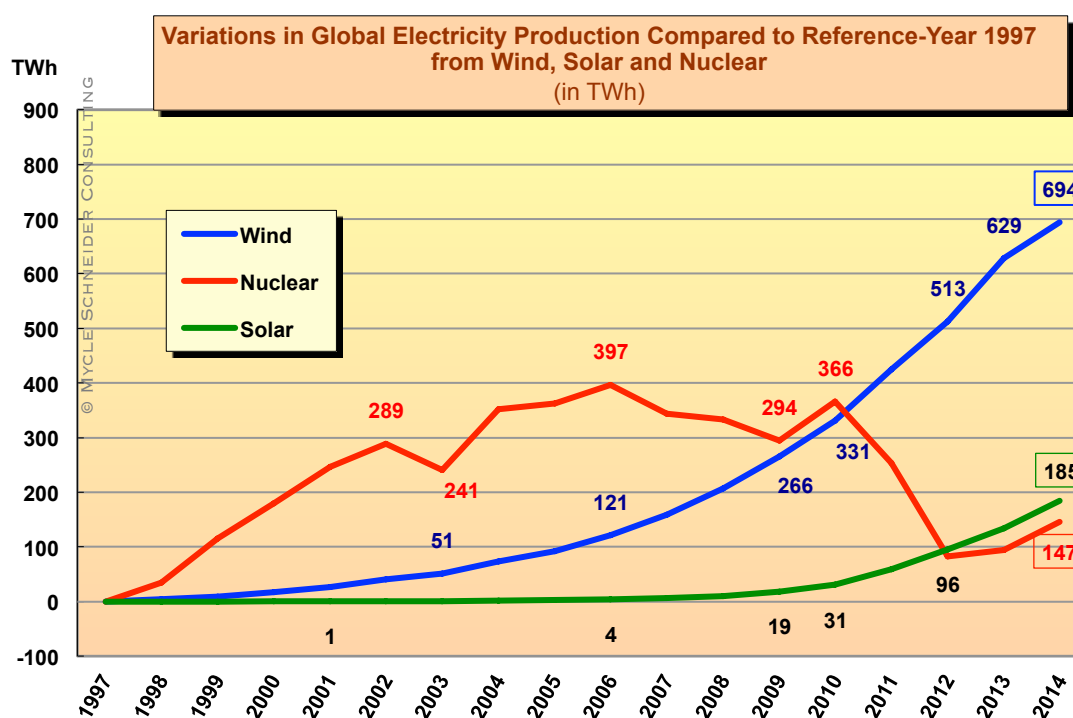
It is important to note the characteristics of electricity generation technologies and the different amounts of electricity produced per installed unit of capacity. In general, nuclear power plants tend to produce more electricity per MW of installed capacity than renewables, whose production capabilities are determined by external factors, such as the wind blowing or the sun shining. However, empirical data show that the global average capacity factor of nuclear power is less than twice that of all renewables (except large hydro) which reaches about 40–45 percent, according to data compiled by Rocky Mountain Institute.³⁴¹

³³⁹ Collaboration Centre for Climate and Sustainable Energy Finance, “Global Trends in Renewable Energy Investment”, FS-UNEP, and BNEF, April 2015.

³⁴⁰ BP, “Statistical Review of World Energy”, June 2015.

³⁴¹ See methodological section of “Micropower Database”, July 2014, [see www.rmi.org/Knowledge-Center/Library/2014-18_MicropowerDatabase](http://www.rmi.org/Knowledge-Center/Library/2014-18_MicropowerDatabase), accessed 30 June 2015.

Figure 21: Variations in Global Electricity Production from Wind, Solar and Nuclear



Sources: BP, IAEA-PRIS, MSC, 2015

Despite their variable output, which can generally be forecasted at least as accurately as electricity demand, wind and solar photovoltaic power are now becoming significant sources in some countries and internationally. Figure 21 above presents the actual electricity produced by solar photovoltaics, wind, and nuclear power, highlighting the changing levels of production since 1997. As can be seen, during this period there has been an additional 694 TWh per year of wind power produced in 2014 compared to 1997, 185 TWh more power from solar photovoltaics, and just an additional 147 TWh of nuclear electricity.

In 2014, annual growth rates for the generation from wind power was over 10 percent globally, while it was over 38 percent for solar PV and 2.2 percent for nuclear power. Nuclear generation increased in 19 countries, while in nine countries it declined and remained stable in three. Of the 20 countries that operate nuclear power and solar PV, 18 saw an increase in output from solar and two a decrease, while for those that operate wind and nuclear, 25 saw an increase in output from wind power and only four a decrease. In terms of actual production, Brazil, China, Germany, India, Japan, Mexico, Netherlands, and Spain now all generate more electricity from non-hydro renewables than from nuclear power. These eight countries represent more than three billion people or 45 percent of the world's population. 2014 was also significant as in the UK, renewables, including hydropower, overtook the output from nuclear for the first time in decades.

The reference date in Figure 21 is 1997, as this was the date of the signing of the Kyoto Protocol. Despite attempts to restrict greenhouse gas emissions growth, worldwide emissions, primarily from the energy sector, have continued to grow and have risen from 32 billion tons per year in 1997 to 43.8 billion tons of CO₂-equivalent in 2011.³⁴² Consequently, additional efforts are needed

³⁴² World Resources Institute (WRI), "CAIT 2.0", WRI climate data explorer, see [http://cait.wri.org/historic/Country%20GHG%20Emissions?indicator\[\]=Total%20GHG%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&indicator\[\]=Total%20GHG%20Emissions%20Including%20Land-Use%20Change%20and%20Forestry&year\[\]=2011&chartType=geo](http://cait.wri.org/historic/Country%20GHG%20Emissions?indicator[]=Total%20GHG%20Emissions%20Excluding%20Land-Use%20Change%20and%20Forestry&indicator[]=Total%20GHG%20Emissions%20Including%20Land-Use%20Change%20and%20Forestry&year[]=2011&chartType=geo), accessed 14 June 2015.

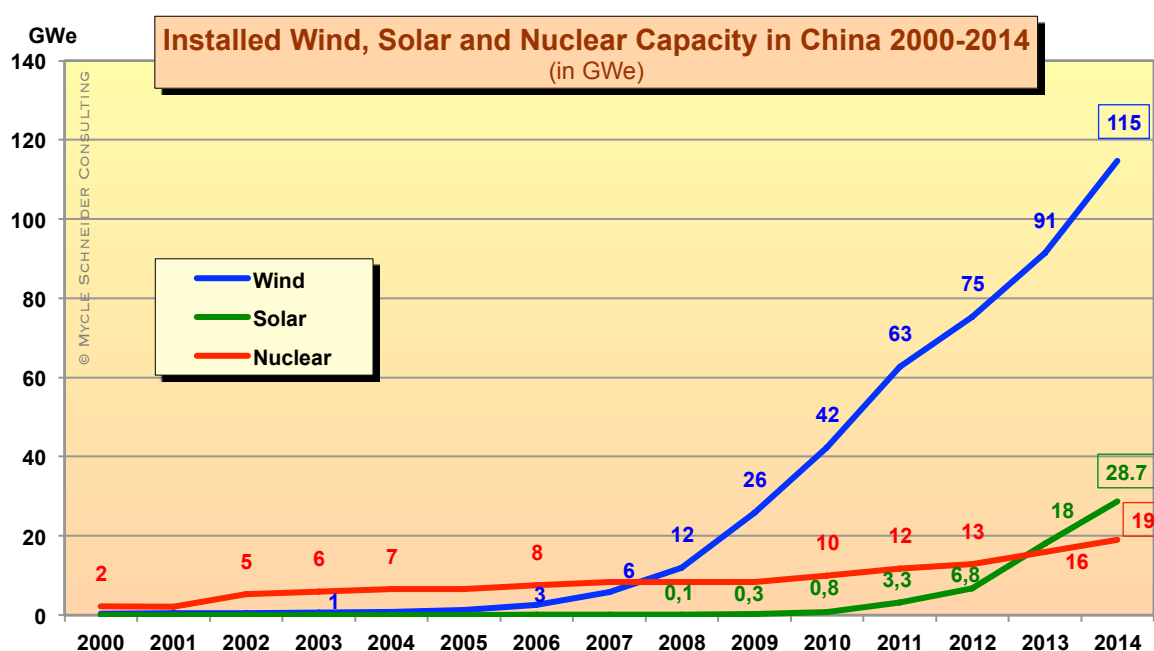
to rapidly accelerate the use of low carbon energy sources. The current deployment and energy production trends reflect the level of public and political support as well as the views of the investment community in the different technologies.

Status and Trends in China, the European Union, India, and the United States

China continues to be a global leader for most energy technologies. In 2014, China installed more wind power and solar photovoltaics than any other country (see Figure 22), so worldwide it now has the largest capacity of wind power and the second largest of solar photovoltaics. China also installed more nuclear capacity in 2014 than any other country. Investment in renewables in China was by far the largest of any country with a total of US\$83.3 billion of which solar PV was US\$40 billion and wind power was US\$38 billion.³⁴³

On the other hand, total investment in nuclear power was 56.9 billion Yuan (US\$9.1 billion), down 13.8 percent.³⁴⁴ In 2014, China installed between 10.6 GW and 12 GW of solar³⁴⁵, a level similar to that deployed in 2013, which exceeded cumulative U.S. PV additions in the past 60 years.

Figure 22: Installed Capacity in China from Wind, Solar and Nuclear 2000–2014



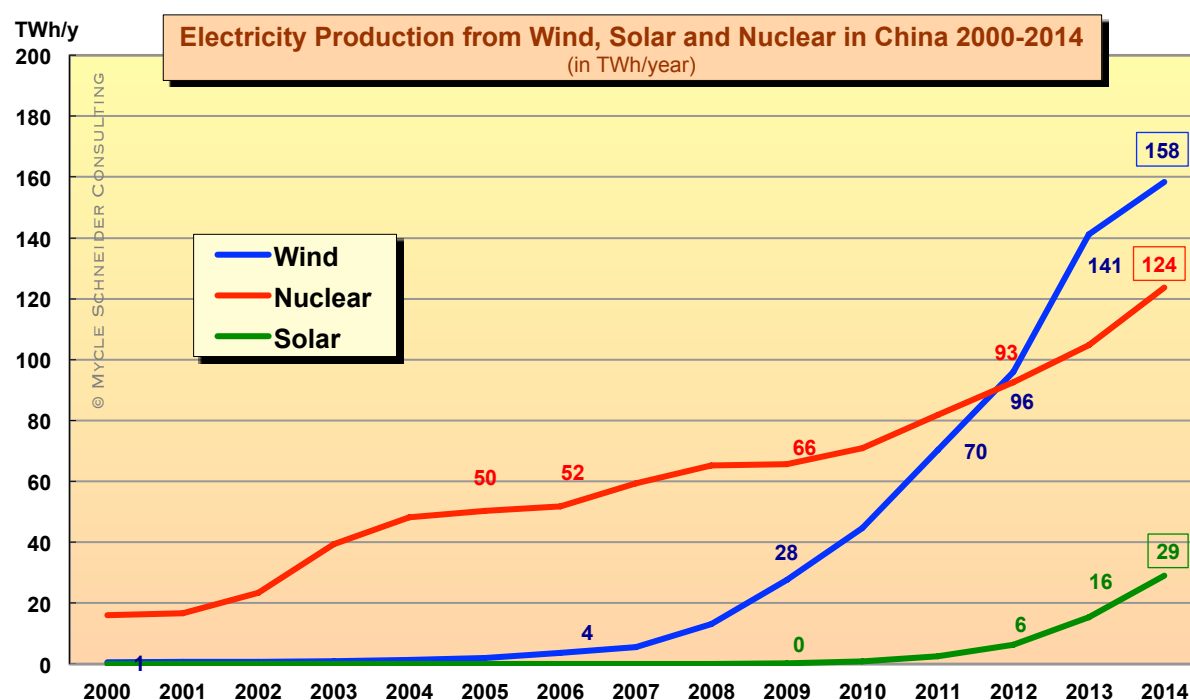
Sources: EPIC, IAEA-PRIS and Global Wind Energy Council (GWEC), 2015

³⁴³ BNEF/UNEP, “Global trends in renewable investment 2015”, Frankfurt School, FS-UNEP Collaborating Centre for Climate and Sustainable Energy Finance.

³⁴⁴ Chinese Electricity Council, “China Power Industry Situation and Prospects”, 10 March 2015, see <http://www.wusuobuneng.com/archives/17665>, accessed 14 June 2015.

³⁴⁵ Mark Osborne, “Has China raised its PV installation target to 17.8GW?”, *Pv-Tech.org*, 17 March 2015, see http://www.pv-tech.org/news/has_china_raised_its_pv_installation_target_to_17.8gw, accessed 25 March 2015.

Figure 23: Electricity Production in China from Wind, Solar and Nuclear 2000–2014



Source: BP 2015, IAEA-PRIS 2015

China is making progress in moving away from its coal dependency. In total 103 GW of new capacity was installed on the grid in 2014, of which less than half, or 46 GW, was conventional fossil-fueled (largely coal) capacity. China's total coal burn fell in 2014 despite 7.4 percent GDP (Gross Domestic Product) growth.

In the **European Union**, between 2000 and 2014, the net changes in the capacity of power plants are estimated to be an increase of 116.8 GW in wind, 101.6 GW in natural gas and 87.9 GW in solar, while nuclear has decreased by 13 GW, and coal and fuel oil each by 25 GW.³⁴⁶ The implementation of the 2009 Renewable Energy Directive has helped to boost renewable energy from just under eight percent in 2004 to 15 percent of commercial primary energy in 2014.³⁴⁷ Compared to Kyoto Protocol Year 1997, in 2014, wind added 242 TWh and solar 98 TWh, while nuclear power generation declined by 47 TWh (see Figure 24).

According to provisional data for 2014 from the European Network of Transmission System Operators for Electricity (ENTSO-E), renewables provided 28.1 percent of total EU electricity or 848 TWh, of which 13 percent was from non-hydro renewables. This compares to 27.7 percent or 831 TWh from nuclear power.³⁴⁸

³⁴⁶ European Wind Energy Association, "Wind in Power, 2014 European statistics", February 2015.

³⁴⁷ Arias Canete, "A 'Renewable Energy Union' ", Commissioner, European Commission, 17 March 2015.

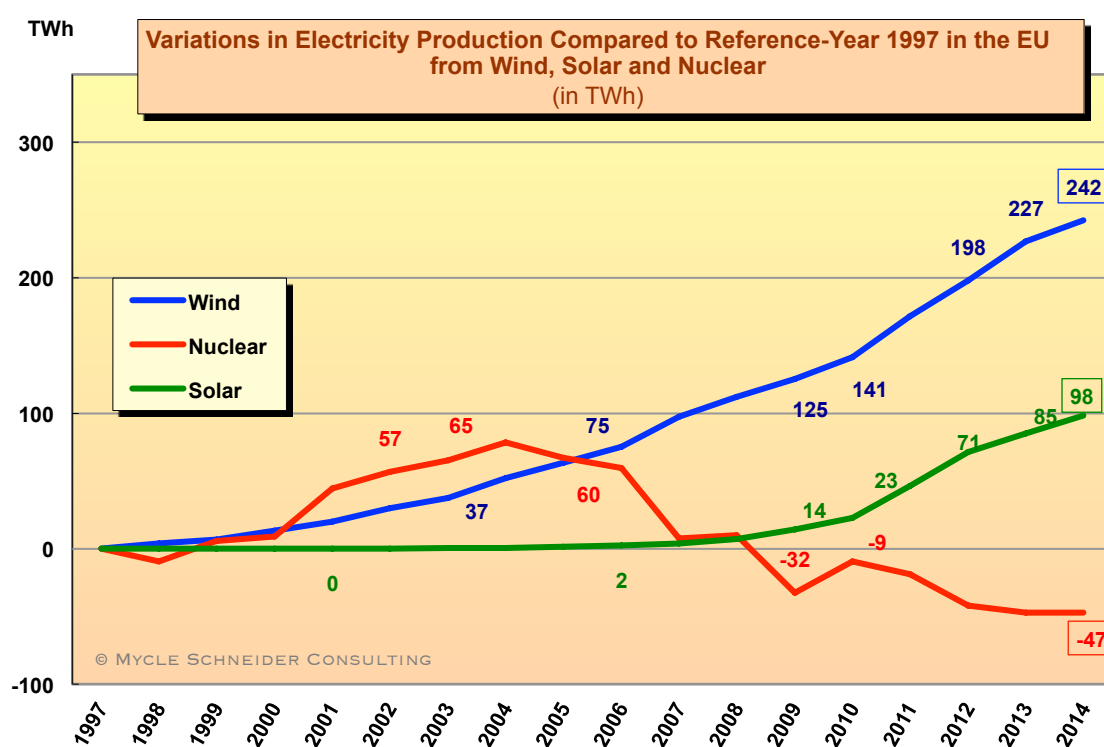
³⁴⁸ *Renewables International*, "Analysis of electricity production in EU-28 up to 2014 with a focus on renewables", 27 April 2015, see <http://www.renewablesinternational.net/2014-renewable-energy-data-for-eu-28/150/537/87150/>, accessed 16 June 2015.

The 2014 renewable electricity production highlights included:

- In Germany, renewables provided 27.8 percent of gross power production, up 2.4 percentage points.
- Denmark had a record year, with wind power providing 39.1 percent of electricity, and a doubling of production over the past decade.³⁴⁹
- In Spain, 22.3 percent of electricity came from wind and solar PV, which together contributed more to the grid than nuclear power did.³⁵⁰
- In the UK, renewables (including hydro) generated 20 percent more power than in the previous year, providing a 19.2 share in electricity production and therefore, for the first time, just surpassed nuclear power, whose share of total generation shrank by almost 10 percent and covered 19 percent of the total.³⁵¹

Under the terms of the European Directive, by 2020, renewable energy is expected to provide 20 percent of the EU's primary energy, including approximately 32 percent of electricity.

Figure 24: Variations in EU Electricity Production from Wind, Solar and Nuclear



Sources: IAEA-PRIS, BP, MSC 2015

The growth in renewables is likely to continue as Figure 25 illustrates the changes in generating capacity in 2014 and thus the dynamic in the sector. While there was an 11.8 GW addition to wind capacity and an increase of 8 GW of solar, there has been a net decrease in the installed capacity of natural gas (-0.4 GW), fuel oil (-1.1GW) and coal (-7.3 GW). The installed nuclear capacity

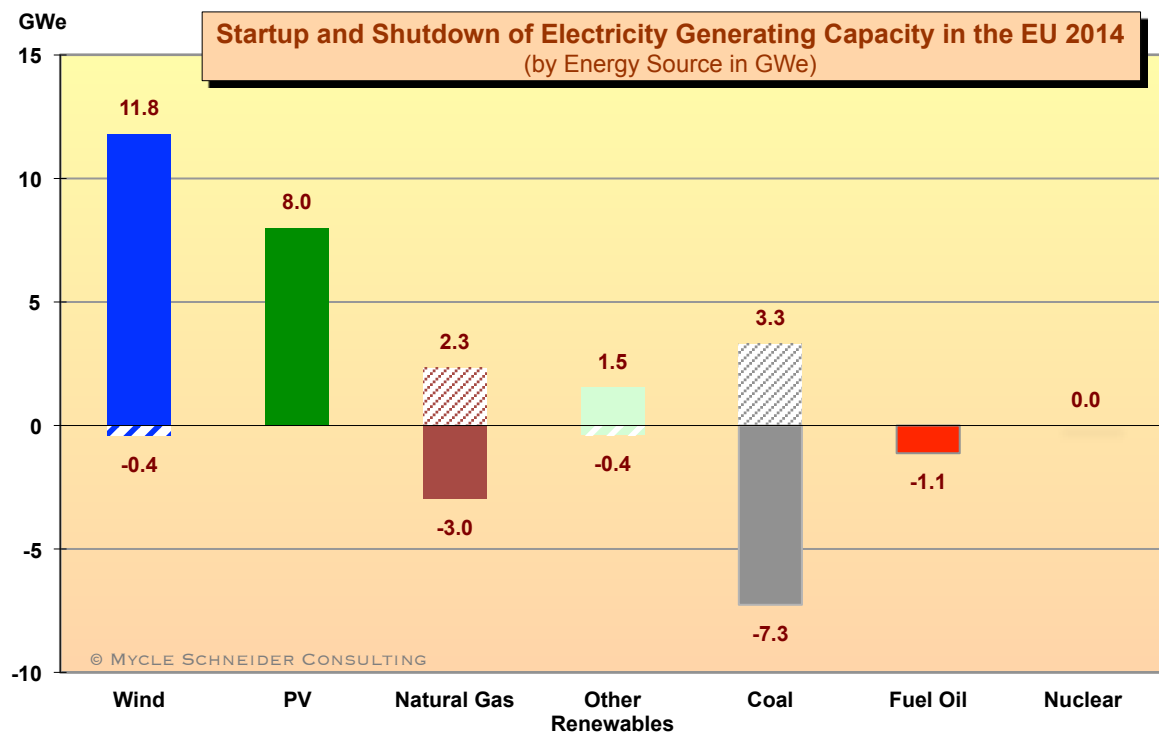
³⁴⁹ *Energinet.dk*, "Wind turbines reached record level in 2014, 39.1% of Danes' electricity consumption was covered by Danish wind turbines in 2014", 20 January 2015.

³⁵⁰ RedElectrica de Espana, "The Spanish Electricity System Preliminary Report, 2014", January 2015.

³⁵¹ U.K. Department of Energy and Climate Change (DECC), "UK Energy Statistics, 2014 and Q4 2014", Statistical Press Release, 26 March 2014, see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/416310/PN_March_15.pdf, accessed 16 June 2014.

remained unchanged over the year 2014, but two reactors were shut down in the first half of 2015 (Doel-1 in Belgium and Grafenrheinfeld in Germany).

Figure 25: Startup and Shutdown of Electricity Generating Capacity in the EU in 2014



Source: European Wind Energy Association (EWEA) 2015³⁵²

This growth in installed renewables capacity is set to continue beyond the current 2020 targets, as in preparation of the UN climate meeting in Paris in December 2015, the EU has agreed a binding target of 27 percent renewables in the primary energy mix by 2030, which is likely to mean 45 percent of power coming from renewables. This will require an escalation of the current rate of renewable electricity deployment. There is no EU-wide nuclear deployment target.

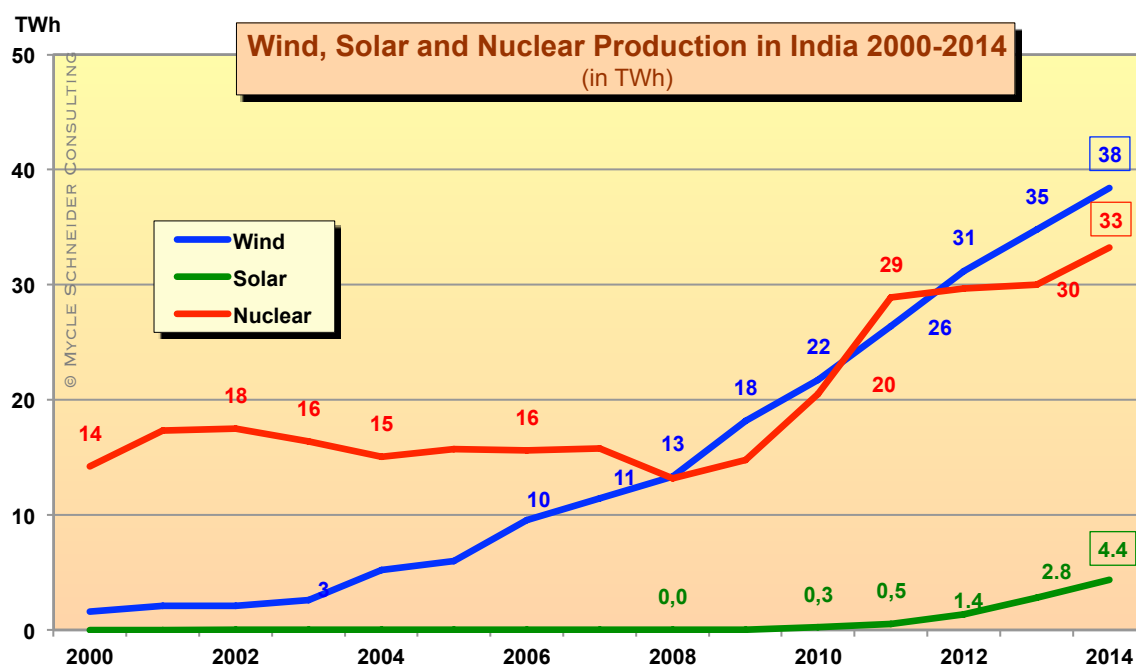
India has one of the oldest nuclear programs, starting electricity generation from fission in 1969. It is also one of the most troubled nuclear sectors in the world and has encountered many setbacks (see India section in Asia). This is in stark contrast to the development of the renewable sector, which is booming. Figure 26 shows how since the turn of the century the wind sector has grown steadily and rapidly and has overtaken nuclear's contribution to electricity consumption for the past two years, while solar is also growing rapidly. Further increases in the growth in renewables are expected in the coming decade; in 2014 a 2022 target of 175 GW of renewable-based power capacity (excluding large hydropower) was announced. Of this total, 100 GW is to be solar (compared to 731 MW in 2014), 60 GW wind (compared to 22.4 GW in 2014), 10 GW biomass-based power, and 5 GW small hydropower projects.

Whether these targets turn out realistic or not remains to be seen. Approximately 300 million people in India currently do not have access to electricity. Therefore how India chooses to meet future growth in demand is absolutely vital domestically and globally. The proposed solar PV

³⁵² EWEA, "Wind in Power, 2014 European statistics", February 2015.

target is undoubtedly ambitious, but is achievable if it follows a similar development pathway as China.

Figure 26: Solar, Wind and Nuclear Production in India (TWh)



Source: BP 2015

In the **United States**, power demand remained largely static in 2014 as it has for the past decade (annual consumption of electricity peaked in 2007). The contribution of fossil fuels also remained largely the same, with a slight move back towards the use of coal over the year as coal and gas battled for market share. In energy terms, renewables (including conventional hydro) accounted for 9.8 percent of total domestic energy consumption, which is the highest share since the 1930s. Since 2001, the average growth rate for renewable energy generation has been 5 percent per year. In the power sector, 13 percent of electricity was generated by renewables in 2014,³⁵³ up from 8.5 percent in 2007.³⁵⁴

U.S. nuclear power production was also constant in 2014, producing 797 TWh or 19.6 percent of the total electricity consumption. The sector that exhibited considerable change was wind, which saw production increase by 8.4 percent or 13 TWh to reach 184 TWh in total. During the year, power production from solar PV doubled, so that it provided a total of 18.5 TWh. However, it is important to note that many figures, including those from the U.S. Energy Information Administration Office (U.S. EIA), do not include “behind the meter” installations—those on the household level. Therefore the number significantly underestimates the contribution of solar, and while the U.S.EIA figure assumes an installed capacity of 8.3 GW, others suggest that the actual

³⁵³ U.S.EIA, “Renewables share of U.S. energy consumption highest since 1930s”, 28 May 2015, see <http://www.eia.gov/todayinenergy/detail.cfm?id=21412&src=email>, accessed 14 June 2015.

³⁵⁴ U.S.EIA, “Table 1.1 Net Generation by Energy Source: Total (All sectors), 2005–March 2015”, see <http://www.eia.gov/electricity/data.cfm#generation>, accessed 16 June 2015.

figure is at least double this, raising PV output by about 10 TWh/y³⁵⁵. Deutsche Bank estimates that, given the levelized cost of electricity (LCOE) in 14 states being now in the range of US\$0.10–0.15/kWh and the retail price range corresponding to US\$0.12–0.38/kWh, approximately 10 GW of additional solar has been installed without subsidies.³⁵⁶ Across the U.S., in 23 of the 51 states, non-hydro renewables produce more electricity than nuclear power, including the large states of Texas and California.³⁵⁷ In total, 38 states have Renewable Portfolio Standards (RPS) or goals, while 27 have energy efficiency standards or goals.³⁵⁸

³⁵⁵ J. Kaminsky & J. Baca, “U.S. Solar Electricity Production 50 Percent Higher Than Previously Thought”, *GreenTechMedia*, 30 June 2015, see <http://www.greentechmedia.com/articles/read/us-solar-electricity-production-50-higher-than-previously-thought>, accessed 30 June 2015.

³⁵⁶ Deutsche Bank 2015, “Crossing the Chasm”, February 2015.

³⁵⁷ *Renewables International*, “Analysis of Electricity Production in USA up to 2014 with a Focus on Renewables and on Wind Power”, 19 March 2015, see <http://www.renewablesinternational.net/us-renewable-energy-data-2014/150/537/86312/>, accessed 16 June 2015.

³⁵⁸ United States Environmental Protection Agency, “Fact Sheet: Clean Power Plan by the Numbers Cutting Carbon Pollution from Power Plants”, June 2014, see <http://www2.epa.gov/carbon-pollution-standards/fact-sheet-clean-power-plan>, accessed 16 June 2015.

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Annex 1: Overview by Region and Country

This annex provides an overview of nuclear energy worldwide by region and country. Unless otherwise noted, data on the numbers of reactors operating and under construction (as of early July 2015) and nuclear's share in electricity generation are from the International Atomic Energy Agency's Power Reactor Information System (PRIS) online database. 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. Load factor figures are drawn from Nuclear Engineering International (NEI), May 2015, unless otherwise noted.

Africa

South Africa has two French (Framatome/AREVA)-built reactors. They are both located at the Koeberg site east of Cape Town and supplied 14.7 TWh or 6.2 percent of the country's electricity in 2014 (the historical maximum was 7.4 percent in 1989). The reactors are situated at the only operating nuclear power plant on the African continent.

The state-owned South African utility Eskom has considered acquiring additional large Pressurized Water Reactors (PWR) and had made plans to build 20 GW by 2025. However, in November 2008, Eskom scrapped an international tender because the scale of investment was too high. In February 2012 the Department of Energy (DOE) published a Revised Strategic Plan that still contained a 9.6 GW target, or six nuclear units, by 2030. Startup would be one unit every 18 months beginning in 2022.³⁵⁹

The November 2013 edition of the Integrated Resource Plan for Electricity, which has not been updated since, concludes:

The nuclear decision can possibly be delayed. The revised demand projections suggest that no new nuclear base-load capacity is required until after 2025 (and for lower demand not until at earliest 2035) and that there are alternative options, such as regional hydro, that can fulfil the requirement and allow further exploration of the shale gas potential before prematurely committing to a technology that may be redundant if the electricity demand expectations do not materialise.³⁶⁰

However, DOE's Strategic Plan 2015–2020, released in April 2015, maintains the 2030 objective, but states that the investment in the 9.6 GWe Nuclear New Build Program “requires an innovative financing mechanism to provide a firm basis to launch procurement”.³⁶¹ A Nuclear Cooperation Agreement (NCA) signed with Russia in September 2014 allows for the delivery of VVER reactors “with total installed capacity of up to 9.6 GW”, in other words potentially covering the entire program. This raised some concerns for the overall procurement process.³⁶² However, the South African government issued a statement saying that: “similar agreements will be signed with other vendors as well.”³⁶³ Indeed, South Africa signed NCAs with France, China, South Korea and the U.S.

³⁵⁹ DOE, “Revised Strategic Plan – 2011/120-02015/16”, February 2012.

³⁶⁰ DOE, “Integrated Resource Plan for Electricity (IRP) 2010-2030”, Update Report 2013, 21 November 2013.

³⁶¹ DOE, “Strategic Plan 2015–2020”, April 2015, see <http://www.energy.gov.za/files/aboutus/DoE-Strategic-Plan-2015-2020.pdf>, accessed 15 May 2015.

³⁶² *NIW*, “Russia Deal Unleashes Fury Over Procurement Process”, 26 September 2014.

³⁶³ DOE, “South Africa's nuclear new build programme”, Media Statement, 1 October 2014.

that have “shown interest in the Nuclear New Build Programme”. Canada and Japan are expected to sign similar agreements in the near future.

The five-year target as outlined in the Strategic Plan, is by 2020 to have completed technology and vendor selection, the procurement process and to have begun construction of the first unit; with connection of the first unit to the grid by 2023 and the second one in 2024. An ambitious timeline.

“Is this focus [on nuclear energy] being driven by the overall affordability of nuclear energy?”, wonders Frost & Sullivan Africa analyst Tom Harris. “The short answer: probably not.” In a straight-forward contribution to *Engineering News*,³⁶⁴ Harris advises the government to “clearly communicate” why it would choose the nuclear power option. Such transparency, he writes, would “encourage industry that the government is following a more consistent, logical and considered policy development process—rather than one that is driven by the whims, fads and fancies of particular individuals”.³⁶⁵

The Americas

Argentina operates three nuclear reactors that in 2014 provided 5.3 TWh or 4.05 percent of the country’s electricity (down from a maximum of 19.8 percent in 1990).

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). After 28 years of operation, the Embalse plant is supposed to get a major overhaul, including the replacement of hundreds of pressure tubes, to enable it to operate for potentially 25 more years.³⁶⁶ Reportedly, contracts worth US\$440 million were signed in August 2011 and main work was to start by November 2013.³⁶⁷ The project could take up to five years and cost about US\$1.5 billion.³⁶⁸ However, as of mid-February 2015, refurbishment work had still not started but was expected to begin “soon”.³⁶⁹ Trade journal *Nuclear Engineering International* commented: “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.”³⁷⁰

³⁶⁴ *Creamer Media’s Engineering News*, “Clarity required on drivers of South Africa’s nuclear policy”, 6 August 2014, see <http://m.engineeringnews.co.za/article/nuclear-conundrum-clashes-with-the-irp-clarity-required-on-drivers-of-policy-decision-2014-08-06>, accessed 15 May 2015.

³⁶⁵ Ibidem.

³⁶⁶ *PowerGenWorldwide.com*, “Argentina’s Embalse Nuclear Plant to Get 25-year Extension”, 5 August 2010.

³⁶⁷ *Research and Markets*, “Nuclear Power Market in Argentina”, May 2012.

³⁶⁸ *NEI*, “Argentina—a possible return to new nuclear?”, 15 October 2013, see

<http://www.neimagazine.com/opinion/opinionargentina-a-possible-return-to-new-nuclear/>, accessed 29 June 2014.

³⁶⁹ *NIW*, “Extending Cernavoda Versus Building New Reactors”, 20 February 2015.

³⁷⁰ *NEI*, “Argentina—a possible return to new nuclear?”, 15 October 2013, see

<http://www.neimagazine.com/opinion/opinionargentina-a-possible-return-to-new-nuclear/>, accessed 29 June 2014.

Atucha-2 had been officially listed as “under construction” since 1981. Finally, on 3 June 2014, the first criticality of the reactor was announced and grid connection was established on 27 June 2014. It took until 19 February 2015 for the unit to reach 100 percent of its rated power.³⁷¹

In early May 2009, Julio de Vido, Argentina’s Minister of Planning and Public Works, stated that planning for a fourth nuclear reactor would begin and that construction could start within a year.³⁷² Six years later, work has not started. In February 2015, Argentina and China ratified an agreement to build an 800 MW CANDU-type reactor at the Atucha site. Construction is to take eight years, but it has not been announced, when work will start.³⁷³ In October 2014, the trade journal *Nuclear Intelligence Weekly* noted that “while it’s unclear when construction on Atucha-3 might start, the goal is to commission the reactor by July 2022”. That schedule seems already compromised. Atucha-3 is expected to cost US\$5.8 billion.³⁷⁴

It was also agreed in principle that China will provide Argentina with a Hualong One reactor, China’s new, and as yet untested, Generation III design. A commercial contract was scheduled to be signed by the end of 2016.³⁷⁵ But in May 2015, as a result of delays in the Hualong One construction at Fuqing in China, it was reported that signature was likely to be pushed into 2017.³⁷⁶

After repeated delays (see Section on Advanced Reactors), construction of a prototype 27 MWe PWR, the domestically designed CAREM25 (a type of pressurized-water Small Modular Reactor with the steam generators inside the pressure vessel) began near the Atucha site in February 2014, with startup planned for 2018. The reactor is said to cost US\$450 million,³⁷⁷ or about US\$17,000 per installed kWe, a record for reactors currently under construction in the world (see also Advanced Reactors Chapter).

Brazil operates two nuclear reactors that provided the country with 15.4 TWh (gross) or 2.9 percent of its electricity in 2014 (down from a maximum of 4.3 percent in 2001). The annual load factor jumped from 79.3 percent in 2013 to an excellent 87.5 percent in 2014.

As early as 1970, the first contract for the construction of a nuclear power plant, Angra-1, was awarded to Westinghouse. The reactor went critical in 1981. In 1975, Brazil signed with Germany what remains probably the largest single contract in the history of the world nuclear industry for the construction of eight 1.3 GW reactors over a 15-year period. However, due to an ever-increasing debt burden and obvious interest in nuclear weapons by the Brazilian military, practically the entire program was abandoned. Only the first reactor, Angra-2, was finally connected to the grid in July 2000, 24 years after construction started.

³⁷¹ 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 16 May 2015.

³⁷² Marketwire.com, “Argentina to Reinforce Nuclear Energy by Adding 700 MW and Building Fourth Nuclear Plant”, 7 May 2009.

³⁷³ WNN, “Argentina and China plan fourth reactor”, 3 February 2015, see <http://www.world-nuclear-news.org/NN-Argentina-and-China-plan-fourth-reactor-03021501.html>, accessed 16 May 2015.

³⁷⁴ WNN, “Argentina-China talks on new nuclear plants”, 8 May 2015, see <http://www.world-nuclear-news.org/NN-Argentina-China-talks-on-new-nuclear-plants-08051501.html>, accessed 16 May 2015.

³⁷⁵ WNN, “Hualong One selected for Argentina”, 5 February 2015, accessed 16 May 2015.

³⁷⁶ WNN, “Argentina-China talks on new nuclear plants”, 8 May 2015, op.cit.

³⁷⁷ NIW, “Cost Overruns Put Mobile Breeder Project in Quandary”, 7 November 2014.

The construction of Angra-3 was started in 1984 but abandoned in June 1991. However, in May 2010, Brazil's Nuclear Energy Commission issued a construction license and the IAEA noted that a "new" construction started on 1 June 2010. In early 2011, the Brazilian national development bank (BNDES) approved a 6.1 billion Reais (US\$3.6 billion) loan for work on the reactor.³⁷⁸ Reportedly, in November 2013, Eletrobras Eletronuclear signed a €1.25 billion (US\$1.425 billion) contract with French builder AREVA for the completion of the plant.³⁷⁹ According to AREVA, in the first quarter of 2015, 13 percent of the "work packages" had been approved for delivery to Brazil. "Progress on the project is dependent on the securing of project financing by the customer", AREVA added.³⁸⁰ Commissioning was previously planned for July 2016 but has been recently delayed to May 2018. No reasons were given for the new delays.³⁸¹

In early May 2012, a top-level Brazilian Government official announced that the country will not proceed with the previously stated plans to launch up to eight new nuclear power plants. "The last plan, which runs through 2020, does not envisage any [new] nuclear power station because there is no need for it", the energy ministry's executive secretary stated. "Demand is met with hydro-electrical power and complementary energy sources such as wind, thermal and natural gas."³⁸² In December 2013, a new Decennial Energy Plan 2022 was released. It includes only the three Angra plants without any further program extension.³⁸³ No significant support is to be expected from the recently re-elected Brazilian President Dilma Rousseff, who "is considered to be reluctantly accepting of nuclear energy. Dilma's government continues to finance Angra 3 construction, but she does not openly support the nuclear energy industry, and the government does not seek to expand the production of nuclear energy beyond the third power plant."³⁸⁴ Meanwhile, unsubsidized renewable competition is so strong that the government recently had to exclude wind power from one of its regular power auctions because it is so cost-effective that no other generating technology would bid against it.³⁸⁵

Canada operates 19 reactors, all of which are CANDU (CANadian Deuterium Uranium), providing 100.9 TWh—an increase of 7 percent over the previous year—or 16.8 percent of the country's electricity in 2014 (down from a maximum of 19.1 percent in 1994), but close to 60 percent of Ontario's provincial power supply.

³⁷⁸ However, it is surprising to note that AREVA's 400-page Reference Document 2012 does not even contain the word "Angra".

³⁷⁹ *NucNet*, "Brazil Releases Production Figures For Angra Nuclear Station", 20 January 2014, see <http://www.nucnet.org/all-the-news/2014/01/20/brazil-releases-production-figures-for-angra-nuclear-station>; and *WNN*, "Areva contracted to complete Angra 3", see <http://www.world-nuclear-news.org/C-Areva-contracted-to-complete-Angra-3-081134.html>; both accessed 30 June 2014.

³⁸⁰ AREVA, Press Release, 29 April 2015.

³⁸¹ *NW*, "Briefs—Brazil", 9 January 2015.

³⁸² WNISR, "Brazil Abandons New Build Plans", 11 May 2012, see <http://www.worldnuclearreport.org/Brazil-Abandons-New-Build-Plans>, accessed 17 July 2014.

³⁸³ Ministério de Minas e Energia, "Plano decenal de expansão de energia 2022", December 2013.

³⁸⁴ Togzhan Kassenova, "Where Would Marina Silva Take Brazil's Nuclear Policy?", Carnegie Endowment for International Peace (CEIP), 2 October 2014, see <http://carnegieendowment.org/2014/10/02/where-would-marina-silva-take-brazil-s-nuclear-policy>, accessed 16 May 2015.

³⁸⁵ Amory Lovins, personal communication, 15 June 2015.

In January 2010, operator Ontario Power Generation (OPG, Ex-Ontario Hydro) requested a five-year license renewal for the four Pickering-1 to -4 reactors,³⁸⁶ but in July 2010 the Canadian Nuclear Safety Commission (CNSC) decided to limit the license to three years. For all of the remaining six Pickering units, the licenses expired on 30 June 2013.³⁸⁷ However, these licenses were extended in late June 2013 for two months to August 2013,³⁸⁸ and in August 2013 for a five-year period to 31 August 2018.³⁸⁹ The Ministry for Energy stated that the remaining two Pickering reactors are “expected to be in service until 2020” but with an earlier shutdown “possible depending on projected demand going forward, the progress of the fleet refurbishment program, and the timely completion of the Clarington Transformer Station”.³⁹⁰

Bruce Power has filed a request for a five-year license extension from 1 June 2015 to 31 May 2020 for all the eight reactors it operates. CNSC renewed the license for all eight reactors for the five-year period requested in extremis on 28 May 2015.³⁹¹

The launch of a nuclear new-build program has not got beyond initial stages. In May 2012, the Government accepted the Environmental Impact Assessment report for the construction by OPG of up to four units at the Darlington site. On 17 August 2012, the CNSC issued a “Site Preparation License” for the Darlington project, “a first in over a quarter century”.³⁹² But before the project proceeded, in October 2013, the Ontario Government pulled the plug and “decided against spending upwards of CAD10 billion to buy two new nuclear reactors”.³⁹³ Ontario’s Long-Term Energy Plan, released in December 2013, confirmed the decision: “Ontario will not proceed at this time with the construction of two new nuclear reactors at the Darlington Generating Station.”³⁹⁴

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 2014, nuclear power produced 9.3 TWh (after a record 11.4 TWh in 2013) or 5.6 percent of the country’s electricity, down from a maximum of 6.5 percent in 1995. An uprating

³⁸⁶ Also called Pickering A reactors.

³⁸⁷ *NEI*, “Pickering A Gets 3-year Licence Extension”, 2 July 2010, see <http://www.neimagazine.com/news/newspickering-a-gets-3-year-licence-extension>, accessed 3 August 2014.

³⁸⁸ CNSC, “CNSC Extends Operating Licences for Pickering A and B Nuclear Generating Stations”, 24 June 2013, see http://www.suretenuclaire.gc.ca/eng/mediacentre/releases/news_release.cfm?news_release_id=462, accessed 24 June 2013.

³⁸⁹ CNSC, “CNSC Renews Pickering Nuclear Generating Station Operating Licence”, 9 August 2013, see http://www.suretenuclaire.gc.ca/eng/resources/news-room/news-releases/index.cfm?news_release_id=469, accessed 30 June 2014.

³⁹⁰ Ministry of Energy, “Achieving Balance—Ontario’s Long-Term Energy Plan”, December 2013, see http://www.energy.gov.on.ca/docs/LTEP_2013_English_WEB.pdf, accessed 1 July 2014.

³⁹¹ CNSC, “Canadian Nuclear Safety Commission renews Bruce Power’s power reactor operating licences”, 28 May 2015, see <http://news.gc.ca/web/article-en.do?nid=981099>, accessed 29 May 2015.

³⁹² OPG, “Joint Review Panel issues Licence to Prepare Site”, 17 August 2012, see <http://www.opg.com/nb/index3.asp>, accessed 8 May 2013.

³⁹³ *Globe and Mail*, “Ontario backs away from plans to buy new nuclear reactors”, 10 October 2013, see <http://www.theglobeandmail.com/news/politics/ontario-backs-away-from-plans-to-buy-new-nuclear-reactors/article14793803/>; and WNI SR, “The End of New Build in Canada?”, 11 October 2014, see <http://www.worldnuclearreport.org/The-End-of-New-Build-in-Canada.html>; both accessed 30 June 2015.

³⁹⁴ Ministry of Energy, “Achieving Balance—Ontario’s Long-Term Energy Plan”, December 2013, see http://www.energy.gov.on.ca/docs/LTEP_2013_English_WEB.pdf, accessed 1 July 2014.

project boosted the nameplate capacity of both units by 20 percent to 765 MW each. The power plant is owned and operated by the Federal Electricity Commission (Comisión Federal de Electricidad).

Energy Minister Pedro Joaquín Coldwell confirmed in May 2014 the country's aim to double the share of renewable energy in the electricity generating capacity from 17 percent to 33 percent by 2018.³⁹⁵ Currently, fossil fuel plants account for four-fifths of the installed capacity and nuclear for the remaining 3 percent.

United States Focus

The United States is on course to install 12 gigawatts of renewable capacity this year, more than all conventional sources combined.

McKinsey & Company, June 2015³⁹⁶

The United States has more nuclear power plants than any other country in the world, with 99 commercial reactors currently operating. This is the lowest number since the Chernobyl accident in 1986. The highest number of operating units, 108, was reached in 1990. Four units were officially closed in the first half of 2013, the first time reactor shutdowns were announced since 1998. In addition, on 29 December 2014, Entergy closed its Vermont Yankee plant, although it had obtained a 20-year license extension only in 2011.

The U.S. reactor fleet provided 797.1 TWh in 2014, a 1.1 percent increase over the previous year, but still below record year 2010 with 807.1 TWh. The load factor increased by an impressive 4.6 percentage points to 87.8 percent in 2013 over the previous year, and of an additional 1.2 percentage points in 2014 to 89 percent. Also, seven units reported annual load factors of over 100% in 2014. Nuclear plants provided 19.6 percent of U.S. electricity in 2014 (down from a peak of 22.5 percent in 1995).

With only five reactors under construction (one of them since 1972) and no new reactor started up in 19 years, the U.S. reactor fleet continues to age, with a mid-2015 average of 35.6 years, amongst the highest in the world: 33 units—every third reactor, up from every fourth reactor a year ago—have operated for more than 40 years (see Figure 27). Projects are being proposed and implemented to allow reactors to operate for potentially up to 60 years. At the end of May 2015, 74 of the 99 operating U.S. units had received a license extension with a further 18 applications under review (see Annex 6 for details).³⁹⁷ No approval was granted between May 2012 and

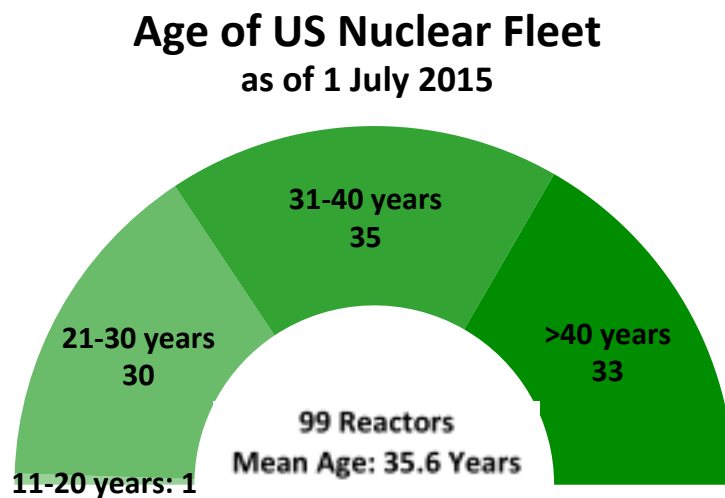
³⁹⁵ Solar Server, "Mexico sets goal for renewables to grow to 33% of installed capacity", 21 May 2014, see <http://www.solarserver.com/solar-magazine/solar-news/current/2014/kw21/mexico-sets-goal-for-renewables-to-grow-to-33-of-installed-capacity.html>, accessed 1 July 2014.

³⁹⁶ McKinsey&Company, "Lower oil prices but more renewables: What's going on?", June 2015, see http://www.mckinsey.com/insights/energy_resources_materials/lower_oil_prices_but_more_renewables_w_hats_going_on, accessed 26 June 2015.

³⁹⁷ U.S.NRC, "Status of License Renewal Applications and Industry Activities", see www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 31 May 2015.

October 2014, awaiting the issuance in September 2014 of the final rule on Continued Storage of Spent Fuel and the Generic Environmental Impact Statement (GEIS).³⁹⁸

Figure 27: Age of U.S. Nuclear Fleet



Sources: IAEA-PRIS, MSC, June 2015.

Not all these life extension options are taken up. Common factors cited for early reactor closure decisions and the wider challenge to the nuclear industries existing nuclear fleet are low natural-gas prices, cheap wind power in the Midwest and flat electricity demand. But another increasingly prominent challenge is the cost of maintaining aging nuclear reactors. Rising operating and maintenance costs during 2002–2012 have been significant, particularly for the 26 single-unit reactors, which on industry figures for 2012 are more than 50 percent costlier to run than the nuclear power plant sites with multiple reactors.³⁹⁹ Analysis by Mark Cooper from Vermont Law School's Institute for Energy and the Environment showed how rising costs of an aging nuclear reactor fleet and the availability of lower-cost alternatives are both likely to persist over the next decades.⁴⁰⁰ The decision by Entergy to close the Vermont Yankee reactor in 2014 was justified on the basis of low gas prices but also due to the high costs of maintaining the single-unit plant.⁴⁰¹ Mark Cooper, writing in *Forbes Magazine*, stated:

³⁹⁸ NRC, “Continued Storage of Spent Nuclear Fuel”, Updated 13 April 2015, see <http://www.nrc.gov/waste/spent-fuel-storage/wcd.html>, accessed 2 June 2015.

³⁹⁹ Electric Cost Utility Group (<https://www.eucg.org/committees/nuclear.cfm#guidance>) as cited by Nuclear Energy Institute (NEI), “Status and Outlook—Annual Briefing for the Financial Community”, 13 February 2014, see <http://www.nei.org/CorporateSite/media/filefolder/Policy/Wall%20Street/WallStreetBrief2014slides.pdf?ext=.pdf>, accessed 31 May 2014.

⁴⁰⁰ Mark Cooper, Senior Fellow For Economic Analysis, “Renaissance In Reverse: Competition Pushes Aging U.S. Nuclear Reactors To The Brink Of Economic Abandonment”, Institute For Energy And The Environment, Vermont Law School, 18 July 2013, see <http://will.illinois.edu/nfs/RenaissanceInReverse7.18.2013.pdf>, accessed 31 May 2014. See also Mark Cooper, “The Economic Failure of Nuclear Power and the Development of a Low Carbon Electricity Future: Why Small Modular Reactors are Part of the Problem, Not the Solution”, May 2015.

⁴⁰¹ Entergy, “Entergy to Close, Decommission Vermont Yankee”, Frequently Asked Questions section, see <http://www.entergy.com/vy/>, accessed 2 July 2014.

Shuttering old, uneconomic reactors like Vermont Yankee is important not only because it removes an economic obstacle to change, but also because it shows the political will to transform America's electricity system.⁴⁰²

One sign of the uncertainty in the prospects for continuing operation of aging nuclear reactors was the decision made in 2013 to cancel planned power uprates. Exelon Corporation, the largest nuclear operator in the U.S., abandoned plans to increase power by a total of 423 MW at four of its reactors, two at LaSalle in Illinois and two at Limerick in Pennsylvania, due to "a lack of significant improvement in long-term [electricity] pricing and [the] large size and long payback period of the investments."⁴⁰³ In early 2014, Exelon made it clear that three of its six Illinois nuclear plants were "at risk" of closure due to lack of competitiveness in the power market. In response, the Illinois General Assembly commissioned an assessment from various institutions and organizations into "impacts and market-based solutions" to "potential nuclear power plant closings in Illinois".⁴⁰⁴ Illinois is the largest nuclear producer in the U.S. with 11 nuclear plants operating with exports of about one quarter of the power production to neighboring states. The Illinois Department of Commerce concluded that the plant closure would have "significant negative economic impact" but that "economic losses can be mitigated", in particular through "investments in energy efficiency and renewable energy resources".⁴⁰⁵ *Monitoring Analytics* stated: "If a well structured wholesale power market does not provide enough revenue to support one or both plants, then an appropriate conclusion would be that the clear market signal is to retire one or both plants."⁴⁰⁶ Exelon stated, it will decide by September 2015, whether to close the two Quad Cities merchant nuclear reactors. If the Illinois Assembly does not legislate on a low-carbon portfolio standard and the reactors don't pass the next capacity auction "we'll have to take the next steps in announcing its early demise", Exelon CEO David Crane declared.⁴⁰⁷ The same applies to the two Byron reactors, a spokesperson added. In May 2014, the four reactors failed to secure contracts to provide power to the electrical grid at an annual PJM (Pennsylvania-New Jersey-Maryland Interconnection LLC) auction (see WNISR2014). PJM is a regional transmission organization that coordinates the movement of wholesale electricity for 61 million people in 13 States on the East coast, South East and Midwest plus the District of Columbia.

Unmoved by the debate about early closures, some utilities are preparing to apply for a second life extension to 80 years. However, some question this approach with George Apostolakis, then an NRC Commissioner, wondered:

I don't know how we would explain to the public that these designs, 90-year-old designs, 100-year-old designs, are still safe to operate. (...) Don't we need more convincing arguments than just "We're managing aging effects"? I mean, will you buy a car that was designed in '64?⁴⁰⁸

⁴⁰² Mark Cooper, "Why Closing Vermont Yankee Won't Raise New England's Power Bills", *Forbes*, 31 December 2014.

⁴⁰³ NW, "New US nuclear plant orders uncertain, but licensing continues", 11 July 2013.

⁴⁰⁴ State of Illinois, "Potential Nuclear Power Plant Closings in Illinois—Impacts and Market-Based Solutions", 5 January 2015.

⁴⁰⁵ Ibidem.

⁴⁰⁶ Ibidem.

⁴⁰⁷ *Platts*, "Exelon to decided fate of Quad Cities nuclear power plant in September", 29 May 2015.

⁴⁰⁸ *New York Times*, "Power Plants Seek to Extend Life of Nuclear Reactors for Decades", 19 October 2014, see <http://www.nytimes.com/2014/10/20/business/power-plants-seek-to-extend-life-of-nuclear-reactors.html>, accessed 2 June 2015.

The OECD's International Energy Agency concluded in its 2014 review of U.S. energy policy:

The economic basis of nuclear power has been severely challenged by competition from shale gas developments as well as weak power prices and slow growth in electricity demand. The domestic nuclear industry is therefore at a critical juncture as a consequence of its declining economic competitiveness, and existing market mechanisms do not favour investment in high capital-intensive nuclear technology.⁴⁰⁹

The U.S. Energy Information Administration Office (EIA) in its 2014 *Annual Energy Outlook to 2040* reported that wholesale electricity prices have reduced quark spreads (the difference between electricity prices and the cost of nuclear fuel – the latter being a small fraction of annual costs) for all nuclear power plants, especially those with increasing operations and maintenance (O&M) costs or capital addition costs.⁴¹⁰ As the industry's Electric Utility Cost Group has reported, O&M costs for U.S. nuclear plants rose at an average annual rate of 3.5 percent during 2008-12 period.⁴¹¹ On the basis of these figures, EIA assumes under its Accelerated Nuclear Retirements case that O&M costs for nuclear power plants will grow by 3 percent per year through 2040; that all nuclear plants not retired for economic reasons are retired after 60 years of operation; and that no additional nuclear power plants are built after the 5.5 GW of capacity currently under construction is completed. As EIA concluded, “this case reflects uncertainty regarding actions and costs associated with continued operation of the existing nuclear fleet.”⁴¹²

New Reactor Projects—Delayed, Suspended, Cancelled

Tennessee Valley Authority (TVA) stated in early 2012 that it would not start working on completion of two Bellefonte units until after the initial fuel loading at Watts Bar-2, under construction since 1972. “On track for completion as planned”, TVA stated on its website in early June 2015,⁴¹³ 43 years after construction started at Watts Bar-2. According to the NRC's April 2015 Quarterly Nuclear Power Deployment Summary, commercial operation is “expected to begin by June 2016.”⁴¹⁴ In the previous January 2015 edition of the Development Summary, the NRC indicated yet “a most likely commercial operation date of December 2015.”⁴¹⁵ On 26 May 2015, the NRC Commissioners voted unanimously to grant authority to the Director of the Office of Nuclear Reactor Regulation (NRR) “to issue a full-power operating license effective upon issuance” to Watts Bar-2, “if the proceeding is uncontested.”⁴¹⁶

⁴⁰⁹ IEA, “Energy Policies of IEA Countries – The United States – 2014 Review – Executive Summary”, 2014.

⁴¹⁰ Office of Integrated and International Energy Analysis, “Annual Energy Outlook 2014 With Projections to 2040”, U.S.EIA, DOE, April 2014, see [http://www.eia.gov/forecasts/aeo/pdf/0383\(2014\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf), accessed 30 May 2014.

⁴¹¹ Electric Utility Cost Group (<https://www.eucg.org/committees/nuclear.cfm#guidance>) as cited by NEI, “Nuclear Energy 2014: Status and Outlook—Annual Briefing for the Financial Community”, 13 February 2014, see <http://www.nei.org/CorporateSite/media/filefolder/Policy/Wall%20Street/WallStreetBrief2014slides.pdf?ext=.pdf>, accessed 31 May 2014.

⁴¹² Office of Integrated and International Energy Analysis, “Annual Energy Outlook 2014 With Projections to 2040”, U.S.EIA, DOE, April 2014, see [http://www.eia.gov/forecasts/aeo/pdf/0383\(2014\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf), accessed 30 May 2014.

⁴¹³ TVA, “Watts Bar Unit 2”, see http://tva.com/power/nuclear/wattsbar_unit2.htm, accessed 2 June 2015.

⁴¹⁴ NRC, “Quarterly Nuclear Power Deployment Summary—April 2015”, April 2015.

⁴¹⁵ NRC, “Quarterly Nuclear Power Deployment Summary—April 2015”, January 2015.

⁴¹⁶ NRC, “Staff Requirements – SECY-15-0068 – Watts Bar Nuclear Plant, Unit 2 – Review Status and Authority of the Director of the Office of Nuclear Reactor Regulation (NRR) for Operating License Issuance”, Memorandum to Mark A. Satorius, ED for Operations, from Annette L. Vietti-Cook, 26 May 2015, see <http://pbadupws.nrc.gov/docs/ML1514/ML15146A213.pdf>, accessed 2 June 2015.

Construction has continued of four AP1000 reactors, Vogtle-3 and -4 in Georgia and VC Summer-2 and -3 in South Carolina (see also Chapter on Generation III Reactor Delays).

In the case of Vogtle, a report for the Georgia Public Service Commission (PSC) in June 2014 warned that projected startup of unit-3 had slipped from April 2016 to January 2018.⁴¹⁷ In April 2015, the NRC reported that “revised estimates for substantial completion...now stand at June 2019 and June 2020. Primary reasons for the delay included issues with submodule design and fabrication.”⁴¹⁸ In June 2015, PSC Commissioner Tim Echols said during a radio interview that he doesn’t believe the utility building the Vogtle plants can meet those deadlines and that he fears that the utility might lose US\$600 million in production tax credits because the two reactors will not be completed by 2020.⁴¹⁹

In February 2014, the U.S. Department of Energy confirmed that the two main owners of plant Vogtle, Georgia Power and Oglethorpe Power, will receive a combined US\$6.5 billion in federal loan guarantees to complete their 2,200-MW nuclear plant expansion.⁴²⁰ The third co-owner, a public power agency with 22.7 percent, got the final tranche of loan guarantees in June 2015.⁴²¹

Construction of VC Summer-2 began in March 2013, followed by Summer-3 in November 2013 with startup dates projected for unit 2 for 2017 and for unit 3 for late 2017 or early 2018.⁴²² In its first 2015 Quarterly Report to the Public Service Commission, builder/operator South Carolina Electric & Gas Co (SCE&G) “delays the substantial completion date of Unit 2 by 27 months and of Unit 3 by 25 months” and raises the price estimate from US\$4.5 billion to US\$5.2 billion.⁴²³ In April 2015, the NRC reports that the “revised estimates for substantial completion (...) now stand at June 2019 and June 2020. Primary reasons for the delay included issues with submodule design and fabrication.”⁴²⁴

SCE&G has repeatedly applied for an electricity price increase to cover soaring construction costs at VC Summer. If the latest one is granted by the Public Service Commission in autumn 2015, it will be the eighth since 2009.⁴²⁵ Under the South Carolina Base Load Review Act, utilities are permitted to increase electricity prices for current customers to pay for the financing costs of the construction of nuclear plants before they go into operation. A request to recover capital costs through tariffs can only be introduced starting seven months prior to startup. The State’s

⁴¹⁷ *Athens Banner Herald*, “Monitor warns of delays building Plant Vogtle”, 23 June 2014, see <http://m.onlineathens.com/local-news/2014-06-23/monitor-warns-delays-building-plant-vogtle>, accessed 17 July 2014.

⁴¹⁸ NRC, “Quarterly Nuclear Power Deployment Summary—April 2015”, April 2015.

⁴¹⁹ *WABE*, “Vogtle Construction Making Progress, But Deadline Fears Loom”, 4 June 2015, see <http://wabe.org/post/vogtle-construction-making-progress-deadline-fears-loom>, accessed 14 June 2015.

⁴²⁰ *Platts*, “Georgia Power, Oglethorpe to receive nuclear loan guarantees totaling \$6.5 bil”, 19 February 2014, see <http://www.platts.com/latest-news/electric-power/washington/georgia-power-oglethorpe-to-receive-nuclear-loan-21240192>, accessed 31 May 2014.

⁴²¹ *WNN*, “Vogtle Receives Final Loan Guarantees”, 22 June 2015, see <http://www.world-nuclear-news.org/NN-Vogtle-receives-final-loan-guarantees-2506157.html>, accessed 3 July 2015.

⁴²² *WNN*, “Second Summer AP1000 under construction”, 6 November 2013, see <http://www.world-nuclear-news.org/NN-Second-Summer-AP1000-under-construction-0611134.html>, accessed 31 May 2014.

⁴²³ SCE&G, “V.C. Summer Nuclear Station Units 2 & 3 - Quarterly Report to the South Carolina Office of Regulatory Staff - Quarter Ending March 31, 2015”, May 2015.

⁴²⁴ NRC, “Quarterly Nuclear Power Deployment Summary—April 2015”, April 2015.

⁴²⁵ See <http://www.regulatorystaff.sc.gov/Documents/News%20Archives/NND%20Report-%204%20QTR%20without%20CoverLtr-3.19.2015.pdf>, accessed 3 June 2015.

Supreme Court confirmed in October 2014 that the utility has the right to pass on cost increases to the customers.⁴²⁶

Many other State Utility Commissions prohibit any construction cost related price increases prior to power production. Between a portfolio of Federal subsidies (not just the loan guarantee) and the special Georgia and South Carolina laws ostensibly transferring all costs and risks to federal taxpayers and state utility customers, while any potential upside goes to utility investors and the companies themselves, one might expect the utilities to be at low risk. But these two states' pay-as-you-go laws give price elasticity longer to work and political support more scope to deteriorate during construction, increasing the risk of lower demand and less sympathetic regulators by the time the plants are finished. These arrangements also seem unlikely to be repeated in other states, and in due course may not offer utilities the degree of protection from cost overruns that they intended.

Pending Combined Operating License Applications (COLA)

As of June 2015, the NRC had received 18 Combined Operating License Applications (COLA) for a total of 28 reactors. All were submitted between July 2007 and June 2009. Nine were subsequently suspended indefinitely or cancelled and 16 have been delayed. Construction and Operation Licenses (COLs) were granted for the AP1000 reactors at Vogtle-3 and -4 and VC Summer-2 and -3, as well as, on 1 May 2015, for an Economic Simplified Boiling-Water Reactor (ESBWR) at Fermi-3 in Michigan.⁴²⁷ The NRC certified GE-Hitachi's ESBWR design in September 2014.⁴²⁸

Of the 10 reactors listed as under review by the NRC⁴²⁹—two less than a year earlier with Fermi-3 COL granted and Calvert Cliffs-3 suspended—six are AP1000 designs, though none of the utilities have committed to building them. For three of the remaining four reactors—two Advanced Boiling Water Reactors (ABWR), one Evolutionary Power Reactors (EPR)⁴³⁰ and one ESBWR—the NRC must certify the designs before issuing COLs. In February 2015, UniStar requested the suspension of NRC's review of its Calvert Cliffs-3 COL application⁴³¹, after NRC suspended the review activities on the EPR design certification application. Major uncertainties remain as to how many, if any, of these projects will actually go ahead. (For a detailed review of the status of the other COL applications, see WNISR2014).

The U.S. EIA projects in the Reference case of its 2015 Annual Energy Outlook⁴³² that 9 GW of new nuclear capacity would be added until 2040 versus 77 GW of renewables (about 90 percent wind and solar) and 144 GW of natural gas-fired capacity. "High construction costs for nuclear plants

⁴²⁶ *The State*, "SC Supreme Court: SCE&G has right to raise rates", 22 October 2014, see <http://www.thestate.com/news/business/article13901756.html>, accessed 3 June 2015.

⁴²⁷ Federal Register, NRC, Docket No. 52-033; NRC-2008-0566, 7 May 2015, see <http://www.gpo.gov/fdsys/pkg/FR-2015-05-07/html/2015-11038.htm>, accessed 3 June 2015.

⁴²⁸ NRC, "NRC Certifies GE-Hitachi New Reactor Design", 16 September 2014, see <http://pbadupws.nrc.gov/docs/ML1425/ML14259A197.pdf>, accessed 3 June 2015.

⁴²⁹ NRC, "Combined License Applications for New Reactors", Updated 26 May 2015, see <http://www.nrc.gov/reactors/new-reactors/col.html>, accessed 3 June 2015.

⁴³⁰ Outside the United States, EPR stands for European Pressurized Water Reactor.

⁴³¹ UniStar, Letter to NRC, dated 27 February 2015.

⁴³² U.S. EIA, Office of Integrated and International Energy Analysis, "Annual Energy Outlook 2015 With Projections to 2040", U.S. DOE, April 2015, see <http://www.eia.gov/forecasts/aeo/>, accessed 3 June 2015.

limit their competitiveness to meet new demand in the Reference case. In the near term, 5.5 GW of planned additions are put into place by 2020, offset by 3.2 GW of retirements over the same period”, the report states. Recalling the 19 percent nuclear share in 2013, the EIA notes: “From 2013 to 2040, the nuclear share of total generation declines in all cases, to 15 percent in the High Oil and Gas Resource case and to 18 percent in the High Oil Price case....” The EIA summarizes the trend:

Rising long-term natural gas prices, the high capital costs of new coal and nuclear generation capacity, state-level policies, and cost reductions for renewable generation in a market characterized by relatively slow electricity demand growth favor increased use of renewables.

In 2014, renewable sources (including conventional hydro) covered 9.8 percent of the primary energy consumption in the U.S., the highest share since the 1930s. Slightly more than half of that renewable energy was used to generate electricity, and the renewable share of electricity reached 13 percent.⁴³³

Asia

China Focus

China started construction of its first commercial reactor in 1985 and according to the IAEA, by the middle of June 2015 had 27 reactors (23 GWe net) in operation (see Annex 7 for detailed overview of the Chinese Reactor Program). In 2014, nuclear provided a record 130 TWh or 2.4 percent of the country’s electricity, but still the lowest nuclear share of any country operating more than one commercial nuclear plant. During 2014, three new reactors were connected to the grid, and so far in 2015 an additional four units have come on line. The nuclear industry has said that another two to four are likely to be approved for startup this year, which would make it the biggest increase in China’s history.⁴³⁴ Logically, China has the youngest reactor fleet in the world with an average age of 7.1 years (see Figure 28).

While the 3 GW of new nuclear capacity in 2014 in China represented two-thirds of the world’s total, it is only a small fraction of the total electricity capacity added in China, with 47 GW fossil-fueled power plants, 21 GW of hydro, 23 GW of wind, and 11 GW of solar photovoltaics added to the grid.

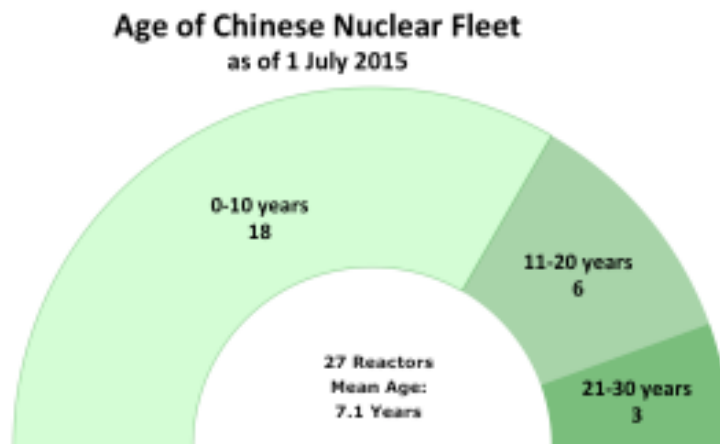
Despite being the global leader in nuclear construction, with work underway on 24 reactors (23.7 GWe net) or nearly 40 percent of the global total, no new projects were approved in 2014. Only in February 2015 were units 5 and 6 at Hongyanhe given the green light; yet apparently these two units were already approved prior to the March 2011 Fukushima disaster. On 7 May 2015, first concrete was poured for Fuqing-5, which houses the first of the Chinese National Nuclear Company’s (CNNC) Hualong design. Even so, this hiatus in orders highlights the challenges to China’s nuclear power program. These include delays in construction and cost increases for the Westinghouse AP1000 reactors and AREVA EPRs, continuing doubts over the siting of reactors in inland provinces, questions over which design or designs of reactors to

⁴³³ U.S.EIA, “Today in Energy”, 28 May 2015, see <http://www.eia.gov/todayinenergy/detail.cfm?id=21412>, accessed 3 June 2015.

⁴³⁴ *South China Morning Post*, “China to approve up to eight more nuclear reactors this year”, 22 April 2015, see <http://www.scmp.com/news/china/policies-politics/article/1773417/china-approve-eight-more-nuclear-reactors-year>, accessed 20 May 2015.

develop, questions over safety and regulatory oversight, and questions about the commercial contract between Westinghouse and the State Nuclear Power Technology Corporation (SNPTC).

Figure 28: Age of Chinese Reactor Fleet



Sources: IAEA-PRIS, MSC, June 2015

Despite these uncertainties and problems, the State Council published in November 2014 the Energy Development Strategy Action Plan 2014–2020, which proposed specific targets for the increase of the share of non-fossil fuels in the total primary energy mix from 9.8 percent in 2013 to 15 percent in 2020. This includes an increase of nuclear capacity to 58 GW by 2020, with an additional minimum of 30 GW under construction at the same time.⁴³⁵ While the target is undoubtedly ambitious—and even industry strategists consider that “it now seems almost certain that it cannot be reached”—it is in fact 12 GW below the target recommended by the State Council Research Office (SCRO) in 2011 and a very significant reduction in the 130 GW forecast by officials in 2010. However, even meeting this revised target will be difficult and will require the completion of all of the existing construction plus the ordering and completion of an addition 12 GW by 2020. Concerns have been raised about the safety implications of such a rapid construction program. The State Council’s plan also envisages an installed capacity of 350 GW of hydro, 200 GW of wind, and 100 GW of solar photovoltaics by 2020. Many observers expect the wind and solar targets to be exceeded.

At the heart of the slowdown in nuclear development in China is the cancellation of projects and plans to build reactors inland, with all operating reactors currently found on the coast. It is reported that no inland plants will be started under the 12th Five-Year Plan, which finishes at the end of 2015, and discussions are underway about whether they will be included in the following 13th Plan now being formed. This is in marked contrast to 2007, when it was anticipated that of the more than 40 sites reserved for the development of nuclear power plants, 31 were inland. In total, 17 of the 29 mainland provinces have inland nuclear sites reserved.⁴³⁶ While it would seem likely that the industry may eventually move inland, it is far from clear where and at what speed. The most controversial issue, inside and outside the nuclear sector, appears to be potential siting of reactors along the Changjiang River. With the rate of growth in electricity consumption slowing considerably—only 3.8 percent growth in 2014 compared to a 6.5–7.5 percent forecast—new

⁴³⁵ *NIW*, “China—Inland Nuclear Developers Await Policy Change”, 2 January 2015.

⁴³⁶ *Ibidem*.

generation projects in oversupplied regions will need to be put on hold to allow demand to catch up.⁴³⁷

Meanwhile, ever-cheaper renewables are steadily gaining market share and policy momentum. Moreover, nuclear plants were recently reclassified as load-following rather than must-run resources, just like fossil-fueled plants, so their output may be curtailed in favor of renewables, reducing their profitability. This is one of a wide variety of market reforms expected in grid planning and operation in the next few years. Together, these reforms are likely to make it tougher for traditional large thermal plants, especially nuclear units, to compete both for construction approvals and in operation.

Central to the rate of new ordering are the terms of the State Council Nuclear Power Safety Plan announced in October 2012.⁴³⁸ These revised plans, following the March 2011 Fukushima nuclear disaster, specified that all new commercial reactor projects approved for construction would be of Generation III design, even though the majority of reactors currently under construction in China are Generation II CPR-1000 reactors. However, this goal has not been adhered to, and since then, construction has started at nine units, mostly Gen II: in 2012, Fuqin-3, a CPR 1000 (Gen II), Shidao Bay-1 (a 200 MW HTR, Gen III), Tiawan-3 (a Russian 990 VVER, Gen II), and Yangjiang-4 (a CPR 1000, Gen II); in 2013, Tianwan-4 (another 990 MW VVER) and two so-called next-generation ACPR-1000 units at Yangjiang; and in 2015, two additional ACPR-1000 reactors at Hongyanhe. However, questions have been raised about the justification of classifying the ACPR-1000 reactors as Generation III; rather, they are said to be “Gen II+ technology with Gen III technology features”.⁴³⁹

In April 2015, the State Council announced the commissioning of the first of a new design of reactor, the Hualong One, with two of the reactors planned for Fuqing. This design is the result of the merging of the designs of two Chinese reactor builders' latest designs, CNNC's ACP1000 and China General Nuclear Power Group's (CGN) ACPR1000. The Hualong One is said to be the first nuclear design for which China has owned all intellectual property rights.⁴⁴⁰ Construction at Fuqing was said to have started in May 2015,⁴⁴¹ but the reactor is also being developed for export. According to the State Council, “Intellectual property rights for key technologies and equipment used in nuclear power plants will facilitate the country's efforts to explore third party markets.”⁴⁴²

The Hualong One design is a direct competitor to the AREVA EPR and Westinghouse AP1000, both being built and both experiencing construction problems in China. When initially ordered, both Western firms hoped and anticipated that these would be the first of a number of units. However, ongoing delays and higher construction costs have put future orders in doubt. Specifically, the estimated installed overnight costs of both the EPR and the AP1000 are now

⁴³⁷ *China Clean Tech*, “Grid – NEA releases 2014 electricity statistics”, 20 January 2015, see <http://www.azure-international.com/en/public-outreach/cleantech-news.html?start=6>, accessed 17 April 2015.

⁴³⁸ *Xinhua*, “China passes energy development, nuclear power plans”, 24 October 2012, see http://news.xinhuanet.com/english/china/2012-10/24/c_131927898.htm, accessed 24 May 2015.

⁴³⁹ A. King, M.V. Ramana, “The China Syndrome? Nuclear Power Growth And Safety After Fukushima”, *Asian Perspective*, (Forthcoming), 2016.

⁴⁴⁰ *Nucleonics Week (NW)*, “China regulator approves first Hualong One project, analysts say”, 16 April 2015.

⁴⁴¹ WNISR, “Construction Start of First Hualong One Generation III Reactor at Fuqing, China”, 9 May 2015, see <http://www.worldnuclearreport.org/Construction-Start-of-First.html>, accessed 22 May 2015.

⁴⁴² *Breakbulk.com*, “China Greenlights Hualong One Construction”, 17 April 2015, see <http://www.breakbulk.com/china-greenlights-hualong-one-construction/>, accessed 4 June 2015.

expected to have reached US\$3,500/kW, which while significantly below the construction cost of the same reactors in Europe and the US, are approaching twice the cost of the CPR1000s.⁴⁴³

Details have emerged of construction delays of up to three years for the AP1000 reactors, and of at least 13–15 months for the two EPR reactors. For the four AP1000 reactors at Sanmen and Haiyang, escalating costs, late design changes, and component failures were confirmed by Chinese officials.⁴⁴⁴ In addition, concerns about a lack of commissioning test procedures are an additional challenge, according to Li Jigen, director of AP1000 nuclear plant regulation for the National Nuclear Safety Administration (NNSA). According the 12th Five Year Plan, the Sanmen units were expected to be operational by end of 2013 and the Haiyang units by mid-2014. However, it is now expected that grid connection will not take place until mid 2016 and end 2016 respectively. The reason given for the delay was problems in the US manufacturing of the reactor coolant pumps, causing this equipment to be returned and remade.⁴⁴⁵

More details of the problems at Sanmen and serious criticism of the performance of both Westinghouse and SNPTC were provided in February 2014. Significant design changes, quality assurance failures, and lack of support between design teams had resulted in delays and cost increases for the Sanmen AP1000 unit one reactor, according to Shan Sun, a senior official at China's National Energy Administration, in a presentation made to the IAEA.⁴⁴⁶

According to Shan Sun, there had been “18,000 design changes by end of 2013”. Rather than taking the average of one month for regular design changes, it took four to six months. The delays in completing the engineering stage are said to be caused by Westinghouse's unfamiliarity with Chinese regulations, with the design teams not having sufficient authority to handle basic design changes and insufficient support for regulatory review from “the offshore team”. The relationship between SNPTC and its Sanmen project subsidiary, the State Nuclear Power Engineering Corporation, was described as confused. Shan also highlighted quality assurance issues, which “need to be reinforced after decades of inactivity”, and “ineffective quality assurance” oversight with the subcontractors.

A two-year delay in the first EPR project is now expected, with completion of Taishan unit 1 expected “in principle” at the end of 2015, with connection to the grid and commercial operation still to come. Unit 2 is expected to be connected three to four months later.⁴⁴⁷ However, these dates were given prior to the emergence of problems of the material used in the construction of parts of the pressure vessel at the Flamanville EPR, also potentially affecting the Taishan reactors. In reaction to the news that the metal used in the reactor pressure vessel head and bottom was potentially unsuitable,⁴⁴⁸ the Chinese Government announced that it would not load fuel into the reactor until further investigations had occurred. Tang Bo, a nuclear safety administration official, told the Beijing-based newspaper *China Environment News*: “Only when problems in reactors...are

⁴⁴³ Steve Kidd, “China's nuclear programme—how serious are the delays?”, *NEI*, 24 March 2015, see <http://www.neimagazine.com/opinion/opinionchinas-nuclear-programme-how-serious-are-the-delays-4538898/>, accessed 22 May 2015.

⁴⁴⁴ *NW*, “Design changes, parts issues slow Chinese AP1000 projects: regulator”, 20 March 2014.

⁴⁴⁵ *NIW*, “China, More delays at Sanmen over RCPs”, 20 June 2014.

⁴⁴⁶ Shan Sun, “Challenges during construction of new NPPs”, Huaneng Shandong Shidao Bay Nuclear Power Company, 4 February 2014, see http://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-02-04-02-07-TM-INIG/Presentations/37_S7_China_Sun.pdf, accessed May 2015.

⁴⁴⁷ *NIW*, “Briefs—China”, 30 January 2015.

⁴⁴⁸ 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 22 May 2015.

identified and solved will we allow nuclear fuels to be loaded into the Taishan plant for the first time and for it to begin to operate.”⁴⁴⁹

Previously, one of the reasons cited for delays at Taishan is the knock-on effects from the major delays in the AREVA EPR projects at Olkiluoto in Finland and Flamanville in France.⁴⁵⁰ The NNSA has not been able to rely on testing and qualification results from the EPR European projects. In addition, malfunctions with equipment suppliers at Taishan have been cited as typical of first-of-a-kind reactor projects. One consequence of the problems at the Taishan project, a joint-venture project owned 70 percent by CGN and 30 percent by French state utility EDF, is that CGN will delay before committing to additional EPR projects. Industry strategist Steve Kidd stated: “It is generally expected that two more EPRs will be ordered for Taishan, but that they will be the last in China.”⁴⁵¹

Evidence of regulatory oversight and quality control challenges emerged in June 2014. Stephane Pailler, head of international relations at France's Nuclear Safety Authority (ASN), described how it was not easy to know, what is happening at the Taishan site in contrast to the European EPR projects.⁴⁵² The concerns in France over their EPR projects surfaced in February 2014, when in testimony to the National Assembly, ASN Commissioner Philippe Jamet warned that “collaboration isn't at the level we would wish it to be” and that “one of the explanations for the difficulties is that the Chinese safety authorities lack means. They are overwhelmed.”⁴⁵³

The *Guardian* newspaper interviewed He Zuoxiu, physicist and member of the Chinese Academy of Social Science, who made some startling statements:

They want to build 58 [gigawatts of nuclear generating capacity] by 2020 and eventually 120 to 200. This is insane.,,,

The safety reviews after Fukushima found some problems, but only minor ones, and the final conclusion is that China's nuclear power is safe. But the safety checks were carried out under the old standards and the standards themselves clearly need big improvements....

At the moment, the ministry of environmental protection is considering a new watchdog. When they invited me over for a discussion, I told them: “Your safety watchdog is not independent. It listens to the national nuclear corporation and hence the scrutiny is fake”.⁴⁵⁴

China is also keen to expand its export market. To assist in this, China is merging some of its companies. As noted, CNNC and CGN are producing a single design for the next generation of reactor, while China Power Investment Corp. and SNPTC have merged into a new company, named National Power Investment Corporation, with assets of over 700 billion yuan

⁴⁴⁹ *Global Times*, “Watchdog urges nuclear plant to address potential safety issues”, 15 April 2015.

⁴⁵⁰ *NIW*, “Taishan's Delays Hinder Further Areva EPR Sales”, 21 March 2014.

⁴⁵¹ Steve Kidd, “China's nuclear programme—how serious are the delays?”, *NEI*, 24 March 2015, see <http://www.neimagazine.com/opinion/opinionchinas-nuclear-programme-how-serious-are-the-delays-4538898/>, accessed 22 May 2015.

⁴⁵² *Bloomberg*, “Nuclear Regulators ‘Overwhelmed’ as China Races to Launch World's Most Powerful Reactor”, 19 June 2014, see <http://www.bloomberg.com/news/2014-06-18/french-nuclear-regulator-says-china-cooperation-lacking.html>, accessed 17 April 2015.

⁴⁵³ *Ibidem*.

⁴⁵⁴ *The Guardian*, “China warned over ‘insane’ plans for new nuclear power plants”, see <http://www.theguardian.com/world/2015/may/25/china-nuclear-power-plants-expansion-he-zuoxiu>, accessed 25 May 2015.

(\$112.94 billion).⁴⁵⁵ It is suggested that the merger would represent a major vote of confidence by the government in the future of the AP1000 (and scaled-up derivative designs such as the CAP1400) as designs for the Chinese fleet.⁴⁵⁶ According to the Energy Development Strategic Action Plan, China has nuclear co-operation agreements with 16 countries, but sees particular potential in the Middle East, South Africa, and Turkey.⁴⁵⁷

Also high on the list is Argentina, where in February 2015 a bilateral deal was signed that would see CNNC assist in the construction of Atucha-3 and supply equipment for the construction of the country's fifth reactor.⁴⁵⁸ This is expected to be an 800 MWe unit based on a CANDU design and to cost US\$5.8 billion, with construction to start in 2016. However, as is seen in the case of Russia, financing is key to the deal, and it is reported that "several Chinese government agencies involved are demanding that the loan from China be contingent on Chinese companies being given priority in all aspects, including design, construction and fuel cycle." The second part of the US\$13 billion deal is for the construction of a sixth Argentinian reactor, a Hualong design, where construction is scheduled to start in 2017.⁴⁵⁹ This will be an important test for the fledgling Chinese nuclear export program. By joining forces, the two reactor builders will pool resources in the construction of the Hualong design and reduce intra-Chinese competition, both of which could be positive. However, with no domestic completion experience, this is potentially a high-risk strategy, as significant cost over-runs or delays could endanger China's export strategy as they have done for France.

India operates 20 nuclear power reactors, one less than a year ago, with a total capacity of 5.2 GWe; the majority have a capacity of 220 MWe per unit. In 2014, nuclear power provided a record 33.2 TWh. That is just 3.5 percent of India's electricity—slightly below the record level of 3.7 percent achieved in 2001/02, when nuclear generation was only around 17 TWh, half the 2014 production. This bespeaks India's rapid growth in electricity demand.

One reactor, Rajasthan-1, has not generated any power since 2004 and, according to the new WNISR criteria, was moved to the LTO category in 2014. In September 2014, the chairman of the Atomic Energy Commission stated that Rajasthan-1 (or RAPS-1) would not be restarted.⁴⁶⁰

India lists six units as under construction with a total of 3.9 GW. Most operating reactors experienced significant construction delays, and operational targets have rarely been achieved. Grid connection of the Russian-procured reactor Kudankulam-2, for example, under construction for 13 years, has been delayed numerous times. First criticality is now scheduled for September 2015.⁴⁶¹ Kudankulam-1, which started construction four months before unit 2, went into

⁴⁵⁵ *Reuters*, "China nuclear power firms merge to fuel global clout", 30 May 2015, see <http://www.reuters.com/article/2015/05/30/us-china-nuclear-m-a-idUSKBN00F06W20150530>, accessed 31 May 2015.

⁴⁵⁶ *NIW*, "SNPTC-CPI Merger", 9 May 2015.

⁴⁵⁷ *WNN*, "Argentina-China talks on new nuclear plants", 8 May 2015, see <http://www.world-nuclear-news.org/NN-Argentina-China-talks-on-new-nuclear-plants-08051501.html>, accessed 12 May 2015.

⁴⁵⁸ *NIW*, "Weekly roundup", 6 February 2015.

⁴⁵⁹ *WNN*, "Argentina-China talks on new nuclear plants", 8 May 2015, see <http://www.world-nuclear-news.org/NN-Argentina-China-talks-on-new-nuclear-plants-08051501.html>, accessed 12 May 2015.

⁴⁶⁰ *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 21 May 2015.

⁴⁶¹ NPCIL, "Plants Under Construction, Kudankulam", as of May 2015, see <http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=77>, accessed 6 June 2015.

commercial operation only on 31 December 2014. Construction of the Prototype Fast Breeder Reactor (PFBR) began in 2004, and the startup date has been repeatedly delayed.

India's lifetime average nuclear load factor is only 61.3 percent as of the end of 2014, the lowest of any country operating more than two units. With an annual load factor in 2014 of 72.8 percent (comparable to Sweden and Ukraine), it increased its lifetime load factor by meager 0.8 percentage points, which, nevertheless, is now almost equal to Japan's (61.6 percent).

In December 2010, the Nuclear Power Corporation of India Ltd. (NPCIL) and AREVA signed an agreement—though not yet a commercial contract—for the construction of two EPRs (and potentially four more) for a site in Jaitapur and a fuel supply for 25 years.⁴⁶² The contract reportedly would be worth some €7 billion (US\$10 billion) for two EPRs⁴⁶³, a surprisingly low figure considering that the cost estimate for the French and Finnish EPRs has escalated to over €8.5 billion (US\$11.6 billion) *each*. India's 2010 Civil Liability for Nuclear Damage Act, which holds suppliers (not just operators) liable to some degree in case of a major accident, remains a potential stumbling block to the project. So, of course, does the financial condition of AREVA's reactor business, now to be absorbed by EDF.

After a January 2015 meeting between the President Obama and Prime Minister Modi, some saw a “nuclear breakthrough”. Others saw more “symbolism than reality”.⁴⁶⁴ As the Indian economic journal *Business Standard* put it: “Equipment suppliers are keeping the champagne on ice”.⁴⁶⁵ The resolution of the civil liability issue remains precarious unless current legislation is overturned by the Indian Parliament.

During an India visit in December 2014, Russian President Putin did not wait for the resolution of the liability issue and stated:

We have just signed a document of great significance—the strategic vision for strengthening Indian-Russian cooperation in the peaceful use of nuclear power. It contains plans to build over 20 nuclear power units in India, as well as cooperation in building Russia-designed nuclear power stations in third countries, in the joint extraction of natural uranium, production of nuclear fuel and waste elimination.⁴⁶⁶

However, as far as reported, no commercially binding contracts have been signed since. In 2011, the state of West Bengal scrapped a project for up to six Russian reactors at the coastal site of Haripur.⁴⁶⁷

India's current Five Year Plan counts on doubling the currently installed nuclear capacity and starting construction of a further 19 units. Indian nuclear planning has been always overly

⁴⁶² AREVA, “India: Agreements Between AREVA and NPCIL for the Supply of Two EPR Reactors and Fuel for 25 Years”, Press Release, 6 December 2010.

⁴⁶³ *Bloomberg.com*, “India Signs \$9.3 Billion Deal for Areva to Build Two Nuclear Power Plants”, 6 December 2010.

⁴⁶⁴ *Deutsche Welle*, “Breakthrough in US-India civil nuclear deal ‘more symbolism than reality’”, 28 January 2015, see <http://www.dw.de/breakthrough-in-us-india-civil-nuclear-deal-more-symbolism-than-reality/a-18221115>, accessed 21 May 2015.

⁴⁶⁵ *Business Standard*, “Nuclear ‘breakthrough’ has CEOs wary of fin print”, 27 January 2015, see http://www.business-standard.com/article/current-affairs/nuclear-breakthrough-has-ceos-wary-of-fine-print-115012700070_1.html, accessed 21 May 2015.

⁴⁶⁶ *WNN*, “Putin: Russia ready to build ‘more than’ 20 reactors in India”, 11 December 2014, see <http://www.world-nuclear-news.org/NP-Putin-Russia-ready-to-build-more-than-20-reactors-in-India-11121401.html>, accessed 21 May 2015.

⁴⁶⁷ *NW*, “West Bengal eliminates Haripur as second VVER site: reports”, 25 August 2011.

optimistic, not to say unrealistic.⁴⁶⁸ And as previously noted, the Russian nuclear industry and government do not look adequately funded to deliver on many of their proposed reactor exports. In contrast, Prime Minister Modi is a strong advocate of renewable energy and has increased India's renewable targets by severalfold, as well as strengthened efforts to improve end-use efficiency and modernize the grid. Competitive pressure on proposed nuclear projects can be expected to rise rapidly.

Japan Focus

As a consequence of the continued shutdown of all reactors in Japan, no nuclear electricity generation occurred during the entire calendar year of 2014—the first such year since Japan's first commercial reactor Tokai-1 was connected to the grid on 10 November 1965, almost 50 years ago (see Figure 5). (The 10 MWe Japan Power Demonstration Reactor was connected to the grid even earlier, on 26 October 1963, but it is unclear whether it was generating power in 1964.)

This compares with nuclear generation of 13.6 TWh and 1.6 percent of total electricity in 2013, 2 percent in 2012, 18 percent in 2011, 29 percent in 2010, and the historic maximum of 36 percent in 1998.⁴⁶⁹ Since 15 September 2013, when Ohi Unit-4 was shut down, no commercial nuclear reactor has operated. As a result, all of Japan's nuclear reactors are in the WNISR category of Long Term Outage (LTO).⁴⁷⁰ (See Annex 2 for a detailed overview of the Japanese Reactor Program.)

Industry expectations on early nuclear restart have proved consistently wrong over the past two years. The Sendai-1 reactor, which would be the first to commence operation since September 2013, and slated for restart in 2014, has passed the three stage review of the NRA, but has yet to complete its pre service safety assessment as of 1 July 2015. A summer restart is increasingly likely, with the reactors owner, Kyushu Electric announcing that fueling would begin 7 July 2015.⁴⁷¹ However, there is the possibility of further delays depending on conclusion of pre operational safety inspections and start up problems. In June 2015, it was announced that “discovery of numerous incomplete documents and erroneous written entries”, which led the regulator to announce it was “redoing portions of the pre-service inspections that it had already completed”.⁴⁷²

Figure 5 shows the collapse of nuclear electricity generation in Japan. While the most dramatic decline has been since the 2011 Fukushima Daiichi accident, in fact it is 17 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 shutdown of all 17 of Tokyo Electric Power's (TEPCO) reactors—seven at Kashiwazaki Kariwa and ten at Fukushima Daiichi and Fukushima Daini (Daiichi means “Number One” and Daini means “Number Two”, each referring to a multi-reactor generating complex). The shutdown was following an admission from

⁴⁶⁸ See WNISR 2013, “Nuclear Power in India: Planning, Projection or Fantasy?”, Table 7, 30 July 2013, see <http://www.worldnuclearreport.org/World-Nuclear-Report-2013.html#asia>, accessed 14 July 2014.

⁴⁶⁹ IEA, “Monthly Electricity Statistics”, February 2015, see <https://www.iea.org/media/statistics/surveys/electricity/mes.pdf>, accessed 21 May 2015.

⁴⁷⁰ M. Schneider, A. Froggatt, et. al., “WNISR2014”, 18 August 2014, see <http://www.worldnuclearreport.org/WNISR2014.html>, accessed 6 July 2015.

⁴⁷¹ Nishi Nippon, “Unit 1 Kyushu Electric Sendai nuclear power plant: nuclear fuel loaded on the 7th July”, 3 July 2015, see <http://www.nishinippon.co.jp/nnp/kagoshima/article/179824>, accessed 4 July 2015.

⁴⁷² JAIF, “NRA to Partially Redo Pre-service Inspections at Sendai-1”, 10 June 2015.

TEPCO that its staff had deliberately falsified data for inclusion in regulatory safety inspections reports.⁴⁷³ 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, with a total installed capacity of 8.2 GWe, following the Niigata Chuetsu-oki earthquake in 2007.⁴⁷⁴ TEPCO was struggling to restart the Kashiwazaki Kariwa units when the Fukushima earthquake occurred.

The Fukushima-Daiichi accident, which began on 11 March 2011 (see Fukushima Status Report), has led to the shutdown of all 50 nuclear reactors and the destruction of four at the Fukushima-Daiichi site. Four years on, the consequences of the accident continue to define the future prospects for nuclear energy in Japan. The number of reactors theoretically available to resume operation declined further during the past year with the confirmation of the permanent closure of five reactors in March 2015.⁴⁷⁵ While the nuclear industry has failed to resume operation of nuclear power plants, a consistent majority of Japanese citizens, when polled, continue to oppose the continued reliance on nuclear power, support its early phaseout, and remain opposed to the restart of reactors—all despite intensive pressure by the national government, the nuclear and utility industries, and their allies.⁴⁷⁶

The government of Prime Minister Abe, elected in December 2012, confirmed in 2014 a new Strategic Energy Plan. It reversed the previous government's position, announced in September 2012, that called for a zero nuclear power future by the 2030s.⁴⁷⁷ In late 2014, a Subcommittee on Long-term Energy Supply-demand Outlook was established under the auspices of the Ministry of Economy, Trade and Industry (METI) to develop a long-term energy supply and demand balance.⁴⁷⁸ The sub-committee was to propose an energy mix that would set the electricity share for nuclear, renewable and fossil fuel energy for the year 2030. In 28 April 2015, METI presented its draft with the proposed nuclear share by 2030 to be 20–22 percent, with renewable energy proposed for 22–24 percent, and fossil fuels coal and oil 56 percent.⁴⁷⁹ The proposed nuclear share is below the pre-Fukushima projection within METI's 2010 Strategic Energy Plan expecting

⁴⁷³ Hiroyuki Kuroda, "Lesson Learned from TEPCO Nuclear Power Scandal", Manager Corporate, Communications Department, TEPCO, 24 March 2004, see <http://www.tepco.co.jp/en/news/presen/pdf-1/040325-s-e.pdf>, accessed 28 May 2015.

⁴⁷⁴ TEPCO, "Impact of the Niigata Chuetsu-oki earthquake on the Tokyo Electric Power Company (TEPCO) Kashiwazaki Kariwa Nuclear Power Station and Countermeasures", September 2007, see <http://www.tepco.co.jp/en/news/presen/pdf-1/040325-s-e.pdf>, accessed 30 May 2015.

⁴⁷⁵ WNISR, "Japanese Utilities Confirm Closure of Five Reactors", 21 March 2015, see <http://www.worldnuclearreport.org/Japanese-Utilities-Confirm-Closure.html>, accessed 22 May 2015.

⁴⁷⁶ *Asahi Shimbun*, "Asahi Poll: 59 percent oppose restart of nuclear reactors", 18 March 2014, see <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201403180058>, accessed 6 June 2014; and Daniel P. Aldrich, "Japan's Post-Fukushima Nuclear Power Program", Mansfield Foundation, November 2014, see <http://mansfieldfdn.org/mfdn2011/wp-content/uploads/2014/11/Aldrich-Mansfield-OpEd.pdf>, accessed 22 May 2015.

⁴⁷⁷ The Energy and Environment Council, "Innovative Strategy for Energy and the Environment", Government of Japan, 14 September 2012.

⁴⁷⁸ Agency for Natural Resources and Energy (ANRE), "Establishment of the Subcommittee on Long-term Energy Supply-demand Outlook", METI, December 2014, see http://www.meti.go.jp/english/press/2014/1226_01.html, accessed 22 May 2015.

⁴⁷⁹ CleanTech Institute, "Japan Announces Energy Mix Plan for 2030", 1 May 2015, see http://techon.nikkeibp.co.jp/english/NEWS_EN/20150501/416800/?ST=msbe, accessed 29 May 2015.

50 percent by 2030,⁴⁸⁰ and also below the actual pre-accident 29 percent in March 2011. However, challenges to the proposed nuclear share were evident inside the drafting subcommittee, with dissenting expert opinion that the nuclear share did not reflect a commitment in 2014 to reduce nuclear power to the extent possible.⁴⁸¹ In response, Industry Minister Yoichi Miyazawa stated that high energy costs from renewables would require a nuclear share of at least 20–22 percent.⁴⁸² To attain that nuclear share all 25 reactors currently under NRA review, plus most of those yet to be reviewed, would need to be restarted—a prospect that in reality appears unattainable. Miyazawa stated that to achieve this percentage would require the operation of 35 reactors by 2030, a target that does not reflect the reality of the many challenges facing Japan's nuclear reactor fleet.⁴⁸³ Within the utility industry, it is acknowledged that it will be a challenge to reach the government target and that 15 percent by 2030 is more realistic. However, even attaining this figure looks uncertain.⁴⁸⁴ Wider corporate Japan is even more skeptical of the prospects for attaining a high percentage share.⁴⁸⁵ A number of scenarios indicating a percentage share of less than 10 percent were published during 2015.⁴⁸⁶ The uncertainties in the prospects for reactor restart mean that, no matter what target percentage is set, the Japanese Government and utilities do not know how many of Japan's 40 remaining reactors 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. However, in November 2014, the Federation of Electric Power Companies (FEPCO) announced that it will postpone the large-scale start of the MOX “pluthermal” program.⁴⁸⁷ Originally, FEPCO had intended to use plutonium from spent fuel at 16 to 18 nuclear reactors in Japan by fiscal 2010, and then, due to further setbacks, by 2015. However, the completion of two key facilities in the plutonium project has been delayed along with the LTO of all of Japan's commercial reactors. FEPCO will decide on a new deadline after reviewing possible reactor restarts. The first reactor to resume operation with MOX fuel is likely to be Ikata Unit 3 in 2016. The 21st delay in commercial operation of the Rokkasho-mura reprocessing plant, intended to

⁴⁸⁰ METI, “The Strategic Energy Plan of Japan—Meeting global challenges and securing energy futures”, Revised June 2010, see http://www.meti.go.jp/english/press/data/pdf/20100618_08a.pdf, accessed 29 May 2015.

⁴⁸¹ *Asahi Shimbun*, “Nuclear power crucial as renewable energy too costly, ministry says”, 27 May 2015, see http://ajw.asahi.com/article/behind_news/politics/AJ201505270040, accessed 30 May 2015.

⁴⁸² *Ibidem*.

⁴⁸³ *Asahi Shimbun*, “Japan needs 35 nuclear reactors operating by 2030, says industry minister”, 11 June 2015, see http://ajw.asahi.com/article/behind_news/politics/AJ201506110038, accessed 30 June 2015.

⁴⁸⁴ Shigeru Muraki, “Plenary Discussion: Managing Global Risks — Markets, Geopolitics and Climate”, Member of the Board and Executive Advisor, Tokyo Gas, 2015 Columbia Global Energy Summit, 28 April 2015, see <http://energypolicy.columbia.edu/events-calendar/2015-columbia-global-energy-summit>, accessed 30 May 2015.

⁴⁸⁵ *Reuters*, “Japan Inc not as keen as Abe government on nuclear power - Reuters poll”, 24 May 2015, see <http://www.reuters.com/article/2015/05/24/japan-companies-nuclear-idUSL3N0YB2PR20150524?feedType=RSS&feedName=utilitiesSector>, accessed 30 May 2015.

⁴⁸⁶ Shaun Burnie, “Reality Check: Energy Mix 2030 and Japan's Collapse in Nuclear Power Generation”, Greenpeace Germany, 24 April 2015, see <http://www.greenpeace.org/japan/Global/japan/pdf/20150428-briefing-energy-mix.pdf>; and *BNEF*, “Japan's likely 2030 energy mix: more gas and solar”, 2 June 2015, see <http://about.bnef.com/white-papers/japans-likely-2030-energy-mix-gas-solar/>, accessed 30 June 2015.

⁴⁸⁷ *Asahi Shimbun*, “Industry group to postpone ‘pluthermal’ program again” 3 November 2014, see http://ajw.asahi.com/article/behind_news/social_affairs/AJ201411030039, accessed 29 May 2015.

produce plutonium for use in MOX fuel, was announced in October 2014.⁴⁸⁸ Originally scheduled to begin operation in 1997, construction of the plant began in 1993.

NRA Nuclear Safety Review

As of 19 June 2015, ten power companies that own nuclear reactors have applied to Japan's Nuclear Regulation Authority (NRA) for safety assessments of a total of 25 nuclear reactors (see Annex 2 for details). Compliance with the NRA guidelines, which came into force in July 2013⁴⁸⁹, is a requirement for utilities in their plans for reactor restart, along with "securing local public understanding" and approval from the Prefectural government and local town mayors. The new guidelines cover a range of issues related to the safety risks of nuclear power plants, including seismic and tsunami assessments and protective measures undertaken by utilities;⁴⁹⁰ fire protection; the management of the reactor in the event of a loss of offsite electrical power, cooling function, and accident management,⁴⁹¹ including prevention of hydrogen explosion; and the containment or filtered venting of radioactive materials into the environment. In the case of seismic assessment, reactors that are located above active faults would not be permitted to resume operations. Reactor owners are also required to assess their vulnerability to volcanic eruptions, which depending on scale of risk would not be permitted to operate or would be required to have safety countermeasures in place. Emergency evacuation plans are also required to be agreed with local communities within a 30 km radius of the nuclear plant. Upon completion of the preliminary approval of the safety case, the NRA is to hold a series of local public information meetings—an issue that has created controversy as to whether communities not immediately within the vicinity of a plant, but at risk in the event of a severe accident, would participate.

PWRs are the most advanced in the review process, based on the regulator's analysis that it is easier to secure them against seismic events than it is Boiling Water Reactors (BWRs). Reactors at Sendai, Tomari, Ikata and Genkai emerged in late 2013 as frontrunners for passing NRA safety guidelines and therefore restart. However, as of 1 July 2015, none of these reactors have resumed operation.

In March 2014, the NRA announced that the two Sendai reactors owned by Kyushu Electric would be a priority for safety screening.⁴⁹² On 10 September 2014, the NRA granted approval for the Basic Design of Sendai-1 and -2, the first stage in the review process prior to restart.⁴⁹³ The NRA

⁴⁸⁸ IPFM, "Launch of the Rokkasho reprocessing plant is delayed again", October 2014, see http://fissilematerials.org/blog/2014/10/launch_of_the_rokkasho_re.html, accessed 30 May 2015.

⁴⁸⁹ NRA, "New Regulatory Requirements for Light-Water Nuclear Power Plants—Outline—August 2013", see http://www.nsr.go.jp/english/e_news/data/13/0912.pdf, accessed 6 June 2014.

⁴⁹⁰ NRA, "Outline of New Regulatory Requirements For Light Water Nuclear Power Plants (Earthquakes and Tsunamis)", 3 April 2013, see http://www.nsr.go.jp/english/data/new_regulatory_requirements2.pdf, accessed 6 June 2013.

⁴⁹¹ NRA, "Outline of New Regulatory Requirements For Light Water Nuclear Power Plants (Severe Accident Measures)", 3 April 2013, see http://www.nsr.go.jp/english/data/new_regulatory_requirements3.pdf, accessed 6 June 2014.

⁴⁹² *Asahi Shimbun*, "NRA to designate nuclear plants for priority safety screenings", 20 February 2014, see <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201402200032>, accessed 30 May 2015.

⁴⁹³ JAIF, "NPPs filed application for restart – Sendai", see <http://www.jaif.or.jp/en/npps/sendai-1/>, accessed 1 June 2015.

received over 17,000 public comments during the one-month public comment review period.⁴⁹⁴ This was followed on 18 March 2015 by approval of the Construction Plan for the two Sendai reactors,⁴⁹⁵ and on 27 May 2015, of the reactors' Operational Safety Plan, which included emergency response plans in case of fire, flooding or other natural disasters, or a serious accident.⁴⁹⁶ Onsite inspection of equipment at the Sendai reactors began in March 2015 with the aim of completion prior to start-up of unit 1 in late July or August, and unit 2 in late September 2015. In early July 2015, Kyushu Electric announced it planned unit 1 to restart in August 2015, with no change for unit 2.⁴⁹⁷ These would be the first commercial reactors to operate since September 2013.

In addition to the NRA review process, restart of the Sendai reactors, as with all nuclear plants in Japan, requires approval by the community closest to the plant and by the Governor of the Prefecture. This is a political though not a legal requirement. Kagoshima Prefecture, the location of the Sendai reactors, was considered by the central government and nuclear industry as likely to witness least resistance to restart. However, during 2014, communities in Kagoshima expressed opposition to restart, in particular due to the perceived inadequacy of emergency planning procedures.⁴⁹⁸ Following approval on 28 October 2014 by Satsumasendai town council for restart,⁴⁹⁹ the Governor of Kagoshima on 7 November 2014 granted approval for restart, stating that "that there was no choice but to approve the resumption of the Sendai plant, after comprehensively taking into account various factors surrounding the situation."⁵⁰⁰ A legal injunction request against restart of the Sendai plant was turned down by the Kagoshima District Court on 22 April 2015.⁵⁰¹

However, other prospects for the resumption of additional reactors in 2015 receded further during the year. The two reactors expected to follow the Sendai plant were Kansai Electric

⁴⁹⁴ *Japan Times*, "Sendai nuclear plant safety approval attracts 17,000 public comments", 20 August 2014, see <http://www.japantimes.co.jp/news/2014/08/20/national/sendai-nuclear-plant-safety-approval-attracts-17000-public-comments/#.VWr3EiiaH6h>, accessed 30 May 2015.

⁴⁹⁵ NRA, "Approval of Operational Safety Programs for Kyushu Electric Power Company's Sendai Nuclear Power Station Units 1 and 2", 18 March 2015, see <https://www.nsr.go.jp/data/000100712.pdf>, accessed 30 May 2015.

⁴⁹⁶ NRA, "Approval of Operational Safety Programs for Kyushu Electric Power Company's Sendai Nuclear Power Station Units 1 and 2", 27 May 2015, see <https://www.nsr.go.jp/data/000108443.pdf>, accessed 30 May 2015.

⁴⁹⁷ *Reuters*, "Japan's first reactor restart delayed to August – Kyushu Electric", 2 June 2015, see <http://in.reuters.com/article/2015/06/02/japan-nuclear-restarts-idINKBN00I06K20150602>, accessed 2 June 2015.

⁴⁹⁸ *Bloomberg*, "Town divided after Sendai nuclear plant restart clears another hurdle", 29 October 2014, see <http://www.japantimes.co.jp/news/2014/10/29/national/social-issues/satsumasendai-gives-green-light-to-first-nuclear-power-plant-restart-despite-local-unease/>, accessed 29 May 2015.

⁴⁹⁹ *Reuters*, "UPDATE 1-Japan nuclear plant gets approval to restart, over 3 years after Fukushima", 28 October 2014, see <http://www.reuters.com/article/2014/10/28/japan-nuclear-idUSL4N0SN2WG20141028>, accessed 30 May 2015.

⁵⁰⁰ *Asahi Shimbun*, "Kagoshima governor OKs Sendai nuclear plant restart, 1st under new safety rules", 7 November 2014, see http://ajw.asahi.com/article/behind_news/politics/AJ201411070056, accessed 30 May 2015.

⁵⁰¹ JAIF, "Kagoshima District Court Rejects Request for Order Prohibiting Restart of Sendai-1 and -2 NPPs", 23 April 2015, see <http://www.jaif.or.jp/en/kagoshima-district-court-rejects-request-for-order-prohibiting-restart-of-sendai-1-and-2-npps/>, accessed 30 May 2015.

Power's Takahama-3 and -4, with Basic Design approval by the NRA on 12 February 2015.⁵⁰² The utility then planned restart by November 2015. However, in a decisive ruling, the Fukui District Court halted these plans with an injunction on 14 April 2015.⁵⁰³ The legal action initiated by local citizens focused on a number of issues including inadequate seismic resistance (Basic Earthquake Ground Motion Design), which had been raised by the utility from the original 370 Gal⁵⁰⁴ to 700 Gal. The Court ruled that “there is a danger of core damage due to loss of coolant function as a result of an earthquake less than 700 Gal, which is the basic earthquake ground motion.”⁵⁰⁵ The ruling thereby challenged the authority of the NRA, describing its safety standards as “lacking rationality”.⁵⁰⁶ The response of the NRA Chair, Shunichi Tanaka, was that Japanese regulatory standards are “internationally recognized as being the strictest in the world.”⁵⁰⁷ The court decision was subsequently strongly criticized by the Japanese government and nuclear industry. Kansai Electric filed an immediate appeal, which could be ruled upon within 6–12 months.

It is worth noting that Kansai Electric, in May 2014, had a similar injunction served by the same court on its Ohi units 3 and 4. That order has yet to be overturned in an appeal ruling as of 1 July 2015.⁵⁰⁸ The prospects for further legal obstacles to the Takahama reactors, including consideration by the Supreme Court, may see the restart process extend well into 2016 and beyond. Also, the Ohi plant is further behind in the NRA review process, even if the outstanding injunction is overturned on appeal.

During the past year, the issue of consultation with communities beyond the immediate host town and within 30 km of a nuclear plant, remained unresolved, despite growing demands.⁵⁰⁹ One of the most significant interventions came in December 2014, when the Union of Kansai Governments called on the Abe government to establish a legal framework that would grant local governments within 30 km of the Takahama plant a decision making role prior to any restart approval.⁵¹⁰

⁵⁰² JAIF, “NPPs filed application for restart – Takahama”, see <http://www.jaif.or.jp/en/npps/takahama-3/>, accessed 31 May 2015.

⁵⁰³ *Bloomberg*, “Court Bars Kansai Electric From Restarting Takahama Reactors”, 14 April 2015, see <http://www.bloomberg.com/news/articles/2015-04-14/court-bars-kansai-electric-from-restarting-reactors-at-takahama>, accessed 30 May 2015.

⁵⁰⁴ The Gal is a unit of acceleration and is defined as 1 cm per second squared.

⁵⁰⁵ Fukui District Court, “2014 (Heisei 26) No. 31 Petition Seeking a Provisional Disposition Order for an Injunction Barring Operation of Takahama Nuclear Power Station Units 3 and 4”, 14 April 2015.

⁵⁰⁶ WNA, “Court halts restart of Takahama reactors”, 14 April 2015, see <http://www.world-nuclear-news.org/RS-Court-halts-restart-of-Takahama-reactors-1404154.html>, accessed 30 May 2015.

⁵⁰⁷ JAIF, “Kansai EP Appeals Court Decision Prohibiting Restarts of Takahama NPPs”, 22 April 2015, see <http://www.jaif.or.jp/en/kansai-ep-appeals-court-decision-prohibiting-restarts-of-takahama-npps/>, accessed 31 May 2015.

⁵⁰⁸ *Financial Times*, “Japanese court blocks plan to restart nuclear plant, disrupt an already complicated and politically charged effort to restart”, 21 May 2014, see <http://www.ft.com/intl/cms/s/0/838d1532-e0c8-11e3-a934-00144feabdc0.html#axzz342oVrApW>, accessed 6 June 2014.

⁵⁰⁹ Nearly half of all heads of prefectures and municipalities near nuclear power plants say plant operators should be required to obtain their consent before restarting reactors, according to an Asahi Shimbun survey. See *Asahi Shimbun*, “Survey: Nearly half of local government leaders want a say in restarting nuclear reactors”, 4 November 2014, see https://ajw.asahi.com/article/behind_news/politics/AJ201411040025, accessed 31 May 2015.

⁵¹⁰ The Union of Kansai Governments represents 21 million people in 11 municipalities, headed by the Governors of Shiga, Hyogo, Wakayama, Osaka, Kyoto, Tottori, and Tokushima prefectures as well as Mayors from the cities of Kyoto, Osaka, Sakai, and Kobe. *WSJ*, “Western Japan Demands Legal Framework for Reactor

The third nuclear plant most advanced in the NRA review process is Ikata-3, owned by Shikoku Electric. As with the Sendai and Takahama reactors, application for review of the Ikata unit was submitted in July 2013. On 20 May 2015, the NRA announced it had completed a draft review for Ikata-3.⁵¹¹ The review decision will be considered by the Japan Atomic Energy Commission (JAEC) and the Ministry of Economy, Trade and Industry (METI) as well as being open for public comment. The first stage review approval is expected during summer 2015. Shikoku Electric is planning for restart during winter of 2015, but it is not likely before 2016.

There were further setbacks to the prospects for nuclear plant restarts in the past year. The Shika units 1 and 2, owned by Hokuriku Electric Power, had been under investigation for the presence of active seismic fault lines. On 13 May 2015, the NRA announced it could not rule out seismic faults running under the reactors.⁵¹² Hokuriku Electric Power contends that the faults do not run directly under the unit 2 reactor building, but rather cut across important piping for cooling reactor peripheral equipment. Under the post Fukushima safety guidelines, confirmation of active faults beneath Shika would require the nuclear plant to be shutdown permanently.

Despite these setbacks, the Abe government remains committed to the earliest possible restart of reactors, so the fact that not one reactor has resumed operations has led to considerable pressure being applied to the NRA to speed up the process. However, outside the NRA process, there are important external factors that will also 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 utility on the implications of restart or decommissioning;
- Local political and public opposition;
- Impact of electricity deregulation and intensified market competition.

In contrast to previous years,⁵¹³ eight nuclear power utilities announced in early 2015 that their aggregate profit/loss was shifting to a surplus. As noted by the Federation of Electric Power Companies (FEPCO) in terms of earnings, “the rise in electricity tariffs, which we asked our customers to shoulder, helped support profits despite a 3.3 percent decrease in sales”.⁵¹⁴ Additional reasons for returning to profit included the drop in global oil prices,⁵¹⁵ and the deferral of repair works for several years, which is not considered to be sustainable. However,

Decisions”, 7 January 2015, see <http://blogs.wsj.com/japanrealtime/2015/01/07/western-japan-demands-legal-framework-for-reactor-decisions/>, accessed 30 May 2015.

⁵¹¹ JAIF, “NRA Confirms Compatibility of Ikata-3’s Basic Safety Design with New Rules”, 21 May 2015, see <http://www.jaif.or.jp/en/nra-confirms-compatibility-of-ikata-3s-basic-safety-design-with-new-rules/>, accessed 30 May 2015.

⁵¹² JAIF, “NRA Expert Panel: ‘Possibility of Active Faults’ at Shika-1 and -2”, 13 May 2015, see <http://www.jaif.or.jp/en/nra-expert-panel-possibility-of-active-faults-at-shika-1-and-2>, accessed 31 May 2015.

⁵¹³ FEPCO, “Financial assessment of utilities”, Federation of Electric Power Companies, see http://www.fepc.or.jp/english/news/conference/_icsFiles/afiedfile/2014/03/19/kaiken_e_20140314.pdf, accessed 1 April 2014.

⁵¹⁴ FEPCO, “Summary of Press Conference Comments Made by Makoto Yagi, FEPC Chairman”, 20 February 2015, see http://www.fepc.or.jp/english/news/conference/_icsFiles/afiedfile/2015/03/13/kaiken_e_20150220.pdf, accessed 30 May 2015.

⁵¹⁵ *Reuters*, “Lower oil prices help Japan nuclear utilities return to profit”, 30 April 2015, see <http://www.reuters.com/article/2015/04/30/us-japan-nuclear-results-idUSKBN0NL0YN20150430>, accessed 30 May 2015.

Kansai Electric, along with Kyushu Electric, posted losses for 2014, with their electricity generation dependent on nuclear power by 43 and 42 percent respectively. Kansai Electric received government approval on 13 May 2015, to increase electricity prices for households by an average of 8.36 percent from 1 June 2015.⁵¹⁶ The utility had earlier announced a group net loss of 148.38 billion yen (US\$1.2 billion) for fiscal 2014, reportedly due to the cost of thermal power generation to replace nuclear power.

At the same time, however, Japanese utilities are insisting, and the government has granted and reinforced, the right to refuse cheaper 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. 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 competition. 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 utilities' almost complete suppression of Japanese windpower suggests they are concerned on this score. And as renewables continue to become cheaper and more ubiquitous, customers will be increasingly tempted by Japan's extremely high electricity prices to make and store their own electricity and to drop off the grid altogether, as is already happening, for example, in Hawai'i.

Critical Ageing and Life Extensions

A major determinant in the eventual number of reactors operated in Japan will be ageing, permanent decommissioning, and life extension decisions of nuclear power plants. In March 2014, two utilities announced that they would consider the decommissioning of two of their commercial reactors, which at the time were 39 and 40 years old respectively.⁵¹⁷ One year later, in March 2015, four of Japan's nuclear power companies submitted to the METI their plans for the permanent closure of five nuclear reactors.⁵¹⁸ This was a significant departure from the position of utilities prior to the Fukushima Daiichi nuclear accident, when they and METI were proposing operation of nuclear reactors beyond 60 years.⁵¹⁹ The announcement that five reactors

⁵¹⁶ *Japan Today*, "Kansai Electric to increase electricity rates for households by 8.36%", 13 May 2015, see <http://www.japantoday.com/category/national/view/kansai-electric-to-increase-electricity-rates-for-households-by-8-36>, accessed 31 May 2015.

⁵¹⁷ *Japan Times*, "Retiring Shimane reactor 'an option' ", 28 March 2014, see <http://www.japantimes.co.jp/news/2014/03/28/national/retiring-shimane-reactor-an-option/#.U5R60SiyRHx>, accessed 6 June 2014; and *Asahi Weekly*, "Kyushu Electric Power president 'decision by the fall on Genkai nuclear power plant' ", 23-28 April 2014, (in Japanese), see <http://www.asahi.com/articles/ASG4L6KP3G4LTIPE02L.html>, accessed 6 June 2014.

⁵¹⁸ *Asahi Shimbun*, "EDITORIAL: Decommissioning reactors should be step toward ending reliance on nuclear power", 18 March, see <http://ajw.asahi.com/article/views/editorial/AJ201503180044>, accessed 30 May 2015.

⁵¹⁹ T. Tsukada, Y. Nishiyama, et. al., "Research Programs On Aging Of Reactor Structural Materials At Japan Atomic Energy Research Institute", Japan Atomic Energy Research Institute, Japan, 2002, see http://www-pub.iaea.org/mtcd/publications/pdf/csp_021c/pdf/contents.pdf, accessed 31 May 2015; and T. Noda1, K. Tajima, et al., "Current Approaches To Nuclear Power Plant Life Management In Japan", Nuclear And Industrial Safety Agency (NISA), METI, Japan Nuclear Power Plant Life Engineering Center (PLEC), Japan Power Engineering And Inspection Corporation (JAPEIC), Japan, 2002, see http://www-pub.iaea.org/MTCD/publications/PDF/csp_021c/PDF/contents.pdf, accessed 31 May 2015.

(see Table 6) will be permanently shut down highlights the aging issues confronting Japan's nuclear power utilities.

Before the March 2011 nuclear accident at Fukushima Daiichi, Japan had 54 commercial nuclear reactors. As a result of the accident, all six reactor units at Fukushima Daiichi are to be decommissioned over the coming decades. The decision by Kansai Electric, Japan Atomic Power Company (JAPC), Chugoku Electric and Kyushu Electric to decommission five reactors reduces the total number of reactors officially “in operation” to 43. Tokyo Electric Power Company (TEPCO) has yet to announce the permanent closure of its four Fukushima Daini reactors located 12 km south of the Fukushima Daiichi site. However, given the devastation of the accident to Fukushima Prefecture, and resultant opposition to TEPCO and nuclear power in that Prefecture and wider Japan, there is no prospect that these reactors will restart.⁵²⁰ WNISR has taken them off the list of operating reactors in the first edition following 3/11.

Table 6: Japanese Reactors Officially Closed

Owner	Unit	Capacity	Grid Connection	Last Production	Age ⁵²¹
Kansai Electric	PWR Mihama Unit 1	340 MW	1970	2010	40 years
	PWR Mihama Unit 2	500 MW	1972	2011	40 years
Kyushu Electric	PWR Genkai Unit 1	559 MW	1975	2011	37 years
JAPC	BWR Tsuruga Unit 1	357 MW	1969	2011	41 years
Chugoku Electric	PWR Shimane Unit 1	460 MW	1974	2010	37 years

Sources: IAEA-PRIS, MSC, 2015

On 13 March 2015, METI's Agency for Natural Resources and Energy (ANRE) revised the accounting provisions in the Electricity Business Act, whereby the electric power companies can now calculate decommissioning costs in installments of up to ten years, instead of one-time as previously.⁵²² The five reactors to be decommissioned started operating between 40 and 46 years ago, with a total installed generating capacity of 2.2 GW, equal to 4.6 percent of Japan's nuclear capacity as of March 2011. Together with the six reactors at Fukushima Daiichi, this brings to 11 the number of commercial reactors officially to be permanently shut down since 3/11. Including Fukushima Daini, the total rises to 15 nuclear reactors. In total, at the very least, 6.7 GW of nuclear capacity has been removed from future operations, equal to a reduction of 14.1 percent of Japan's installed nuclear electric generating capacity prior to 3/11. This increases to 10.9 GW and 22.9 percent of installed nuclear capacity if the four Fukushima Daini reactors are included. The

⁵²⁰ Mitsuru Obe, “Tepco May Scrap Second Nuclear Plant”, *WSJ*, 4 July 2012, see <http://www.wsj.com/articles/SB10001424052702304141204577506531300365556>, accessed 31 May 2015.

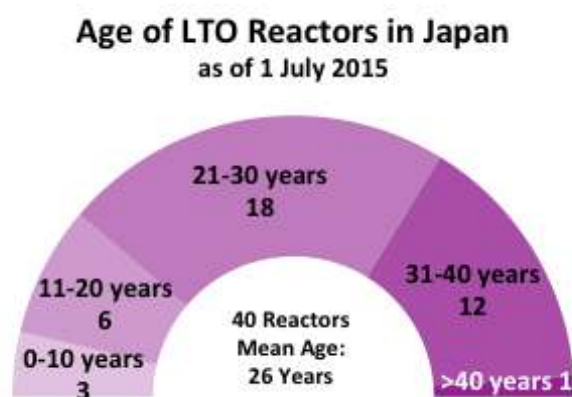
⁵²¹ Note that WNISR considers the age from first grid connection to final disconnection.

⁵²² JAIF, “Power Companies Select Aging NPPs to Concentrate Managerial Resources on Restarts”, 18 March 2015, see <http://www.jaif.or.jp/en/power-companies-select-aging-npps-to-concentrate-managerial-resources-on-restarts/>, accessed 30 May 2015.

permanent closure of five reactors reduces the average age of Japan's remaining nuclear fleet to 26 years as of July 2015, not including the Fukushima Daiichi reactors (see Figure 29).

Signaling a determination to continue operation of older reactors, Kansai Electric announced on 17 March 2015 that it had submitted applications to the Nuclear Regulation Authority (NRA) for the review of Mihama-3 and Takahama-1 and -2.⁵²³ The 780 MW PWR Mihama-3 is 39 years old, while Takahama units 1 and 2 are 41 and 42 years old respectively. On 14 November 2014, the NRA had granted a ten-year life extension for Takahama-1, and on 8 April to Takahama-2.⁵²⁴ Under the revised law on nuclear power plant regulations, the time limit for running a nuclear reactor is 40 years. This can be extended only once, by up to 20 years, if certain conditions are met. On 30 April 2015, Kansai Electric applied for a 20-year life extension for the two Takahama reactors.⁵²⁵ NRA requirements must be met by July 2016 if the plants are to be approved for life extension. In any case, Kansai Electric does not expect the two Takahama units to resume operations before November 2019, at the earliest, because further safety measures will need to be taken before restarting them.

Figure 29: Age Distribution of Japanese Reactor Fleet Currently in LTO



Sources: IAEA-PRIS, MSC, June 2015

Restart Prospects

As of 1 July 2015, all 40 remaining commercial reactors in Japan remain in Long Term Outage, with 25 reactors under review for restart by the NRA.⁵²⁶ At most two reactors will resume operation before the end of December 2015. At the same time, pressure to resume operations to generate electricity and income is clearly mounting. It is possible to speculate that many reactors over 40 years are unlikely to resume operations, and that given the length of time the NRA review

⁵²³ *Asahi Shimbun*, "More reactors to be decommissioned for a total of 5", 18 March 2015, see <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201503180040>, accessed 30 May 2015.

⁵²⁴ *WNN*, "Takahama 2 cleared for ten more years", 9 April 2015, see <http://www.world-nuclear-news.org/RS-Takahama-2-cleared-for-ten-more-years-0904154.html>, accessed 30 May 2015.

⁵²⁵ *Japan Times*, "Kepco asks for permission to run 40-year-old reactors for 20 more years", 1 May 2015, see <http://www.japantimes.co.jp/news/2015/05/01/national/kepco-applies-extend-operating-life-two-aging-reactors-fukui-20-years/#.VWthYyiaH6h>, accessed 31 May 2015.

⁵²⁶ M. Schneider, A. Froggatt, et.al., "WNISR 2014", 18 August 2014, see <http://www.worldnuclearreport.org/WNISR2014.html>, accessed 30 May 2015.

process is taking, it is possible that the eight reactors aged 35 years and more, out of the current 40, will not restart.

However, it is by no means certain that reactors will not operate beyond 40 years. Under existing policy, operators can apply for plant life extension for an additional 20 years beyond their 40-year limit.⁵²⁷ The NRA safety review process remains a frustration to both the Japanese Government and utilities. The replacement of two NRA Commissioners in September 2014, in particular the removal of Kunihiro Shimazaki, a seismologist considered by the utilities as an obstacle to early completion of safety reviews, and his replacement by Satoru Tanaka, who has close ties to utilities⁵²⁸ and favors continued nuclear power operation⁵²⁹ demonstrated the Abe government's determination to speed up the process of reactor restart. Further political pressure on the NRA may follow if plans to bring the NRA under direct Cabinet Office control are confirmed during 2015.⁵³⁰

Of the 25 reactors currently with applications outstanding before the NRA, not all will restart, with many questions and disagreements over seismic issues (including active fault status), and many plants far back in the review and screening queue. At the present rate of review, restart of 3–4 reactors each year from 2016 onwards remains a possibility but also a challenge. Even with final safety approval, and given other unresolved safety issues, there will be as many legal and political challenges to overcome as there are nuclear power plants.

In conclusion, it cannot be predicted with any certainty or precision what future percentage share of electricity in Japan will be nuclear-generated. A 22 percent share of electricity by 2030 would require the restart of all currently available 39 reactors (the 25 currently under NRA review, and those yet to be reviewed—not including the four at Fukushima Daiichi) plus complete construction and operation of the Shimane 3 Advanced Pressurized Water Reactor (APWR) and Ohma Advanced Boiling Water Reactor (ABWR), bringing the total to 41 reactors. This output is based on the near maximum actual generation by these reactors over their latest years of operation, generally during 2010–2011. Securing this percentage share, as planned by METI, looks impossible, while even a 15-percent share appears unlikely.

Pakistan operates three reactors that provided 4.6 TWh and 4.3 percent of the country's electricity in 2014, one percentage point below the historic maximum of 5.3 percent in 2012.

In early 2011, the Pakistan Atomic Energy Commission (PAEC) indicated a target capacity of 8.8 GW with 10 installed units by 2030.⁵³¹ Construction of two 315 MWe units started in 2011 at the Chasnupp site with the engagement of China Zhongyuan Engineering as the general

⁵²⁷ *Japan Times*, "Risky nuclear loophole", 21 January 2012, see <http://www.japantimes.co.jp/opinion/2012/01/21/editorials/risky-nuclear-loophole/#.U0Qq2Y6yT5o>, accessed 20 April 2014.

⁵²⁸ *Asahi Shimbun*, "Experts on nuclear panel got funds from power industry", 6 February 2012 see http://ajw.asahi.com/article/behind_news/social_affairs/AJ201202060056, accessed 9 June 2014.

⁵²⁹ *Japan Times*, "New NRA names revealed", 27 May 2014, see <http://www.japantimes.co.jp/news/2014/05/27/national/politics-diplomacy/new-nra-names-revealed/#.U4SrtyyRHw>, accessed 9 June 2014.

⁵³⁰ *Reuters*, "Japan nuclear regulator advisers fear loss of its 'essential' independence", 18 February 2015, see <http://uk.reuters.com/article/2015/02/18/japan-nuclear-concerns-idUKL4N0VS1ZH20150218>, accessed 30 May 2015.

⁵³¹ *Dawn.com*, "Ten Nuclear Power Plants Planned", 12 January 2011.

contractor and China Nuclear Industry No. 5 as the installer, with finance also coming from China. Grid connection was delayed and is currently planned for December 2016 (unit 3) and October 2017 (unit 4).⁵³²

The first unit at the Karachi site, KANUPP—a 125 MWe CANDU heavy water reactor—was first connected to the grid in October 1971 and is one of the oldest operating reactors in the world.

A groundbreaking ceremony was held on 26 November 2013 for the construction of two additional units of 1100 MW—first of a kind ACP1000 reactors—to be supplied by China National Nuclear Corporation on a turnkey basis. Construction is to be completed in 72 months,⁵³³ a very ambitious schedule.

The project has drawn unusually open and direct opposition from political leaders, local officials, and independent scientists, in particular because of the untested nature of the technology.⁵³⁴ The Karachi site is also part of one of the world's most densely populated areas, with 20 million people living in Karachi city, making mass evacuation in case of a major accident virtually impossible. Three physicists, well known international experts, have challenged the safety case of the project in a detailed high-profile contribution to *Newsweek Pakistan*.⁵³⁵ The Sindh High Court, on 16 October 2014, barred PAEC from continuing work on the two reactors without adhering to environmental laws. An unprecedented temporary stay order was granted by the Court on a petition filed by a group of citizens. The petitioners cited PAEC, the Pakistan Nuclear Regulatory Authority and the federal and the provincial environmental protection agencies as respondents for failing to obtain the necessary environmental clearances.⁵³⁶ In May 2015, however, the Sindh Environmental Protection Agency accorded approval to the project's environmental impact assessment (EIA) report and allowed its construction.⁵³⁷

International nuclear assistance has been practically impossible for most countries, given that Pakistan, like India, has not signed the Non-Proliferation Treaty (NPT) and does not accept full-scope safeguards, and is therefore currently unlikely to be granted the same exception as India to the Nuclear Suppliers Group (NSG)'s export rules. Pakistan also continues the expansion of its weapons material production capabilities.⁵³⁸

On the Korean Peninsula, the **Republic of Korea** (South Korea) operates 24 reactors. Nuclear power provided 149.2 TWh or 30.4 percent of the country's electricity in 2014, down from a maximum of 53.3 percent in 1987. One reactor, Wolsong-1, has not generated any power since 2012 and, according to WNISR's new criteria, was moved to the LTO category in WNISR2014. It restarted in June 2015 and was consequently moved back into the operating

⁵³² WNA, "Nuclear Power in Pakistan", Updated April 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Pakistan/>, accessed 12 June 2015.

⁵³³ WNN, "Pakistan breaks ground for coastal units", 3 December 2013, see http://www.world-nuclear-news.org/NN-Pakistan_breaks_ground_for_coastal_units-0312134.html, accessed 2 July 2014.

⁵³⁴ *NW*, "Opposition Emerges to Karachi Newbuild", 7 February 2014.

⁵³⁵ Pervez Hoodbhoy, et al., "The nuclear shadow over Karachi", *Newsweek Pakistan*, 17 March 2014.

⁵³⁶ For details and sources, see WNISR, "Court Rules Against Construction of Karachi Reactors in Pakistan", 19 October 2014, <http://www.worldnuclearreport.org/Court-Rules-Against-Construction.html>, accessed 22 May 2015.

⁵³⁷ Faiza Ilyas, "Sepa allows construction of nuclear power plants at Paradise Point", *The Dawn*, 20 June 2015.

⁵³⁸ See Institute for Science and International Security (ISIS) publications at <http://isis-online.org/isis-reports/imagery/category/pakistan/>, accessed 12 June 2015.

reactor category. In addition, five reactors were listed as under construction, of which three were scheduled for startup in 2014, but none achieved it. Shin-Wolsong-2 was finally connected to the grid in February 2015. Construction began on Shin-Wolsong-2 in 2008 and was completed in 2013, but planned operation was suspended following disclosure of falsified quality-control certificates (see below).⁵³⁹ In a first for the nuclear program of South Korea, on 12 June 2015, the Ministry of Trade, Industry and Energy announced that it would request the closure of the Kori unit 1 reactor by 18 June 2017, when the reactor will be 40 years old.⁵⁴⁰ Four days later the plant operator, Korea Hydro and Nuclear Power Co (KHNP) part of the KEPCO group, announced it would not apply for a life extension and the reactor would be shutdown.⁵⁴¹ The reactor has been at the centre of civic resistance to its continued operation, including from the nearby city of Busan.

South Korea's reactors have shown excellent performance in the past. After the annual load factor had dropped to a disappointing 72.1 percent (the level of India) in 2013, due to persisting component and quality control issues, it jumped back to 81.3 percent (+9.2 percentage points) in 2014.

Less than a month after 3/11, the Korea Electric Power Corporation (KEPCO) presented plans to double installed nuclear capacity to nearly 43 GW by 2030 and bring the nuclear share in the power generation to 59 percent.⁵⁴² However, observers saw a "dramatic political shift against nuclear power in the year since Fukushima".⁵⁴³ In 2012, for example, 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 reactor. 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. After his overwhelming re-election in June 2014, Mayor Park is also a prime candidate for the next presidential election. 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.⁵⁴⁴

In the past year, the Korean nuclear industry has moved to recover from major equipment falsification scandals and resultant forced shutdown of multiple reactor units.⁵⁴⁵ The disclosures beginning in December 2012 and subsequent investigations by the Nuclear Safety and Security Commission (NSSC), together with the impact of the Fukushima Daiichi accident, severely eroded public support for nuclear power. The ten-year-long falsification of thousands of quality control certificates for equipment installed in Korea Hydro and Nuclear Power (KHNP) reactors widened

⁵³⁹ WNISR, "South Korea: Shin-Wolsong-2 Grid Connected", 1 March 2015, see <http://www.worldnuclearreport.org/South-Korea-Shin-Wolsong-2-Grid.html>, accessed 4 June 2015.

⁵⁴⁰ *Korea Herald*, "South Korea to shut down oldest nuke reactor: Kori-1 will become the nation's 1st nuclear reactor to permanently close down", 12 June 2015, see <http://www.koreaherald.com/view.php?ud=20150612000846>, accessed 30 June 2015.

⁵⁴¹ Yonhap, "S. Korea to shut down oldest reactor in 2017", 16 June 2015, see <http://english.yonhapnews.co.kr/business/2015/06/16/0501000000AEN20150616008100320.html>, accessed 30 June 2015.

⁵⁴² Ki Hak Kim, "Fueling the Sustainable Future", 6 April 2011.

⁵⁴³ *NIW*, "South Korea: Growing Nuclear Skepticism", 23 March 2012.

⁵⁴⁴ For a list of SIEAC Members and background see <http://www.ieac.info/Seoul-International-Energy-Advisory-Council>, accessed 5 July 2015. SIEAC is coordinated by Mycle Schneider.

⁵⁴⁵ Korean Institute of Nuclear Safety (KINS), "CFSI (Counterfeit, Fraudulent, Suspect Item) Investigation", see <http://www.kins.re.kr/en/ourwork/cfsi.jsp>, accessed 4 June 2015.

in May 2013, when the NSSC, following information from an anonymous whistleblower, confirmed that test reports had been forged and that the test in fact failed under Loss-Of-Coolant-Accident (LOCA) conditions. The NSSC investigation found that safety-related control-command cabling with forged documentation had been installed at four of KHNP's reactors: Shin-Kori units 1 and 2 and Shin-Wolsong units 1 and 2.⁵⁴⁶ In May 2013, the four reactors were ordered to be shut down as a result of the falsification and, according to the NSCC, their failure to pass the LOCA test.⁵⁴⁷ Shin-Wolsong-2 was authorized for restart on 25 June 2013,⁵⁴⁸ while the other three remained shut down for most of 2013 (reflecting the reduced electricity share) and were approved for restart in early January 2014.⁵⁴⁹ Shin-Kori-3 and -4, as well as Shin-Wolsong-2, then all under construction, also had falsified quality-control documents and needed to replace the affected cables.⁵⁵⁰ 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. Relatively light penalties for falsifying nuclear safety documents or for corrupt revolving-door hiring were strengthened from 1 July 2015—though with a six-month phase-in period when first offenders will get just a warning.⁵⁵¹

Nuclear safety issues continued to affect reactor operation during and since 2014. In April 2015, the NSSC postponed, by several months, a decision on granting Shin-Kori-3 an operating license, following notification by General Electric that it would recall valve components installed in Shin-Kori units 3 and 4.⁵⁵² These first APR1400 reactors to be commissioned were scheduled for operation in 2014, but were also undergoing re-cabling following the quality-control scandals.⁵⁵³ In May 2015, the NSSC confirmed that KHNP and Doosan Heavy Industries had applied a substandard test for control-rod cabling assemblies at Shin-Kori-3, with follow-up quality-assurance investigations expected to take two to three months.⁵⁵⁴ The NSSC held multiple sessions during early 2015 addressing a range of safety issues at Shin-Kori-3, including design

⁵⁴⁶ WNA, "Reactor restart allays Korean power concerns", 10 June 2013, see http://www.world-nuclear-news.org/RS-Reactor_restart_allays_Korean_power_concerns-1006134.html, accessed 18 June 2014.

⁵⁴⁷ NSCC, "NSSC Approved The Resumption of Shinkori Unit 1.2 and Shinwolsong Unit 1", 2 January 2014, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=6240&pager.offset=10&board_no=501, accessed 18 June 2014.

⁵⁴⁸ WNA, "Another Korean reactor cleared for restart", 27 June 2013, see http://www.world-nuclear-news.org/RS-Another_Korean_reactor_cleared_for_restart-2706135.html, accessed 18 June 2014.

⁵⁴⁹ Reuters, "South Korea cuts future reliance on nuclear power, but new plants likely", 13 January 2014, see <http://www.reuters.com/article/2014/01/14/us-nuclear-korea-idUSBREA0D06G20140114>, accessed 18 June 2014.

⁵⁵⁰ NSSC, "NSSC Confirms Fake Test Reports of Safety-Class Control Cables", 29 May 2013, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=3884, accessed 18 June 2014.

⁵⁵¹ NIW, "South Korea", 3 July 2015.

⁵⁵² NSSC, "NSSC Decided to Put Off Deliberation on the Bill on Operation License of the Shinkori Unit 3", 39th Meeting of the Nuclear Safety and Security Commission, 23 April 2015, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=23309, accessed 3 May 2015.

⁵⁵³ Powermag, "Two Years Later, S. Korea Finally Puts Shin-Wolsong 2 Online", 1 April 2015, see <http://www.powermag.com/two-years-later-s-korea-finally-puts-shin-wolsong-2-online/>, accessed 4 June 2015.

⁵⁵⁴ NSSC, "NSSC ordered to re-conduct QA tests on the part of the cable assemblies of the Shinkori Unit 3", 1 May 2015, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=23454&pager.offset=0&board_no=501, accessed 2 June 2015.

comparisons with the nation's existing fleet, the operator's technical ability, and cybersecurity of instrumentation and control systems. License review for Shin-Kori-3 had begun in 2011.⁵⁵⁵

After a 14-hour marathon session, a majority of the Nuclear Safety and Security Commission (NSSC) voted on 27 February 2015 in favor of plant life extension for the 32-year-old Wolsung-1 pressurized heavy water reactor.⁵⁵⁶ Two of the nine commissioners abstaining from voting. In two previous meetings, the NSSC had failed to reach agreement on granting approval. The operator of the CANDU-6 reactor, KHNP, replaced all pressure tubes and calandria tubes during extended shutdown between 2009 and 2011. The reactor has been shutdown since November 2012 when its operating license expired. The Korea Institute of Nuclear Safety (KINS) concluded in October 2014 that the reactor could operate until 2022, and that it complied with the revised Nuclear Safety Act, including against major natural disasters. KHNP has invested 560 billion won (US\$59 million) in upgrades.⁵⁵⁷

Operation of Wolsung-1 has been a major controversy over recent years, in particular following the Fukushima Daiichi accident, with uncertainty as to whether it would have its license extended. Over the 30 years since the reactor started operating in 1983, the nuclear plant was shut down 39 times due to malfunctions.⁵⁵⁸ The main political opposition party New Politics Alliance for Democracy (NPAD) stated the decision was unacceptable in terms of public safety, with recent polling in Gyeongju showing 60 percent of those surveyed wanted the reactor permanently closed.⁵⁵⁹

Despite the government's commitment to continuing nuclear power growth, public opposition has also continued. For example, all political candidates in the June 2014 elections in Pusan, the closest major city to the Shin-Kori nuclear plant, called for the closure of unit 1, which has been plagued with safety issues, and whose license expires in 2017.⁵⁶⁰ The Shin-Kori nuclear plant remained controversial during the last year, with three fires at the site—the latest in the turbine building of unit 2—leading to growing demands for no life extension of units 1 or 2. The operating license expires in 2023.⁵⁶¹ And hefty financial incentives to nuclear host communities are losing their attractiveness.⁵⁶²

⁵⁵⁵ NSSC, "The 37th Meeting Was Held to Deliberate Issuance of Operation License of the Shinkori Unit 3", 26 March 2015, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=22508&pager.offset=0&board_no=501, accessed 3 June 2015.

⁵⁵⁶ NSSC, "The Commissioners Decided to Approve Continued Operation of Wolsong Unit 1 in the 35th Meeting", 27 February 2015, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=17977&pager.offset=10&board_no=501, accessed 2 June 2015.

⁵⁵⁷ *Korea Herald*, "Restart of aging nuclear reactor sparks controversy", 27 February 2015, see <http://www.koreaherald.com/view.php?ud=20150227000740>, accessed 4 June 2015.

⁵⁵⁸ *Ibidem*.

⁵⁵⁹ *Yonhap New Agency*, " (3rd LD) Nuclear watchdog extends operation of 32-year-old reactor", 27 February 2015, see <http://english.yonhapnews.co.kr/national/2015/02/27/52/0302000000AEN20150227000453315F.html>, accessed 4 June 2015.

⁵⁶⁰ *Shanghai Daily*, "S.Korean activists warn of nuclear disaster from oldest reactor", 2 June 2014, see http://www.shanghaidaily.com/article/article_xinhua.aspx?id=221967, accessed 3 June 2014.

⁵⁶¹ *Hankyoreh*, "Smoke at Kori reactor the latest case of danger at a nuclear plant", 30 May 2015, see http://english.hani.co.kr/arti/english_edition/e_national/693529.html, accessed 4 June 2015.

⁵⁶² *NIW*, "South Korea: How Much to Pay Host Communities?", 3 July 2015.

The political consequences of the multiple scandals surrounding the nuclear sector led to a government-appointed study group's recommending in October 2013 a reduction in projected nuclear electricity share to 22–29 percent by 2035.⁵⁶³ The head of the study group reported that “the implementation of energy policy doesn't just involve the government now, it's become an increasingly important and extremely sensitive issue for each and every citizen. Our suggestion is to set the direction in the policy for social consent, as there are huge social conflicts.”⁵⁶⁴

In the end, the government's draft energy paper released in December 2013 opted for the higher 29 percent option by 2035, below both the 30 percent achieved in 2012 and the 41 percent long-term goal set in the previous long-term plan of 2008.⁵⁶⁵ The government's draft Seventh Basic Long-term Power Development Plan of electricity supply and demand covering the period of 2015 to 2029 reportedly envisages the operation of 36 reactors by 2029. “But it remains to be seen whether the plan will get approval amid intensifying opposition from anti-nuclear politicians and activists”, commented *Korea Times*.⁵⁶⁶

After five years of negotiation, in April 2015 it was announced that the United States and South Korea had reached a provisional agreement for the extension of peaceful nuclear cooperation between the two nations.⁵⁶⁷ The new pact, signed on 25 June 2015,⁵⁶⁸ called the “123 Agreement” after Section 123 of the U.S. Atomic Energy Act (AEA), will replace the existing 1974 agreement, which was due to expire in 2014 but was extended while negotiations continued. Major obstacles to reaching agreement related to South Korean efforts to secure the right to develop the entire fuel chain, in particular uranium enrichment and spent fuel reprocessing, both excluded from the previous agreement. The agreement, does not include the right of South Korea to indigenous development of enrichment or reprocessing, however, in a major concession, it does give the right to export spent fuel for reprocessing, and specifically to France, under advance programmatic approval.⁵⁶⁹ The return of plutonium Mixed Oxide Fuel (MOX) would require case by case U.S. approval.⁵⁷⁰ Such a concession brings the agreement between the two nations on to a level with the U.S. agreement with Japan prior to 1988. The new agreement, when finalized, will require U.S. Congressional approval.

⁵⁶³ *Bloomberg News* and *Reuters*, “South Korea pours cold water on nuclear fuel”, 13 October 2013, see <http://www.thenational.ae/business/energy/south-korea-pours-cold-water-on-nuclear-fuel>, accessed 18 June 2014.

⁵⁶⁴ *Ibidem*.

⁵⁶⁵ *Reuters*, “South Korea cuts future reliance on nuclear power, but new plants likely”, 13 January 2014, see <http://www.reuters.com/article/2014/01/14/us-nuclear-korea-idUSBREA0D06G20140114>, accessed 5 June 2015.

⁵⁶⁶ *Korea Times*, “Korea to add two more nuclear reactors”, 1 June 2015, see http://koreatimes.co.kr/www/news/biz/2015/06/602_179958.html, accessed 5 June 2015.

⁵⁶⁷ *WSJ*, “U.S., South Korea Reach Revised Nuclear Deal The agreement stops short of allowing Seoul to enrich uranium or reprocess spent nuclear fuel”, 22 April 2015, see <http://www.wsj.com/articles/u-s-south-korea-reach-revised-nuclear-deal-1429705290>, accessed 4 June 2015.

⁵⁶⁸ *Korea Herald*, “S. Korea, U.S. formally sign civil nuclear energy cooperation pact”, 16 June 2015, see http://www.koreatimes.co.kr/www/news/nation/2015/06/116_180943.html, accessed 30 June 2015

⁵⁶⁹ Mark Fitzpatrick, “South Korea nuclear cooperation deal not as simple as 123”, International Institute for Strategic Studies (IISS), see <https://www.iiss.org/en/politics%20and%20strategy/blogsections/2015-932e/april-ea11/south-korea-nuclear-cooperation-deal-not-as-simple-as-123-a371>, accessed 4 June 2015.

⁵⁷⁰ International Panel on Fissile Materials (IPFM), “United States grants advance consents rights to Korea for overseas reprocessing”, 25 June 2015, see http://fissilematerials.org/blog/2015/06/united_states_grants_adv.html, accessed 9 July 2015.

Taiwan operates six reactors at three sites—Chinshan, Kuosheng and Maanshan. These generated a record 40.8 TWh in 2014, providing 18.9 percent of the country's electricity (compared with its maximum share of 41 percent in 1988). Among the countries that operate more than four units, Taiwan achieved the highest load factor for 2014, 93.7 percent (2 percentage points higher than in 2013).

Two General Electric 1300 MW Advanced Boiling Water Reactors (ABWR) have been listed as “under construction” at Lungmen, near Taipei, since 1998 and 1999 respectively. Their construction had been delayed multiple times. According to the Atomic Energy Council, as of the end of March 2014, Unit 1 of Lungmen construction was 97.7 percent complete,⁵⁷¹ while Unit 2 was 91 percent complete. The plant is estimated to have cost just under US\$10 billion so far.⁵⁷² After multiple delays, rising costs, and large-scale public and political opposition, on 28 April 2014, Premier Jiang Yi-huah announced that Lungmen unit 1 will be mothballed after the completion of safety checks, while work on unit 2 at the site was to stop. With the official freeze of construction, WNISR took the units off the listing in 2014.

The government sponsored a “National Energy Conference”, postponed from September 2014 to 26–27 January 2015. President Ma Ying-jeou declared in the opening statement: “The country can ill-afford to give up any form of energy, whether it is fossil fuel, natural gas, nuclear, solar or wind”.⁵⁷³ Reportedly, he further stated: “Nuclear plants must be safe and reliable even as the nation seeks to wean itself from a dependence on nuclear power and move toward a low-carbon environment and green energy.” The ultimate goal, he added, is for “a nuclear-free homeland.”⁵⁷⁴ In March 2015, marking the fourth anniversary of the beginning of the Fukushima disaster, an estimated 45,000 took to the streets in several Taiwanese cities to oppose the further use of nuclear power and a new project to send spent fuel for reprocessing to France.⁵⁷⁵ In May 2015, President Ma stated: “We can also ensure nuclear safety, reducing relying on nuclear power, and create a green energy and low carbon environment gradually, become a nuclear free country.”⁵⁷⁶

⁵⁷¹ Planning Department, “Status and Challenges of Nuclear Power in Taiwan”, Atomic Energy Council, April 2014, see <http://www.aec.gov.tw/english/whatsnew/files/20140506-5.pdf>, accessed 15 June 2014.

⁵⁷² WNA, “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 15 June 2014.

⁵⁷³ *Taiwan Today*, “Ma opens national energy conference”, 27 January 2015, see <http://taiwantoday.tw/ct.asp?xItem=226828&ctNode=421>, accessed, 23 May 2015.

⁵⁷⁴ *Taiwan News*, “President, Premier speak to open National Energy Conference”, 26 January 2015, see http://www.taiwannews.com.tw/etn/news_content.php?id=2678320, accessed 23 May 2015.

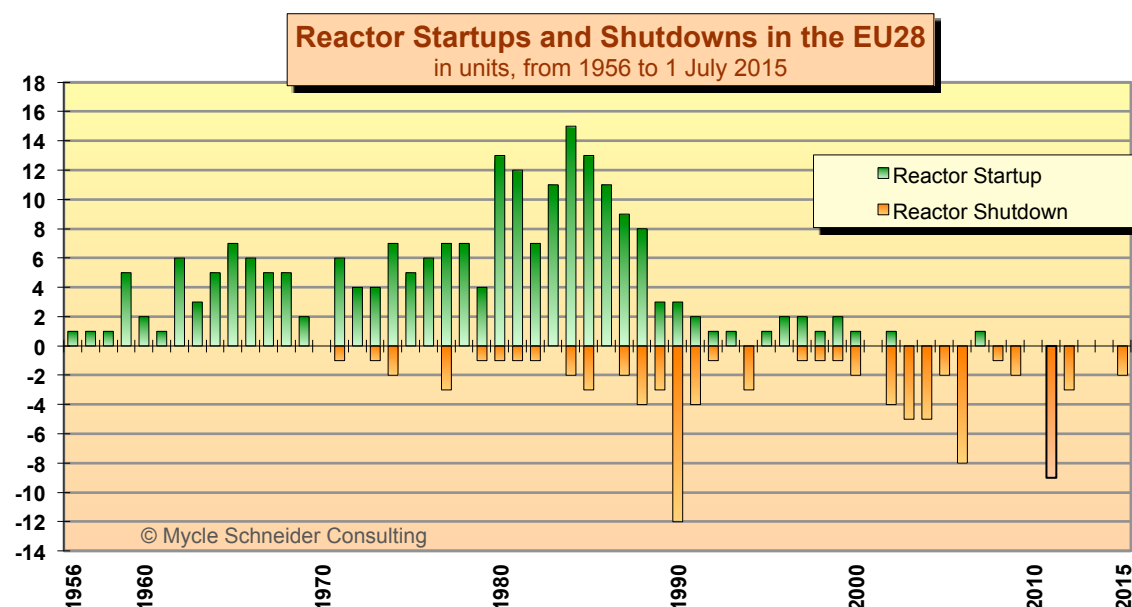
⁵⁷⁵ *The Sunday Times*, “45,000 people join anti-nuclear rallies in Taiwan”, 14 March 2015, see www.straitstimes.com/news/asia/east-asia/story/45000-people-join-anti-nuclear-rallies-taiwan-20150314, accessed 23 May 2015.

⁵⁷⁶ AA Energy News Terminal, “Taiwan to use more green energy”, 18 May 2015, see <http://www.aaenergyterminal.com/newsRegion.php?newsid=5371114>, accessed 23 May 2015.

European Union (EU28) and Switzerland

The European Union 28 member states (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).

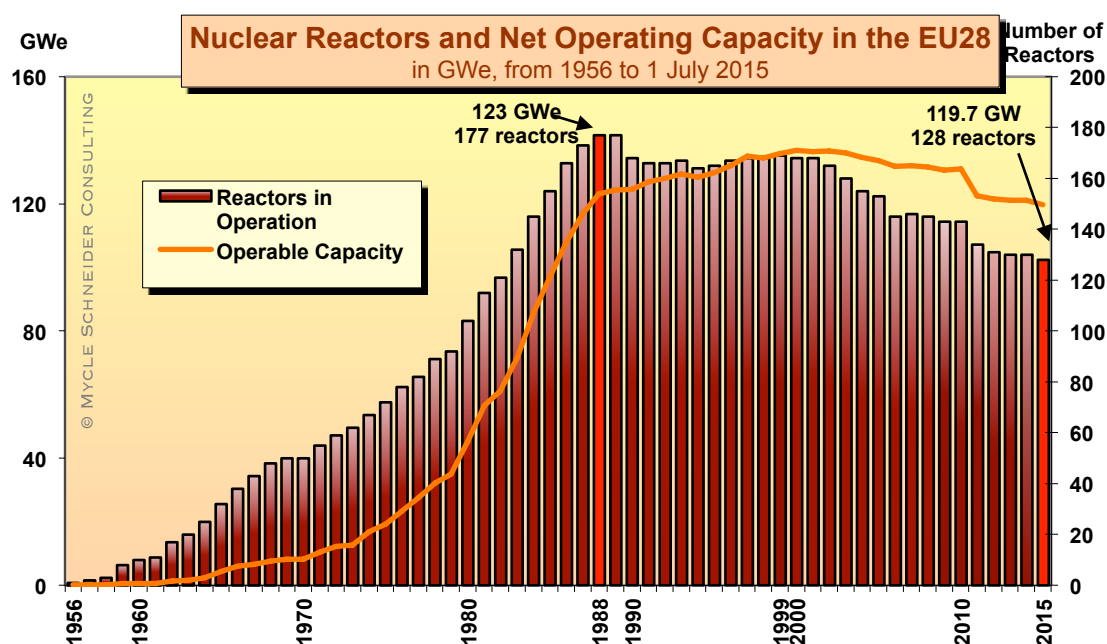
Figure 30: Nuclear Reactors Startups and Shutdowns in the EU28, 1956–2015



Sources: IAEA-PRIS, MSC, July 2015

The region has not had any significant building activity since the 1990s. In the first half of 2015, two reactors were shut down, Doel-1 in Belgium and Grafenrheinfeld in Germany (see Figure 30).

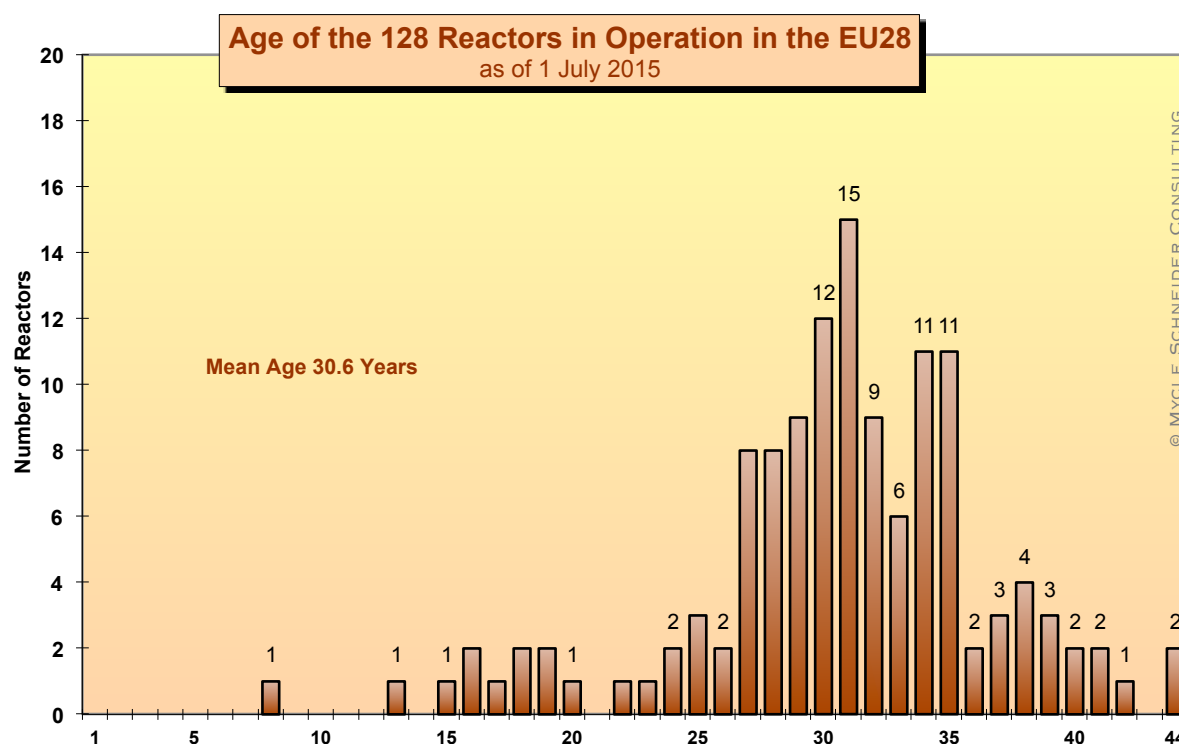
Figure 31: Nuclear Reactors and Net Operating Capacity in the EU28, 1956–2015



Source: IAEA-PRIS, MSC, July 2015

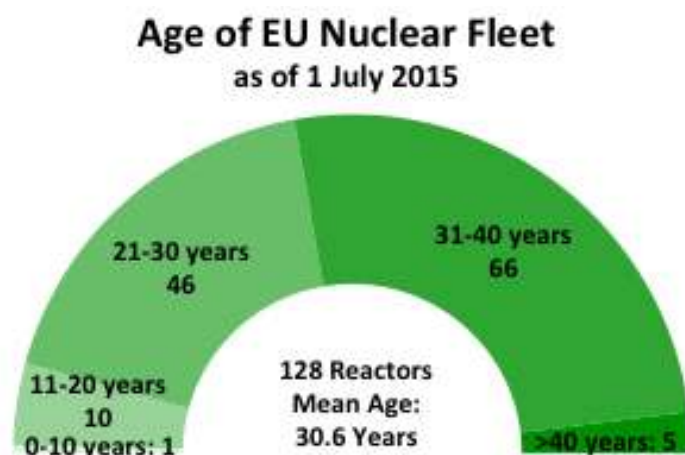
In July 2015, half of the 28 countries in the enlarged EU operated 128 reactors—about one-third of the world total—15 fewer than before the Fukushima events and almost one-quarter below the historic maximum of 177 units in 1989 (see Figure 31). The vast majority of the facilities, 109 units or 85 percent, are located in eight of the western countries, and only 19 are in the six newer member states with nuclear power.

Figure 32: Age Pyramid of the 128 Nuclear Reactors Operated in the EU28



Sources: IAEA-PRIS, MSC, July 2015

Figure 33: Age Distribution of the EU28 Reactor Fleet



Sources: IAEA-PRIS, MSC, 2015

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-2015 stands at 30.6 years (see Figures 32 and 33). The age distribution shows that now over half—71 of 128—of the EU's nuclear reactors have been in operation for over 31 years.

Western Europe

As of July 2015, 109 nuclear power reactors operated in the EU15, 48 units fewer than in the peak years of 1988/89.

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 elsewhere in the report). These are the first construction starts in the region since building began on the French Civaux-2 unit in 1991. Apart from the French projects and the Sizewell-B reactor in the U.K. (ordered in 1987), until the reactor project in Finland, no new reactor order had been placed in Western Europe since 1980.

The following section provides a short overview by country (in alphabetical order).

Belgium operates six pressurized-water reactors and, for many years, had the world's second highest share of nuclear in its power mix, behind France. Due to technical issues described below, it dropped to 47.5 percent in 2014—less than 50 percent for the first time since 1983⁵⁷⁷ (the maximum was 67.2 percent in 1986). The nuclear plants generated 32.09 TWh in 2014 compared to their highest output of 46.7 TWh in 1999. Consequently, the annual load factor dropped by 14 percentage points to 67 percent in 2014.

Doel-1, the country's seventh reactor, was shut down as planned at the end of its license period on 15 February 2015. However, on 18 June 2015, the Belgian Parliament voted to extend the operating licenses of Doel-1 and -2 by ten years.⁵⁷⁸ This lifetime extension remains subject to approval by the nuclear safety authorities. It also does not put into question the nuclear phase-out target of 2025: in 2002, nuclear phase-out legislation required the shutdown of all Belgium's nuclear plants after 40 years, so based on their start-up dates, plants would be shut down between 2015 and 2025. Following Fukushima, the phase-out legislation was left in place even though GDF-Suez, that operates all seven PWRs in Belgium, was lobbying hard to postpone it via an extension of “at least 10 years”.⁵⁷⁹ In December 2013, the phase-out legislation was finally amended for the first time,⁵⁸⁰ granting a 10-year extension for the Tihange-1 reactor while

⁵⁷⁷ World Bank, quoted in Perspective Monde, see

<http://perspective.usherbrooke.ca/bilan/servlet/BMTendanceStatPays?langue=fr&codePays=BEL&codeStat=EG.ELC.NUCL.ZS&codeStat2=x>, accessed 25 May 2015.

⁵⁷⁸ RTBF, “Nucléaire: la Chambre vote la prolongation de Doel 1 et Doel 2”, 18 June 2015, see

http://www.rtbf.be/info/belgique/dossier/gouvernement-michel/detail_nucleaire-apres-70-heures-de-debat-la-chambre-approuvera-la-prolongation-ce-jeudi?id=9009773, accessed 20 June 2015.

⁵⁷⁹ Gérard Mestrallet, et al., “Nuclear in Belgium: recent developments”, GDF Suez, 4 November 2011.

⁵⁸⁰ *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.

imposing an additional operating tax that effectively removed about 70 percent of its profit.⁵⁸¹ The other shutdown dates were confirmed (see Table 7) 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 numbers of hydrogen-induced crack indications in the pressure vessels of Doel-3 and Tihange-2, with respectively over 8,000 and 2,000 previously undetected defects. After several months of analysis, the Belgian safety authority FANC asked the operator to carry out a specific test program prior to any restart decision. However, in late January 2013, AIB-Vinçotte, an international quality-control company based in Belgium working on behalf of the FANC, stated that “some uncertainty about the representativity of the test program for the actual reactor pressure vessel shells cannot be excluded”.⁵⁸²

Table 7: Closure Dates for Belgian Nuclear Reactors 2015–2025

Reactor Name (Net Capacity)	First Grid Connection	End of License (Latest Closure Date)
Doel-1 (433 MW)	1974	shut down on 15 February 2015, subject to 10-year lifetime extension procedure
Doel-2 (433 MW)	1975	1 December 2015, subject to 10-year lifetime extension procedure
Doel-3 (1006 MW)	1982	1 October 2022
Tihange-2 (1008 MW)	1982	1 February 2023
Doel-4 (1039 MW)	1985	1 July 2025
Tihange-3 (1046 MW)	1985	1 September 2025
Tihange-1 (962 MW)	1975	1 October 2025

Sources: Belgian Law of 18 December 2013; Electrabel/GDF-Suez, 2014⁵⁸³

An independent assessment concluded that “the restart of the two power plants has to be considered as hazardous”.⁵⁸⁴ However, on 17 May 2013, FANC issued a statement saying that it “considers it safe to restart the Doel-3 and Tihange-2 reactor units”.⁵⁸⁵ The units restarted in spite

⁵⁸¹ Melchior Wathelet, “Avec la réserve stratégique, Melchior Wathelet finalise l’exécution de son plan”, Energy Minister, 16 December 2013, see <http://wathelet.belgium.be/fr/2013/12/16/avec-la-reserve-strategique-melchior-wathelet-finalise-lexecution-de-son-plan/>, accessed 3 July 2014.

⁵⁸² AIB-Vinçotte, “Synthesis Report Doel165”, 28 January 2013.

⁵⁸³ Electrabel/GDF-Suez, “News from the nuclear plants”, see <https://www.electrabel.com/en/corporate/nuclear-power-plant-belgium/doel-tihange/news>, accessed 3 July 2014.

⁵⁸⁴ Ilse Tweer, “Flawed Reactor Pressure Vessels in Belgian Nuclear Plants Doel-3 and Tihange-2”, Materials Scientist and Consultant, Report commissioned by the Greens/EFA Group in the European Parliament, March 2013, see <http://www.greens-efa.eu/fileadmin/dam/Documents/Studies/Flawed%20Reactor%20Pressure%20Vessels.pdf>, accessed 1 June 2013.

⁵⁸⁵ FANC, “FANC experts give positive opinion on restart of Doel 3 & Tihange 2 reactor units”, 17 May 2013, see <http://www.fanc.fgov.be/GED/00000000/3400/3430.pdf>, accessed 1 June 2013.

of the serious concerns by a range of scientists, and reached full capacity respectively on 9 and 11 June 2013. Then on 25 March 2014, Electrabel/GDF-Suez announced the immediate shutdown of the Doel-3 and Tihange-2 reactors, declared as “anticipating planned outages”, respectively over one month and two months ahead of schedule.⁵⁸⁶ The decision was taken after one of the tests “related to the mechanical strength of a sample analogue to the composition of the concerned vessels did not deliver results in line with experts expectations”. FANC issued a statement:

The results of these tests indicate that a mechanical property (fracture toughness) of the material is more strongly influenced by irradiation than experts had expected. Additional testing and research are necessary to interpret and assess these unexpected results.⁵⁸⁷

Additional inspections have raised the number of identified defects to over 13,000 in the Doel-3 pressure vessel (up to 40 per dm³, up to 2–3 cm long, down to a depth of 12 cm).⁵⁸⁸ In April 2015, under the auspices of FANC, an International Review Board assessed the results of additional inspections and tests carried out by Electrabel. Prior to potential restart of the two units, FANC requests that “Electrabel shall first submit a Safety Case to the FANC in which it convincingly demonstrates that the presence of hydrogen flakes in the walls of the reactor pressure vessel (RPV) does not compromise its structural integrity”. That Safety Case will then be thoroughly analysed by all parties involved before FANC takes any decision whether the reactors are allowed to restart. This process “will take another few months”.⁵⁸⁹ On 13 May 2015, Electrabel/GDF-Suez stated that “the period of unavailability of Doel-3 and Tihange-2 is pushed to November 1st, 2015”, following decisions by the regulator about the review process of the pressure vessel issue.⁵⁹⁰ The fate of the two units remains uncertain and has potentially serious generic implications for the aging of nuclear power plants everywhere. Some scientists involved in the research on the issue concluded that “meticulous inspections [are] needed, worldwide” (underlined in the original).⁵⁹¹

The Belgian government did not wait for the outcome of the Doel-3/Tihange-2 issue and decided in March 2015 to draft legislation to extend the lifetime of Doel-1 and Doel-2 by ten years to 2025.⁵⁹² The initiative is highly controversial and triggered lengthy parliamentary debates. According to the highest administrative court, the Conseil d'Etat, a full-scale licensing procedure is necessary in the case of Doel-1, as it no longer has an operating license that could simply be extended. This would lead to lengthy procedures and rule out the availability of the reactor over

⁵⁸⁶ Electrabel/GDF-Suez, “Anticipating planned outages of Doel 3 and Tihange 2 reactors”, 25 March 2014, see <https://www.electrabel.com/en/corporate/article?article=14-03-25-anticipating-planned-outages-doel3-tihange2-reactors>, accessed 3 July 2014.

⁵⁸⁷ FANC, “Doel 3 and Tihange 2 still temporally shut down until further notice”, 1 July 2014, see <http://www.fanc.fgov.be/GED/00000000/3600/3657.pdf>, accessed 3 July 2014.

⁵⁸⁸ Walter F. Bogaerts, et al., “Hydrogen-induced Damage in PWR Reactor Pressure Vessels”, presentation at Corrosion 2015—Research in Progress Symposium, Dallas, USA, 15–19 March 2015.

⁵⁸⁹ FANC, “Doel 3/Tihange 2: next steps of the review process”, 7 May 2015, see <http://www.fanc.fgov.be/fr/news/doel-3/tihange-2-next-steps-of-the-review-process/766.aspx>, accessed 25 May 2015.

⁵⁹⁰ Electrabel/GDF-Suez, “Period of unavailability of Doel 3 and Tihange 2 reviewed”, Press Release, 13 May 2015, see <https://www.electrabel.com/en/corporate/article?article=15-05-13-doel3-tihange2>, accessed 25 May 2015.

⁵⁹¹ Walter F. Bogaerts, op.cit.

⁵⁹² Minister of Energy, Environment and Sustainable Development, “Measures which intend to assure the security of supply in Belgium”, Press Release, 5 March 2015, see <http://www.marghem.belgium.be/en/measures-which-intend-assure-security-supply-belgium>, accessed 25 May 2015.

the coming winter period,⁵⁹³ although short-term supply security was a key driver to table the legislation in the first place.

Finland operates four units that supplied a record 22.65 TWh or 34.65 percent of its electricity in 2014 (with a maximum of 38.4 percent in 1986). The country also achieved the world's fourth highest annual load factor for 2014 (93.4 percent) and holds the second highest lifetime load factor (87.5 percent, identical to Germany), behind Romania (whose CANDU reactors refuel online, increasing annual availability). 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.

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 Siemens⁵⁹⁴, 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, its reactor-building division will probably be integrated into a subsidiary majority-owned by state utility EDF and open to third-party investment. However, EDF has made it clear that it will not take over the billions of euros' liabilities linked to the costly Finnish AREVA adventure.⁵⁹⁵ Responsibility for those liabilities remains unclear.

The OL3 project was financed essentially on the balance sheets of the country'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 “take-or-pay contract”.

Construction started in August 2005 at Olkiluoto on the west coast. The project is about nine years behind schedule and is now about three times over budget (see also Chapter on Generation III Reactor Delays). As of October 2014, the plant was expected to start up at the end of 2018⁵⁹⁶. The latest official cost estimate from early 2014, no doubt already an underestimate, had been raised to €8.5 billion (US\$11.6 billion). It remains unclear who will cover the additional cost: the vendors and TVO blame each other and are in litigation. TVO is requesting €2.3 billion (US\$2.9 billion) in compensation from AREVA until 2018.⁵⁹⁷ In November 2014, AREVA has updated its own claims to €3.4 billion (US\$4.2 billion), a claim considered by TVO as “without merit”.⁵⁹⁸ And even if it wins this dispute, TVO might be unable to recover the obligation. In May 2015, credit-rating agency Standard & Poor's downgraded TVO to BBB-, just one notch above

⁵⁹³ *Le Soir*, “Doel 1 ne peut pas rouvrir cette année”, 23 April 2015, see <http://www.lesoir.be/859751/article/actualite/belgique/2015-04-23/doel-1-ne-peut-pas-rouvrir-cette-annee>, accessed 25 May 2015.

⁵⁹⁴ Siemens quit the consortium in March 2011 and announced in September 2011 that it was abandoning the nuclear sector entirely.

⁵⁹⁵ *Le Monde*, “Areva, chantier de démantèlement”, 13 May 2015, see http://lemonde.fr/economie/article/2015/05/19/edf-pose-ses-conditions-au-rachat-des-reacteurs-d-areva_4636164_3234.html, accessed 25 May 2015.

⁵⁹⁶ TVO, “TVO updated its estimate in the ICC arbitration proceedings concerning the delay of OL3 project”, 22 October 2014.

⁵⁹⁷ Ibidem.

⁵⁹⁸ TVO, “Report of the Board of Directors and Financial Statements 2014”, February 2014, see http://www.tvo.fi/uploads/files/Sijoittajat/Vuosijulkaisut/TVO_Report_of_the_board_of_directors_and_financial_statements_2014_final.pdf, accessed 25 May 2015.

“junk”, with a negative outlook, “owing to continued deterioration in market prices and increased risk of higher production costs related to TVO's third nuclear power plant, Olkiluoto-3”.⁵⁹⁹

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.

The problems produced by the OL3 project have not prevented 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”.⁶⁰⁰ The decision was ratified by the Finnish Parliament on 1 July 2010. In May 2014, TVO requested a five-year extension on the time allowed to submit the construction license, with a subsequent revision of the estimated startup of the reactor to the “latter half of the 2020’s”.⁶⁰¹ The Government refused to grant the extension, and in May 2015, TVO announced that it had decided not to apply for a construction license during the validity of the decision-in-principle made in 2010.⁶⁰²

In parallel, Fortum Power has been planning a similar project, known as Loviisa-3. In January 2009, the company Fennovoima Oy submitted an application 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 and to being an EPR or ABWR. Startup was planned for 2020. Bids were received on 31 January 2012 from AREVA and Toshiba.⁶⁰³ In August 2012, a group of minority stakeholders left the Fennovoima consortium, followed by E.ON, which sold its 34 percent share in April 2013 to Voimaosakeyhtiö SF, a consortium of 60 companies and municipalities that already held the remaining 66 percent. Fennovoima ended the formal tender process in February 2013, inviting Toshiba to direct negotiations over a 1300 MW ABWR design and effectively dropping the EPR from the competition. In addition, in April 2013, to the general surprise of AREVA and Toshiba, Fennovoima invited Rosatom to direct negotiations over its 1200 MW AES-2006. Fennovoima stated that it will select the plant supplier “during 2013”.⁶⁰⁴ However, while Toshiba and AREVA were explicitly mentioned in government and parliament planning authorizations, Rosatom was not. Despite this, in March 2014 Rosatom, through a subsidiary company ROAS Voima Oy, completed the purchase of 34 percent of Fennovoima, the price of which was not disclosed⁶⁰⁵, 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 of a supplement to the decision-in-principle to include Rosatom's reactor design. A construction license application had to be

⁵⁹⁹ S&P, “Finnish Nuclear Power Producer TVO Downgraded T 'BBB-/A3'; Outlook Negative”, 28 May 2015.

⁶⁰⁰ TVO, “Construction of a Nuclear Power Plant Unit at Olkiluoto—General Description—OL4”, August 2008.

⁶⁰¹ TVO, “TVO applies for an extension to submit construction license application of Olkiluoto 4 plant unit”, Press Release, 20 May 2014.

⁶⁰² 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 25 May 2015.

⁶⁰³ Fennovoima, “Fennovoima received bids for nuclear power plant”, Press Release, 31 January 2012.

⁶⁰⁴ Rosatom, “Fennovoima invites ROSATOM to direct negotiations”, Press Release, 5 April 2013, see <http://www.rosatom.ru/en/presscentre/news/2df4ec804f260b62bd2afd2c0ad82648>, accessed 1 June 2013.

⁶⁰⁵ Fennovoima, “Rosatom acquired 34% of Fennovoima”, Press Release, 27 March 2014.

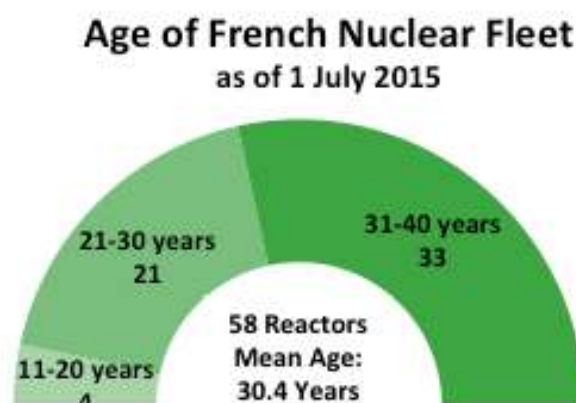
submitted by the end of June 2015⁶⁰⁶. It was—but without Fennovoima’s being able to demonstrate clearly that it met the requirement of being at least 60 percent owned by EU companies. A murky last-minute 8.89 percent indirect ownership claim by a Croatian firm, said by critics to be a Russian front company, remains to be clarified, so as of mid-2015, the project remains in question.⁶⁰⁷

France Focus

France’s nuclear industry is seen to be a world leader and it is exceptional in many ways. But after four decades of continual public support for nuclear power, the Government under President François Hollande has initiated a significant shift in energy policy. On 27 May 2015, the National Assembly, the French lower house, adopted on second reading a draft energy bill that stipulates the reduction of the nuclear share in France’s electricity mix from three-quarters to half. The final vote on the legislation could take place before the end of summer. At the same time, the French nuclear industry is undergoing an unprecedented crisis.

In 2014, France’s 58 reactors⁶⁰⁸ produced 415.9 TWh or 77 percent of the country’s electricity, both indicators on the rise after two consecutive declining years. In the peak year 2005, 431.2 TWh of nuclear electricity was produced, providing 78.5 percent of the total. The annual load factor increased by 1.6 percentage points in 2014 to 74.3 percent.

Figure 34: Age Distribution of French Nuclear Fleet (by Decade)



Sources: IAEA-PRIS, MSC, 2015

France is by far Europe's largest electricity exporter with 65.1 TWh exported net in 2014, the highest level since 2002.⁶⁰⁹ France has profited in particular from the continued outage of two nuclear reactors in Belgium (see section on Belgium). However, contrary to the general perception, France remains a net *importer* of power from Germany, by 5.9 TWh in 2014, and has been for a number of years, because German wholesale electricity generally undercuts French wholesale prices.

⁶⁰⁶ WNN, “Parliament approves Fennovoima’s amendment”, 5 December 2014, see <http://www.world-nuclear-news.org/NN-parliament-approves-Fennovoimas-amendment-5121401.html>, accessed 25 May 2015.

⁶⁰⁷ NIW, “Finland; Ownership Questions in Fennovoima’s License Application” 3 July 2015.

⁶⁰⁸ All pressurized water reactors, 34 x 900 MW, 20 x 1300 MW, and 4 x 1400 MW.

⁶⁰⁹ Réseau de Transport d’Electricité (RTE), “2014 Annual Electricity Report”, 29 January 2015.

The average age of France's power reactors is 30.4 years in mid-2015 (see Figure 34). In the absence of new reactor commissioning, the fleet is simply aging by one year every year. Simultaneously, questions are being raised about the investment needed to enable them to continue operating, as aging reactors increasingly need parts to be replaced. Operating costs have increased substantially over the past five years. Investments for life extensions will need to be balanced against such factors as: the already excessive nuclear share in the power mix; the shutdown in 2012 of the EURODIF gaseous diffusion uranium enrichment plant, replaced by the Georges-Besse II centrifugation plant, and the subsequent significant reduction in electricity demand (by two to three reactor-equivalents); and energy efficiency and renewable energy production targets on both the EU and the French level. It now looks plausible that EDF will attempt to extend lifetimes of some units, while others might be closed prior to reaching the 40-year age limit.

If the French Government and state controlled utility Électricité de France (EDF) in 2005 opted to proceed with the construction of a new unit, they would be motivated not by lack of generating capacity but by the industry's serious problem of maintaining nuclear competence. In December 2007, EDF started construction of Flamanville-3 (FL3). The FL3 site has encountered quality-control problems including basic concrete and welding similar to those at the OL3 project in Finland, which started two-and-a-half years earlier. (See also Chapter on Generation III Reactor Delays).

The French project is now at least five years late—one year more since WNISR2014—and not expected to start operating before 2017. The CGT trade union has stated that they don't trust that planning. "2017 is tomorrow. And now, we are working just four days a week", a spokesperson declared, as some of the work is delayed.⁶¹⁰ This was before the French Nuclear Safety Authority (ASN) revealed in April 2015 that the bottom piece and the lid of the FL3 pressure vessel had "very serious" defects. Both pieces were fabricated and assembled by AREVA in France, while the center piece was forged by Japan Steel Works (JSW) in Japan. The same fabrication procedure was applied to 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. At this point, it cannot be excluded that all three pressure vessels assembled in France will be rejected by the respective safety authorities and will have to be re-manufactured (raising the question of the viability of the entire projects, since replacing the ends of the huge steel pressure vessels already inside concrete is probably not feasible).⁶¹¹

The official cost estimate for Flamanville-3 has more than doubled since construction began, to €8.5 billion (US\$11.6 billion) as of December 2012—€2 billion (US\$2.7 billion) more than the previous estimate in 2011.⁶¹² However, in view of the additional delays and new technical problems, it is clear that the 2012 cost estimate is outdated.

⁶¹⁰ AFP, "Réacteur EPR de Flamanville: la CGT doute qu'il démarre en 2017", 27 January 2015, see <http://www.romandie.com/news/Reacteur-EPR-de-Flamanville-la-CGT-doute-qu'il-demarre-en-2017/559636.rom>, accessed 26 May 2015.

⁶¹¹ For a 4-page briefing on the issue see Yves Marignac, "Fabrication Flaws in the Pressure Vessel of the EPR Flamanville-3", WISE-Paris, 12 April 2015, see <https://www.dropbox.com/s/njavhw7ihvkbyeu/WISE-Paris-Fabrication-Flaws-EPR-Flamanville-Latest.pdf>, accessed 4 July 2015.

⁶¹² *Usine Nouvelle*, "EDF a évité le pire sur l'EPR de Flamanville", 7 December 2012, see <http://www.usinenouvelle.com/article/edf-a-evite-le-pire-sur-l-epr-de-flamanville.N187560>, accessed 1 June 2013.

In addition, there have been major difficulties with large investment projects—in Italy, the United Kingdom, and the United States—all of which are taking a toll on the balance sheet and credit rating of France’s major nuclear companies. EDF has a €34 billion (US\$41 billion) debt, as of the end of 2014, and steadily rising operational costs. Power price increases, which should reach around 30 percent between 2012 and 2017 in order to cover the operating costs—a legal requirement—would prevent EDF from selling at loss and help funding necessary investments. But these tariff increases could also negatively affect EDF by resulting in a loss of market share, as alternative energy suppliers and resources, along with energy efficiency, will thereby become more competitive.⁶¹³

The largest nuclear operator in the world is also struggling with a rapidly widening skills gap, as about half of its nuclear staff are eligible for retirement during 2012–17. EDF admitted that it will be faced with an extremely difficult period with a “forecasted doubling of expenditures between 2010 and 2020 (operation and investment)” and with “a peak of departures for retirement coinciding with a peak in activities.”⁶¹⁴

AREVA, self-proclaimed “global leader in nuclear energy”⁶¹⁵, filed losses for the fourth year in a row, with an unprecedented €4.8 billion (US\$5.8 billion) loss in 2014 raising its cumulative losses over four years to almost €8 billion (US\$9.7 billion—nearly its 2014 turnover of €8.3 billion (US\$10.1 billion). Debt reached €5.8 billion (US\$6.6 billion), while capital remained below €3.5 billion (US\$4 billion). Attempts to raise significant additional capital have failed in the past. Credit agency Standard & Poor’s (S&P) downgraded AREVA to “junk” (BB+) in November 2014⁶¹⁶, and by another two notches to BB-, deep into the speculative domain in March 2015.⁶¹⁷ By 9 July 2015, AREVA’s share price had plunged to a historic low and had lost 90 percent of its peak 2007 value.

AREVA is technically bankrupt and will not survive the year in its current form. Various rescue options have been discussed. A simple government bailout is impossible considering the current state of the country’s finances and the sheer volume of the sums involved.⁶¹⁸ The most probable scenario being discussed is the break-up of AREVA with the sale of the reactor division. EDF would purchase AREVA NP and create a subsidiary inviting other potential shareholders. The scenario is not without risks as the takeover could turn out to exacerbate EDF’s own difficulties: the two largely state-owned firms have long been intimately linked by transactions and dependencies, and the French state itself does not have infinite capacity to support long-term losses.

⁶¹³ In 2017, Enercoop, a 100-percent renewable power provider that used to be the most expensive distributor in France but which has never increased its tariffs, will sell power at a lower price than nuclear EDF. While the current Energy Minister has so far refused to grant any significant rate increase in 2014, the measure is only on-hold, since it is illegal for EDF to sell electricity at rates that does not cover its costs.

⁶¹⁴ EDF, “Les grands chantiers du nucléaire civil—Le ‘grand carénage’ du parc nucléaire de production d’EDF”, 14 January 2014.

⁶¹⁵ AREVA, see homepage www.areva.com, accessed 25 May 2015.

⁶¹⁶ S&P, “French Nuclear Group AREVA Downgraded To ‘BB+/B’ On Expected More Negative Cash Flows; Outlook Negative”, 20 November 2014.

⁶¹⁷ S&P, “French Nuclear Group AREVA Downgraded to ‘BB-’ on Further Profit Challenges and Cash Burn; Outlook Developing”, 5 March 2015.

⁶¹⁸ As a matter of comparison: the French Government spent months negotiating with the European Union an additional delay to conform with the EU’s rule not to exceed a budget deficit below 3 percent of the country’s Gross Domestic Product (GDP). France’s budget deficit was about 4 percent in 2014. The 1 percentage point between 3 and 4 percent deficit corresponds to €11 billion.

EDF shares lost up to 85 percent of their peak value, hitting bottom in January 2013. In early July 2015, they remained more than three-quarters below their best performance. Credit-rating agencies have had EDF on their watch lists for a couple of years. Fitch Ratings placed EDF on negative outlook on 1 July 2013, "as the electricity tariff rises were considered too low to maintain a level of indebtedness consistent with an A+ rating".⁶¹⁹ In April 2015, Moody's downgraded EDF to A1 from Aa3 with a negative outlook, reflecting:

...the risks associated with the transition of EDF's French power generation and supply activities from a predominantly regulated cost-reflective tariff model towards an increasing exposure to market power prices. Moody's notes that this transition is happening at a time when market prices are low and below the regulated price for nuclear output (ARENH)...

Furthermore, regulated tariffs for midsize and large business customers will cease from 1 January 2016. As a result, the share of domestic electricity volumes that EDF sells to end-customers under regulated tariffs will decrease to less than 50% in 2016 from 84% in 2014.⁶²⁰

Standard & Poor's maintained EDF's A+ rating but revised the outlook to negative from stable, on 7 May 2015, for various reasons:

- We think the rapidly changing regulatory and competitive landscape for Electricité de France's (EDF's) domestic activities is taking a toll on the group's strong market positions and defensive profile.
- This comes at a time of high investment needs, and we think the group's stretched credit metrics and negative discretionary cash flows weigh on its credit quality. (...)
- The negative outlook reflects the potential unfavorable developments that could stress EDF further, including declining power prices, a possible transaction with nuclear services provider Areva, or risks on nuclear new builds. It also reflects the negative outlook on France.⁶²¹

The report of a 2014 National Assembly Enquiry Committee on the "Past, Present and Future Costs of Nuclear Power", in its final recommendations, raised "concerns about the development of the costs of nuclear power", called on the government to define a clear energy policy framework and requested a pluralistic assessment of the scenarios providing the basis for planning of the future electricity generation mix.⁶²²

The current Government under President Hollande proposes a radical change in direction on nuclear power from not only the previous administration under Nicolas Sarkozy, but also with all recent Governments. For the first time since 1974, a French Administration drafted legislation that is breaking with the four-decades-old "tout électrique—tout nucléaire" principle. The draft Energy Bill was expected to be voted on before the end of the year 2014⁶²³ but was delayed

⁶¹⁹ EDF, "Reference Document 2012", 5 April 2013, see http://press.edf.com/fichiers/fckeditor/Commun/Finance/Publications/Annee/2014/ddr2013/EDF_DDR2013_va.pdf, accessed 4 July 2014.

⁶²⁰ Moody's Investors Service, "Rating Action: Moody's downgrades EDF to A1; negative outlook", 16 April 2015, see https://www.moodys.com/research/Moodys-downgrades-EDF-to-A1-negative-outlook--PR_323011, accessed 27 May 2015.

⁶²¹ S&P, "Electricite de France Outlook Revised to Neg On Heightened Exposure To Unregulated Activities; 'A+/A-1' Ratings Affirmed", 7 May 2015, see http://www.standardandpoors.com/en_US/web/guest/article/-/view/type/HTML/id/1397578, accessed 27 May 2015.

⁶²² François Brottes (Président), Denis Baupin (Rapporteur), "Rapport fait au nom de la Commission d'Enquête relative aux coûts passés, présents et futurs de la filière nucléaire (...)", 5 June 2014, see <http://www.assemblee-nationale.fr/14/pdf/rap-enq/r2007-tl.pdf>, accessed 4 July 2014.

⁶²³ Ministère de l'écologie, du développement durable et de l'énergie, "Projet de loi de programmation pour un nouveau modèle énergétique français", 22 June 2014.

several times. After the second vote in the lower house on 27 May 2015, the bill is still containing the following key points:

- The capping of the installed nuclear capacity at the current absolute level. This means that before the reactor under construction in Flamanville can be connected to the grid, an equivalent capacity must shut down.
- The reduction of the nuclear energy share in electricity generation to 50 percent by 2025 (from about 75 percent these past years). However, neither reactors to be closed nor their closure dates have been specified.
- The increase of the renewable energy share in electricity generation to 40 percent by 2030 (from just under 20 percent in 2014).
- The introduction of a compulsory, reactor-by-reactor, public inquiry prior to any formal decision by ASN to authorize lifetime extensions beyond 40 years.

The draft bill is currently scheduled for the second reading in the Senate on between 9 and 17 July 2015. Final plenary vote in the National Assembly is now expected just prior to summer break or immediately after reconvening parliamentary sessions. Whatever the precise calendar, it is definitely planned to be passed before the United Nations Climate Conference in Paris in November/December 2015.

Renewable energy development has been slow in France and the biggest share remains large hydropower, but for the first time in 2014, new renewables (other than hydropower) generated more power than fossil fuels.⁶²⁴ Wind power capacity additions have accelerated with 1.1 GW added in 2014, 84 percent more than in 2013, to reach a total of 9.3 GW. Less than 1 GW of solar was installed in 2014 and cumulated capacity reached 5.6 GW. In the first quarter of 2015, wind covered 4 percent of national electricity consumption versus a modest 0.8 percent contribution of solar photovoltaics.⁶²⁵

Germany's post-3/11 decision to shut down immediately eight of its 17 operating reactors and phase out the remaining nine until 2022 triggered comments around the world, from disbelief to certitude of failure. That this choice was led 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, makes it virtually irreversible under any political constellation.

Nuclear power plants still generated 91.8 TWh net in 2014—44 percent less than in their record year 2001—and provided 15.8 percent of Germany's gross electricity generation (just over half of the historic maximum of 30.8 percent in 1997). Of all countries operating more than two units, Germany, along with Finland, has the highest lifetime capacity factor with 87.5 percent. Eight of the nine units operated in Germany in 2014 are among the Top Ten lifetime electricity generators.

Germany exported a record 35.5 TWh net in 2014. Renewables, for the first time ever, were the largest contributor to the power mix and supplied 27.8 percent of gross national electricity consumption—more than lignite with 25.4 percent, hard coal 17.8 percent, and natural gas 9.5 percent. Coal consumption was 1.4 percentage points and natural gas 1.2 percentage points below 2013, while lignite's share remained identical.⁶²⁶ In another record, on 11 May 2015, renewables provided 80 percent of the capacity needed to cover German power needs. Wind

⁶²⁴ RTE, "2014 Annual Electricity Report", 29 January 2015.

⁶²⁵ Commissariat Général au Développement Durable, "Tableau de bord éolien-photovoltaïque—Premier trimestre 2015", Ministère de l'Ecologie, June 2015.

⁶²⁶ Energibilanzen AG, "Struktur der Stromerzeugung in Deutschland 2014", February 2015.

power output is expected to rise significantly in 2015, with offshore wind adding some 2.4 GW, while a record onshore addition of 3.4 GW will become fully operational in 2015.⁶²⁷

Table 8: 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 ⁶²⁸	1976	
Isar-1 (BWR, 878 MW)	E.ON	1977	
Krümmel (BWR, 1346 MW)	KKW Krümmel ⁶²⁹	1983	
Neckarwestheim-1 (PWR, 785 MW)	EnBW	1976	
Philippsburg-1 (BWR, 890 MW)	EnBW	1979	
Unterweser (BWR, 1345 MW)	E.ON	1978	
Grafenrheinfeld (PWR, 1275 MW)	E.ON	1981	31 December 2015 (closed 27 June 2015)
Gundremmingen-B (BWR, 1284 MW)	KKW Gundremmingen ⁶³⁰	1984	31 December 2017
Philippsburg-2 (PWR, 1402 MW)	EnBW	1984	31 December 2019
Brokdorf (PWR, 1410 MW)	E.ON/Vattenfall ⁶³¹	1986	31 December 2021
Grohnde (PWR, 1360 MW)	E.ON	1984	
Gundremmingen-C (BWR, 1288 MW)	KKW Gundremmingen	1984	
Isar-2 (PWR, 1410 MW)	E.ON	1988	31 December 2022
Emsland (PWR, 1329 MW)	KKW Lippe-Ems ⁶³²	1988	
Neckarwestheim-2 (PWR, 1310 MW)	EnBW	1989	

Notes: PWR=Pressurized Water Reactor; BWR=Boiling Water Reactor; RWE= Rheinisch-Westfälisches Elektrizitätswerk

Sources: Atomgesetz, 31 July 2011, Atomforum Kernenergie May 2011; IAEA-PRIS 2012

⁶²⁷ Agora Energiewende, "The Energiewende in the Power Sector: State of Affairs 2014", 7 January 2015.

⁶²⁸ Vattenfall 66,67%, E.ON 33,33%.

⁶²⁹ Vattenfall 50%, E.ON 50%.

⁶³⁰ RWE 75%, E.ON 25%.

⁶³¹ E.ON 80%, Vattenfall 20%.

⁶³² RWE 87,5%, E.ON 12,5%.

On 6 June 2011, the Government passed far-reaching energy transition legislation that passed the Bundestag on 31 July 2011 almost by consensus and came into force on 6 August 2011. The seven-part new laws addressed many aspects of energy consumption and production. Key elements included:

- Nuclear operating licenses will expire once the production credit is used up and at the latest according to Table 8. This meant that the eight units that had been shut down after 3/11 lost their operating license with the coming into force of the legislation.
- The production credit can be transferred from older to newer plants.

In addition to these decisions, the German Government decided on 12 June 2014 to rule out for the future any loan guarantees for the export of nuclear facilities, new or existing. Economy and Energy Minister and Vice-Chancellor Sigmar Gabriel declared:

Germany said goodbye to nuclear energy because it is intrinsically linked to considerable, non-controllable risks. These risks exist in foreign countries the same way. Therefore, it is logical that we do not support nuclear power plants in foreign countries in the future via Hermes guarantees.⁶³³

In March 2014, utility E.ON announced its intention to shut down its Grafenrheinfeld plant in May 2015, seven months earlier than required by law. E.ON planned to simply run the reactor until the fuel was used up. In April 2015, the date was delayed, because of the lower than expected operating hours in the winter due to low electricity demand.⁶³⁴ The reactor finally closed on 27 June 2015.⁶³⁵ Because of “lacking profitability”, the premature closure would be “unavoidable, also in the interest of the shareholders of the company”; E.ON argued that the particular weight of the German nuclear fuel tax was unbearable considering the short remaining lifetime of the reactor.⁶³⁶

Germany also made notable progress in energy efficiency, and gross electricity consumption in 2014 was the lowest in 15 years. While the mild winter softened energy consumption in all European countries, the temperature sensitivity in France,⁶³⁷ for example, is 4.5 times higher than in Germany. German electricity consumption fell by 4 percent while the economy grew by 1.4 percent. Greenhouse gas emissions dropped to the second lowest level since 1990, again partially due to the mild winter.⁶³⁸ Germany’s fossil-fueled power generation reached a 35-year

⁶³³ Bundesministerium für Wirtschaft und Energie, “Gabriel: Keine Hermesdeckungen mehr für Nuklearanlagen im Ausland”, 12 June 2014, see <http://www.bmwi.de/DE/Presse/pressemitteilungen,did=642020.html>, accessed 5 July 2014.

⁶³⁴ *Bayerischer Rundfunk*, “AKW Grafenrheinfeld bleibt bis 20. Juni am Netz”, 28 April 2015, see <http://www.br.de/nachrichten/unterfranken/inhalt/akw-atomkraftwerk-grafenrheinfeld-laufzeit-100.html>, accessed 28 May 2015.

⁶³⁵ E.ON, “Sicher bis zum letzten Tag: Nach 33 Jahren erfolgreichem Betrieb stellt das Kernkraftwerk Grafenrheinfeld die Stromproduktion ein”, 28 June 2015, accessed 29 June 2015.

⁶³⁶ E.ON, “E.ON nimmt Kernkraftwerk Grafenrheinfeld vor Ende der Laufzeit außer Betrieb”, 29 March 2014, see <http://www.eon.com/de/presse/news/pressemitteilungen/2014/3/28/eon-nimmt-kernkraftwerk-grafenrheinfeld-vor-ende-der-laufzeit-ausser-betrieb.html>, accessed 5 July 2014.

⁶³⁷ France has a high level of electric space heating in the housing sector, causing the highest temperature sensitivity in Europe. When the thermometer drops 1°C in winter, the capacity need increases by 2.4 GW. See RTE, “2014 Annual Electricity Report”, 29 January 2015.

⁶³⁸ *Agora Energiewende*, “The Energiewende in the Power Sector: State of Affairs 2014”, 7 January 2015.

low⁶³⁹, and coal-fired generation fell back to the 2010–11 level despite the record power exports.⁶⁴⁰

The **Netherlands** operates a single, 42-year-old 480 MW PWR that provided 3.9 TWh or 4 percent of the country's power in 2014, down from a maximum of 6.2 percent in 1986.⁶⁴¹ In June 2006, the operator and the Government reached an agreement to allow operation of the reactor until 2033.⁶⁴²

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”.⁶⁴³ The current government is still considering the possibility of building a new plant in the country, without any site selection yet. A revised version of the Netherlands Structure Plan is due next year that could contain as many as three potential sites for new build.⁶⁴⁴ However, no utility is currently showing any interest in pursuing new build.

In June 2014, Borssele operator EPZ started the use of MOX fuel. EPZ is currently the only remaining foreign customer for commercial spent fuel of AREVA's La Hague reprocessing plant. The plan is to consume all of the plutonium that is separated in as much as 40 percent MOX in the core.⁶⁴⁵

The Netherlands illustrates the significance of the European power market for the operational mode of national electricity generating capacities. The dramatic drop in wholesale power prices in Germany due to the rise in renewables, combined with low coal and relatively high natural gas prices, has led German utilities to shut down their gas-fired power plants in the Netherlands and import power from Germany. The Netherlands imported 17.6 TWh net from Germany in 2014.⁶⁴⁶

In September 2013, the results of a two-year policy development process were announced that has been described by some as a Dutch *Energiewende*. The origin of the initiative was a Parliamentary motion on 26 April 2011 that called on the government to develop a “National Energy Transition Accord”. The Accord is not government policy, though the Minister of Economic Affairs was part of the 40 organizations or departments, including trade unions, business associations, and the National Association of Municipal Councils, that signed up to it. The main

⁶³⁹ C. Morris, “Plummeting demand, renewables slightly up and fossil power generation at a 35 year low”, 22 December 2014, see <http://www.renewablesinternational.net/plummeting-demand-renewables-slightly-up-and-fossil-power-generation-at-a-35-year-low/150/407/84355/>, accessed 3 July 2015.

⁶⁴⁰ C. Morris, “Coal power down, renewables up in Germany”, 2 July 2015, see <http://www.renewablesinternational.net/coal-power-down-renewables-up-in-germany/150/537/88583/>, accessed 3 July 2015.

⁶⁴¹ BP, “Statistical Review of World Energy”, June 2014.

⁶⁴² WNA, “Nuclear Power in the Netherlands”, Updated 27 November 2014, see www.world-nuclear.org/info/inf107.html, accessed 2 June 2013.

⁶⁴³ DELTA, “DELTA puts off decision for a few years, no second nuclear plant at Borssele for the time being”, Press Release, 23 January 2012.

⁶⁴⁴ NIW, “The Netherlands”, 1 May 2015.

⁶⁴⁵ NEI, “Borssele moves to MOX”, 11 March 2015, see www.neimagazine.com/features/featureborssele-moves-to-mox-4530062/, accessed 29 May 2015.

⁶⁴⁶ Agora Energiewende, “The Energiewende in the Power Sector: State of Affairs 2014”, 7 January 2015.

recommendations of the Accord relate to energy efficiency and renewables,⁶⁴⁷ remaining “silent on nuclear”, as the *World Nuclear Association* complained.⁶⁴⁸

Spain operates seven reactors. Nuclear plants provided 54.8 TWh or 20.4 percent of the country’s electricity in 2014 (with a maximum of 38.4 percent in 1989). Beyond the de-facto moratorium that has been in place for decades, the previous 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 has stated that “there will be no new nuclear plants”.⁶⁴⁹

Spain has, however, been implementing both upratings and life extensions for existing facilities. In February 2011, the Spanish parliament amended the Sustainable Energy Law, deleting from the text a reference to a 40-year lifetime limitation and leaving nuclear share and lifetime to be determined by the government.⁶⁵⁰ Nevertheless, on 16 December 2012, Garoña was shut down permanently. The operator Nuclenor had calculated that further operation of the 446 MW plant would not be economic. The Cabinet of the Government elected in November 2011 approved in February 2014 a Royal Decree that would enable any recently shut reactors, in this case Garoña, to re-apply for their operating reactors within the next 12 months. In May 2014, Nuclenor applied for a new license to operate until 2031,⁶⁵¹ and has carried out a number of inspections in the meantime. However, there is no official time schedule for restart. Eleven mayors of towns in the vicinity of the plant have protested against the proposed restart and called for the closure of the unit to be confirmed.⁶⁵²

The recent spectacular rise of the left-wing populist party Podemos in the political landscape, and the general election slated by the end of 2015, could mean more bad news for the nuclear industry in the country. Commenting on the European Commission’s decision to authorize the public support scheme of the Hinkley Point project in the U.K., Podemos tweeted: “No Money for Nuclear Power—Stop Brussels! No to scandalous subsidies for NPP at Hinkley Point”.⁶⁵³

Sweden operates nine reactors that provided 62.27 TWh or 41.47 percent of the country’s electricity in 2014, down from a maximum of 52.4 percent in 1996. Sweden is a large power exporter; in 2014, net exports represented 12 percent or 16 TWh of the electricity consumed in the country or about a quarter of the nuclear generation.

Sweden decided in a 1980 referendum to phase out nuclear power by 2010. The referendum took place at a time when only six out of a planned 12 reactors were operating, with the other six still

⁶⁴⁷ *Energypost.eu*, “The Dutch Energiewende”, 4 October 2013, see <http://www.energypost.eu/the-dutch-energiewende/>, accessed 5 July 2014.

⁶⁴⁸ WNA, “Nuclear Power in the Netherlands”, Updated June 2014.

⁶⁴⁹ *Reuters*, “Spain Insists on Energy Saving, Not Nuclear Plants”, 21 January 2009.

⁶⁵⁰ WNN, “No Limits for Spanish Reactors”, 17 February 2011.

⁶⁵¹ Nuclenor, “Nuclenor submits application to renew the operating licence of the plant Garoña”, Press Release, 27 May 2014.

⁶⁵² EITB, “Mayors urge EU to monitor the possible re-opening of Garoña”, 17 June 2014, see <http://www.eitb.com/es/noticias/sociedad/detalle/2337498/central-nuclear-garona--alcaldes-piden-cierre-plnata/>, accessed 3 July 2014.

⁶⁵³ See <https://twitter.com/laudiopodemos/status/568062057385492480>, accessed 29 May 2015.

under construction. It was therefore effectively a “program limitation” rather than a “phase-out” referendum. 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.

On 5 February 2009, the parties of Sweden’s conservative coalition government signed an agreement on energy and climate policy that proposed ambitious renewable energy and energy efficiency targets and called for the scrapping of the Nuclear Phase-Out Act. In June 2010, the parliament voted by a tight margin (174–172) to abandon the phase-out legislation.⁶⁵⁴ As a result, new plants could again be built—but only if an existing plant is shut down, so the maximum number of operating units will not exceed the current ten. In January 2014, the state utility Vattenfall started a “decade-long public consultation” on the construction of new nuclear power plants.⁶⁵⁵

In the meantime, Vattenfall envisaged extending lifetimes of five of its seven units at Forsmark and Ringhals to 60 years. The previous objective for Ringhals-1 and -2 was a 50-year lifetime.⁶⁵⁶ However, in April 2015, Vattenfall decided “to change direction for operational lifetimes of Ringhals-1 and -2” and the two units “may be closed down between the years 2018 and 2020, instead of, as previously announced, around 2025”—that is after 44 to 46 years of operation. The reasons given were continued low electricity prices and increasing production costs. As for Vattenfall’s five other reactors (Ringhals-3 and 4, Forsmark-1 to -3), the previously planned “at least 60 years of operational lifetime, until the beginning of 2040s, remains”.⁶⁵⁷

Swedish operators have pushed uprating projects to over 30 percent. OSG, 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, a 38 percent capacity increase was under way, but has been “indefinitely postponed” in June 2015.⁶⁵⁸ In March 2015, OSG had estimated that the modernization will be completed “before the turn of the year”, adding that “this is clearly a miscalculation compared with the original time estimate for these works, which were started in June 2013”.⁶⁵⁹ Vattenfall had cancelled its planned 14-percent uprate for Forsmark-3 in November 2014, stating that the “profitability calculation for the power increase at Forsmark 3 has deteriorated since the issue was last discussed by the board about a year ago”.⁶⁶⁰ Indeed, in

⁶⁵⁴ NEI, “Swedish Government Overturns Nuclear Ban”, 21 June 2010.

⁶⁵⁵ WNA, “Nuclear Power in Sweden”, Updated April 2015, see

<http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Sweden/>, accessed 29 May 2015.

⁶⁵⁶ Vattenfall, “Vattenfall plans to provide nuclear power for up to 60 years”, Press Release, 22 May 2013, see <http://www.vattenfall.com/en/pressreleasedetailhidden.htm?newsid=943A721F600C4F72AF3AC1D4F96C601A>, accessed 2 June 2013.

⁶⁵⁷ Vattenfall, “Vattenfall changes direction for operational lifetimes of Ringhals 1 and 2”, Press Release, see <http://corporate.vattenfall.com/news-and-media/press-releases/2015/vattenfall-changes-direction-for-operational-lifetimes-of-ringhals-1-and-2/>, accessed 29 May 2015.

⁶⁵⁸ WNN, “Oskarshamn 2 uprate put on hold”, 17 June 2015, see <http://www.world-nuclear-news.org/C-Oskarshamn-2-uprate-put-on-hold-1706155.html>, accessed 6 July 2015.

⁶⁵⁹ OSG, “Total safety modernisation of Oskashamn 2 completed before the turn of the year”, 13 March 2015, see <http://www.osg.se/en/Media/News/Total-safety-modernisation-of-Oskarshamn-2-completed-before-the-turn-of-the-year/>, accessed 29 May 2015.

⁶⁶⁰ WNN, “Forsmark 3 power uprate cancelled”, 24 November 2014, see <http://www.world-nuclear-news.org/C-Forsmark-3-power-uprate-cancelled-2411145.html>, accessed 29 May 2015.

June 2015, E.ON, the majority owner of Oskarshamn-2, said it wanted to shut down the unit because it was unprofitable to operate; minority owner Forum disagreed.⁶⁶¹

It is not only the economics that have changed quickly and dramatically, but also the political framework. The Red-Green Government that took office in October 2014—the Green Party holds the Environment portfolio and a Deputy Prime Minister position—in its Statement of Government Policy declared:

Nuclear power is to be replaced by renewable energy and energy efficiency measures, and...Sweden, in the long term, is to have 100 per cent renewable energy....

Nuclear power must bear a larger proportion of its economic costs to society. Safety requirements will be made more stringent and the nuclear waste charge will be increased. Vattenfall is to take the lead in the transition of the energy system towards a greater proportion of renewable energy.⁶⁶²

“Goals and visions” of the new Swedish government include:

- By 2020 at least 50 per cent of total energy consumption should come from renewable energy sources.
- By 2020 the transport sector should meet the renewable energy target of at least 10 per cent.
- By 2020 energy efficiency should increase by 20 per cent. This is expressed as a cross-sectoral target of a 20 per cent reduction in energy intensity by 2020 relative to 2008.⁶⁶³

The primary energy and transport sector goals are likely already achieved in 2014.⁶⁶⁴

On 31 May 2015, with a significant share of nuclear down for refurbishment and refueling, for the first time, more wind capacity was spinning than nuclear power operating.

A significant shift is underway in a country that in 2014 represented the world's fifth largest share of nuclear power in its electricity mix, and the largest installed nuclear capacity per capita.

The **United Kingdom** operates 16 reactors, which provided 57.9 TWh or 17.2 percent of the country's electricity in 2014, down from a maximum of 26.9 percent in 1997. The U.K. operators EDF Energy and Magnox Ltd. do not transmit load factor data to *Nuclear Engineering International*. However, data published by the IAEA-PRIS database indicate that the average load factor for the U.K. reactors was 69.4 percent in 2014, among the five worst national performers of the year.

The 11 first-generation Magnox plants, nine with twin reactors and two with four reactors, have all been retired, except for one reactor at Wylfa. It was to be closed by the end of 2014, but in the Periodic Safety Review submitted to the Office for Nuclear Regulation (ONR) in October 2013, the operator requested that the reactor's operating life be extended by one year to enable it to fully

⁶⁶¹ WNA, “Nuclear power in Sweden”, 26 June 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Sweden/>, accessed 3 July 2015.

⁶⁶² Government Offices of Sweden, “The new Government's environment and energy policy”, 29 October 2014.

⁶⁶³ Government Offices of Sweden, “Goals and visions”, published 27 November 2014, Updated 21 March 2015, see <http://www.government.se/government-policy/energy/goals-and-visions/>, accessed 29 May 2015.

⁶⁶⁴ Tomas Kåberger, personal communication, 31 May 2015.

utilize the fuel that it obtained by closing unit 2.⁶⁶⁵ In September 2014, ONR granted permission to operate the last Magnox until December 2015.⁶⁶⁶ The U.K.'s seven second-generation nuclear stations, each with two Advanced Gas-cooled Reactors (AGR), are also at or near the end of their design life. However, owner EDF Energy is planning to extend their life, and announced in January 2015 that it planned to seek a 10-year extension to 2028 for the two Dungeness-B reactors.⁶⁶⁷ The newest plant, Sizewell-B, is the only PWR in the U.K. and was completed in 1995.

In 2006, the Labor Government of Tony Blair started to organize the framework of a new-build program. In July 2011, the Government released the National Policy Statement (NPS) for Nuclear Power Generation.⁶⁶⁸ 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.⁶⁶⁹ Northern Ireland and Scotland⁶⁷⁰ are not included.

EDF Energy, majority-owned by French state utility EDF and currently the only remaining utility with a concrete investment timetable and plan, was given planning permission to build two reactors at Hinkley Point in April 2013. In October 2013, EDF and the UK Government announced the provisional agreement of commercial terms of the deal for the £16 billion (US\$30 billion) overnight cost of construction of Hinkley C. At the time, they said that the deal would be finalized in July 2014, but that timetable has slipped several times. The key points for 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 between £89.5 and £92.5/MWh (US\$152.6–157.7/MWh), with annual increases linked to the retail price index, along with Government debt guarantees expected to cover all the borrowing required, expected to be about £17 billion (US\$26.9 billion). The consortium owning the plant has still to be finalized but in October 2013, it was expected to comprise EDF (up to 50 percent), two Chinese companies (up to 40 per cent, and AREVA (up to 10 percent), with up to 15 percent still to be determined. This led to formal State Aid notification of the proposal to the European Commission in October, and on 18 December 2013, the Commission announced it was investigating the deal. On 8 October 2014, only days before he left office, Commissioner Joaquin Almunia announced the Commission's authorization of the state aid scheme.⁶⁷¹ The announcement stated: “The new Hinkley Point C nuclear power station will require debt financing of GBP 17 billion (around €21.6 billion) and will eventually have a capital of about GBP 34 billion (around €43 billion). The construction costs are estimated at GBP 24.5 billion (around €31.2 billion)” —a significant rise from the previous

⁶⁶⁵ Magnox, “Periodic Safety Review Submitted”, Press Release, 9 October 2014.

⁶⁶⁶ ONR, “Regulatory support for Wylfa's continued operation”, 30 September 2014, see <http://news.onr.org.uk/2014/09/regulatory-support-for-wylfas-continued-operation/>, accessed 29 May 2015.

⁶⁶⁷ WNN, “UK nuclear plant gets ten-year extension”, 20 January 2015, see <http://www.world-nuclear-news.org/C-UK-nuclear-plant-gets-ten-year-extension-2001157.html>, accessed 30 May 2015.

⁶⁶⁸ DECC, “National Policy Statement for Nuclear Power Generation”, July 2011.

⁶⁶⁹ Bradwell, Hartlepool, Heysham, Hinkley Point, Oldbury, Sizewell, Sellafield, and Wylfa.

⁶⁷⁰ The Scottish government is opposed to new-build and said it would not allow replacement of the Torness and Hunterston plants once they are shut down (probably in 2016 and 2023, respectively). Only 18 percent of the Scottish people supported new-build in a pre-Fukushima poll; see *The Scotsman*, “Only 18% of Scots Say ‘Yes’ to New Nuclear Power Stations”, 27 September 2010.

⁶⁷¹ European Commission, “Commission Decision of 08.10.2014 on the aid measure SA.34947 (2013/C)(ex2013/N) which the United Kingdom is planning to implement for Support to the Hinkley Point C Power Station”, 2014, Final Cor. 8 October 2014.

estimates. The decision was published in the Official Journal on 28 April 2015.⁶⁷² As early as 22 January 2015, Reinhold Mitterlehner, Austria's Vice-Chancellor and Minister for Science, Research and Economy, who also holds the energy portfolio, announced that his government would file a complaint with the European Court of Justice (ECJ) against the Commission decision, stating: "We oppose any kind of support of the construction of atomic power plants or the production of nuclear energy."⁶⁷³ Far from being deterred by British threats of comprehensive retaliation,⁶⁷⁴ Austria's Chancellor himself formally announced the complaint in June 2015. It may take 3–4 years to resolve, suspending British state aid meanwhile. It is expected that the Luxemburg Government will join the complaint. In March 2015, the renewable energy utilities Greenpeace Energy, Germany, and the Oekostrom AG, Austria, announced they would lodge a joint legal procedure against the Commission decision with the ECJ.⁶⁷⁵ Another eight energy companies in Austria and Germany have since joined the alliance.⁶⁷⁶

Other new delays were triggered by EPR builder AREVA's 2015 technical bankruptcy, which not only makes it virtually impossible for AREVA to contribute 10 percent to the investment but is throwing the entire nuclear sector in France into great difficulty (see France Focus). Further uncertainties arose in April 2015, after "very serious" material defects were identified on the Flamanville EPR pressure vessel bottom and lid.⁶⁷⁷ The pressure vessel bottom and lid for Hinkley Point might have been fabricated several years ago with the same defect. According to the French regulator, the assessment of the safety implications will take at least until October 2015. It is difficult to imagine any decisive move on Hinkley Point prior to that deadline.

While the Hinkley Point project represents the major focus of public attention, other potential new-build sites turn out highly controversial. The Blackwater Against New Nuclear Group chaired by well-known Prof. Andy Blowers that opposes new-build at the Bradwell site stated that it had "gathered 10,000 signatures in a face-to-face petition against new nuclear development at Bradwell which, he observes, "must surely be one of the most conclusive surveys of public

⁶⁷² Official Journal of the EU, "Commission Decision (EU) 2015/658 of 8 October 2014 on the aid measure SA.34947 (2013/C) (ex 2013/N) which the United Kingdom is planning to implement for support to the Hinkley Point C nuclear power station (notified under document C(2014) 7142) (Text with EEA relevance)", 28 April 2015. The publication date is important as it determines all deadlines for legal procedures.

⁶⁷³ Bundesministerium für Wissenschaft, Forschung und Wirtschaft, "Mitterlehner: Österreich klagt gegen Subventionierung für britische Atomkraftreaktoren", 22 January 2015, see <http://www.bmwf.at/Presse/AktuellePresseMeldungen/Seiten/Mitterlehner-%C3%96sterreich-klagt-gegen-Subventionierung-f%C3%BCr-britische-Atomkraftreaktoren.aspx>, accessed 30 May 2015.

⁶⁷⁴ J. Pickard & J. Shotton, "Austria fears UK retaliation over nuclear challenge", *Financial Times*, 11 February 2015, see <http://www.ft.com/intl/cms/s/0/905342fa-b214-11e4-80af-00144feab7de.html#axzz3esDYEKRO>, accessed 3 July 2015.

⁶⁷⁵ Greenpeace Energy, "Klagebündnis gegen Atombeihilfen formiert sich", 26 March 2015, see <http://www.no-point.de/oekostrom-ag-schliesst-sich-klage-von-greenpeace-energy-an/#more-168>, accessed 30 May 2015.

⁶⁷⁶ Greenpeace Energy et al., "Ten companies take legal action against the European Commission's decision on State Aid for Hinkley Point C", 2 July 2015, see http://www.greenpeace-energy.de/fileadmin/docs/pressematerial/Hinkley_Point/Hinkley_Point_C_PR_150702_final_EN.pdf, accessed 2 July 2015.

⁶⁷⁷ For a 4-page briefing on the issue see Yves Maignac, "Fabrication Flaws in the Pressure Vessel of the EPR Flamanville-3", WISE-Paris, 12 April 2015, see <https://www.dropbox.com/s/njavhw7ihvkbyeu/WISE-Paris-Fabrication-Flaws-EPR-Flamanville-Latest.pdf>, accessed 4 July 2015.

opinion at any of the sites proposed for new nuclear stations in the UK’ ”.⁶⁷⁸ In a rather unusual move, the group has written directly to potential Chinese investors in the site, currently owned by EDF Energy, in order to warn them “about the serious technical, environmental and political difficulties they would face in building on the Blackwater estuary”.

Two other consortia are considering investment in new nuclear in the U.K.

NuGen, in June 2014, finalized a new ownership structure with Toshiba-Westinghouse (60 percent) and GDF-Suez (40 percent), as Iberdrola sold their shares. The group plans to build three AP1000 reactors at the Moorside site, with units proposed to begin operating in 2024.⁶⁷⁹ However, the AP1000 design is not expected to be licensed before January 2017.⁶⁸⁰

Horizon Nuclear was bought by Hitachi from E.ON and RWE for an estimated price of £700 million (US\$1.2 billion). The company has submitted its ABWR for technical review, whilst making it clear that its continuation in the project will depend on the outcome of the EDF negotiations with the Government.⁶⁸¹ The ABWR, planned for the Wylfa site, has passed the justification procedure at both Houses of Parliament in January 2015, the Generic Design Assessment (GDA) is even less advanced than that of the AP1000 and expected to be completed sometime “during 2017”.⁶⁸² If everything did go according to plan, the reactor would start up in 2025.⁶⁸³

The constant decline in energy *and* electricity consumption in the UK does not favor the economic case for nuclear new-build. Annual final electricity consumption fell 4.3 percent in 2014 to the lowest level in 17 years. Meanwhile, renewables’ share of electricity generation increased from 14.9 percent to a record 19.2 percent in 2014,⁶⁸⁴ overtaking nuclear generation for the first time in decades, and British renewable projects continue to demonstrate robustly lower market prices than the price guaranteed for 35 years to the largely French-state-owned owners of Hinkley Point C—a disparity bound to create increasing political tensions in the U.K..

Switzerland is the only non-EU Western European country that operates nuclear power plants. It operates five reactors that generated 26.4 TWh or 37.9 percent of the country’s electricity in 2014, down from a maximum of 44.4 percent in 1996.

With an average age of 40.2 years, Switzerland operates the oldest nuclear fleet and—with Beznau-1, age 46—the oldest reactor in the world. In a compelling 2014 report, Dieter Majer,

⁶⁷⁸ Blackwater Against New Nuclear Group, “BANNG seeks discussions with Chinese developers on future of Bradwell nuclear site—Conditions of EDF transaction queried”, Press Release, 18 June 2015.

⁶⁷⁹ NucNet, “Toshiba Finalises Controlling Stake in UK Nuclear Company NuGen”, 30 June 2014, see <http://www.nucnet.org/all-the-news/2014/06/30/toshiba-finalises-controlling-stake-in-uk-nuclear-company-nugen>, accessed 5 July 2014.

⁶⁸⁰ ONR, “Generic Design Assessment Progress Report, Reporting Period January to March 2015”, 21 May 2015, see <http://www.onr.org.uk/new-reactors/reports/gda-quarterly-report-jan-mar-15.pdf>, accessed 30 May 2015.

⁶⁸¹ *Telegraph*, “Hitachi reluctant about UK nuclear reactor plan”, 14 April 2013.

⁶⁸² ONR, “Generic Design Assessment—Getting involved”, see <http://www.onr.org.uk/new-reactors/public-involvement.htm>, accessed 30 May 2015.

⁶⁸³ *WNN*, “Horizon clears justification hurdle”, 28 January 2015, see <http://www.world-nuclear-news.org/NN-Horizon-clears-justification-hurdle-2801151.html>, accessed 30 May 2015.

⁶⁸⁴ DECC, “Statistics – Energy trends section 5; electricity”, March 2015, see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/415997/electricity.pdf, accessed 30 May 2015.

former Director for Nuclear Facilities Safety of the German Nuclear Regulator, recommended that especially the reactors Mühleberg and Beznau “should be shut down immediately”.⁶⁸⁵

In October 2013 the 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.”⁶⁸⁶ In January 2015, the federal regulator accepted the upgrades proposed by the operator in order to continue operating Mühleberg until 2019.⁶⁸⁷

Until 3/11, the nuclear phase-out option never gained a sufficient majority, but the “Swiss-style” referenda have maintained an effective moratorium on any new project over long periods of time. Fukushima had a very significant impact in Switzerland. Only three days after 3/11, the Government suspended the procedures around license requests for new-build. Opinion polls a week later showed that support for new-build nuclear power had plunged by 34 points, from 55 percent to 21 percent in two months.⁶⁸⁸ On 8 June 2011, the Swiss parliament voted in favor of the phase-out of nuclear power in the country at the end of the projected lifetime of the last operating reactor in 2034.

Since then, a number of initiatives have attempted to modify the schedule, seeking either to accelerate or to slow down the process. While there seems to be a durable consensus in the country that any new-build initiative is off the table, the Government has initiated a process called Energy Strategy 2050 that does not fix any precise shutdown dates and aims to keep the existing reactors operating “as long as they are safe”. The criteria for reactor closure remain uncertain. The Strategy includes measures to reduce energy consumption and to boost renewable energies. It is now being discussed by Parliament, as well as the “Nuclear Phase-out Initiative”. Various environmental, clean energy and anti-nuclear groups have launched a campaign to limit the lifetime of the nuclear plants to 40 years and thus shut down the last reactor by 2029. A national petition drive was launched in late May 2013.⁶⁸⁹ This process could continue into 2016.

On the development of renewables, Switzerland has a long way to go. An analysis by the Swiss Energy Foundation that compares the per-capita generation of wind and solar power found Switzerland behind 25 of the 28 EU countries.⁶⁹⁰

⁶⁸⁵ Dieter Majer, “Risiko Altreaktoren Schweiz”, February 2014, commissioned by Schweizerische Energie-Stiftung (SES), February 2014, see <http://www.energiestiftung.ch/energiethemen/atomenergie/risiken/risiko-altreaktoren/>, accessed 24 July 2014.

⁶⁸⁶ *NIW*, “Switzerland—News Briefs”, 1 November 2013.

⁶⁸⁷ Eidgenössische Nuklearsicherheitsinspektorat (ENSI), “Forderungen des ENSI für den Weiterbetrieb des Kernkraftwerks Mühleberg bis zur endgültigen Ausserbetriebnahme im Jahr 2019”, 23 January 2015.

⁶⁸⁸ AREVA, “Impact of Fukushima event on nuclear power sector – Preliminary assessment”, 25 March 2011.

⁶⁸⁹ SES, “40 Jahre sind genug – Jetzt Petition unterzeichnen”, 22 May 2013, see <http://www.energiestiftung.ch/aktuell/archive/2013/05/22/40-jahre-sind-genug-jetzt-petition-unterzeichnen.html>, accessed 5 June 2013.

⁶⁹⁰ SES, “Neue erneuerbare Energien: Schweiz hinkt der EU hinterher”, 19 May 2015, see <http://www.energiestiftung.ch/aktuell/archive/2015/05/19/erneuerbare-energien-schweiz-kann-nicht-mit-eu-mithalten.html>, accessed 30 May 2015.

Central and Eastern Europe

In **Bulgaria**, nuclear power provided 15 TWh or 33.6 percent of the country's electricity in 2014, down from a maximum of 47.3 percent in 2002. The annual load factor has risen by almost ten percentage points to a remarkable 90.5 percent in 2014. However, the lifetime load factor remains one of the lowest in the world with 60.8 percent. At the country's only nuclear power plant, Kozloduy, there are 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. Despite this, net electricity exports in 2014 were over 9 TWh, equivalent to about 60 percent of the electricity produced by Kozloduy. The two remaining VVER1000 reactors are currently licensed to operate until 2017 and 2021,⁶⁹¹ but the operator has begun a relicensing program and plans to extend their operating lifetimes with an unprecedented 60-year life extension, with an initial agreement signed with EDF and Rosenergoatom and Rusatom Service. If implemented, this would give a total operating life of 90 years.⁶⁹²

There have been ongoing attempts since the mid-1980s to build another nuclear power plant at Belene in Northern Bulgaria including firms from Bulgaria, France, Germany, and Russia. The latest came to a halt in February 2013 when the Parliament finally confirmed the then Prime Minister's decision to abandon the plant. However, due to a new election campaign, later that year the former socialist government proposed to once again restart the construction of Belene, but despite an election win, no practical steps have been taken. In 2013, there was a string of arrests and high-profile raids involving individuals and firms connected with the Belene project.⁶⁹³

The Government and industry have now refocused their efforts on building another reactor at Kozloduy. In April 2012, the Government announced that an additional unit would be built "on market principles, that is, without government money or state guarantees."⁶⁹⁴ In December 2013, the Government approved a report from the Ministry of Economy and Energy to authorize the Bulgarian Energy Holding company (which would operate a new unit) to negotiate with Toshiba (which owns 87 percent of Westinghouse) to become the strategic investor in the construction of an AP1000 reactor. The reactor vendor Toshiba was to be asked to invest 30 percent of the final costs and help secure the remaining 70 percent from foreign lenders, specifically the Japan Bank for International Cooperation and the Export-Import Bank of the United States. The deadline for signing the agreement was 30 September 2014.⁶⁹⁵ The potential involvement of national export-import banks from the U.S. and Japan highlights the difficulties in building a reactor without state support. In early June 2014, Toshiba withdrew from the project and was replaced by Westinghouse as the strategic investor, and in August 2014, Westinghouse signed a "shareholder agreement" committing it to take a 30 percent stake in the project. Furthermore, US Vice-President Kerry offered that Washington could study ways in which it could assist in financing.⁶⁹⁶

⁶⁹¹ Republic of Bulgaria, "Sixth National Report under the Convention on Nuclear Safety", 2013.

⁶⁹² *NIW*, "Newsbriefs", 10 October 2014.

⁶⁹³ *NIW*, "Government says Belene Depends on Rooting Out Corruption", 18 October 2013.

⁶⁹⁴ *AFP*, "Bulgaria approves new reactor at nuclear plant", 11 April 2012.

⁶⁹⁵ *Sofia Globe*, "Bulgaria to begin talks with Westinghouse on new Kozloduy nuclear reactor", 11 December 2013, see <http://sofiaglobe.com/2013/12/11/bulgaria-to-begin-talks-with-westinghouse-on-new-kozloduy-nuclear-reactor/>, accessed 13 June 2014.

⁶⁹⁶ *NIW*, "Bulgaria, Energy Dependence on Russia Looks More Threatening", 16 January 2015.

Westinghouse was asked by the Bulgarian government to take a 49 percent stake in the project,⁶⁹⁷ but it was reported in the Bulgarian press that Westinghouse had refused.⁶⁹⁸ The Bulgarian Government then announced it was dropping the deal with Westinghouse for financial reasons.⁶⁹⁹

It is unclear how final this decision is, especially given the past stop-start history of nuclear power in Bulgaria. While the scoping phase of the Environmental Impact Assessment (EIA) has started, it has yet to begin the trans-boundary consultation. Further timing concerns have been raised over the licensing review of an AP1000 reactor, which according to the chairman of the Nuclear Regulatory Agency could take years.⁷⁰⁰ The increased concern over reliance on Russia for energy sources is increasing pressure to speed up co-operation with non-Russian partners.

Westinghouse had estimated that the cost of electricity produced by an AP1000 in Bulgaria would be US\$75–84/MWh—roughly US\$45/MWh for capital costs and financing, and US\$30/MWh for operational costs.⁷⁰¹ This would mean that the production cost of nuclear, even ignoring the distribution and balancing system costs, would be above the price of €51/MWh⁷⁰² (US\$55/MWh) industrial customers were paying for electricity in February 2015, undermining the claim that the project would be built solely under market conditions.

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 VVER1000-320 units. In 2014, nuclear plants generated 28.6 TWh or 35.8 percent of the electricity in the Czech Republic. At the same time, the country was a net exporter of 16.3 TWh of electricity, equivalent to 57 percent of the nuclear output.

The Dukovany units were started during 1985–87 and have undergone a life extension engineering program under the expectation they would operate until 2025, although it is now expected that operator CEZ [České Energetické Závody] will ask the regulator to extend the operating life for a further 10 years, until 2035–37. The Temelín reactors eventually started in 2000 and 2002 with financial assistance from the U.S. Export-Import Bank linked to the supply of instrumentation and control technology by Westinghouse.

In 2004, Government plans proposed the construction of at least two more reactors. By 2010, three consortia were being considered, led by Westinghouse, AREVA, and Skoda-Rosatom. In November 2012, the AREVA bid was excluded, since it had “not fulfilled some other crucial

⁶⁹⁷ Euroactiv, “Westinghouse: Nuclear has a great future in Poland”, 18 March 2015, see <http://www.euractiv.com/sections/energy/bulgaria-offers-westinghouse-stake-new-nuclear-unit-313314>, accessed April 2015.

⁶⁹⁸ *Mediapool*, “‘Westinghouse’ refused to invest in block VII—Extend Talks to renegotiate the current price of U.S. ‘Maritsa East’ 1 and 3”, 31 March 2015, see <http://www.mediapool.bg/uestinghaus-otkazva-da-investira-v-v-blok-news232408.html>, accessed April 2015.

⁶⁹⁹ *AFP*, “Bulgaria drops \$4 billion Westinghouse nuclear deal”, 2 April 2015, see <https://en-maktoob.news.yahoo.com/bulgaria-drops-4bn-westinghouse-nuclear-deal-161134172--finance.html>, accessed April 2015.

⁷⁰⁰ *NIW*, “Briefs—Bulgaria”, 28 February 2014.

⁷⁰¹ *Novinite.com*, “Planned Unit 7 of Bulgaria’s Kozloduy NPP to Generate USD 11 B”, 27 February 2015, see <http://www.novinite.com/articles/166868/Planned+Unit+7+of+Bulgaria%27s+Kozloduy+NPP+to+Generate+USD+11+B#sthash.1LrAzzB6.dpuf>, accessed 23 March 2015.

⁷⁰² Europe’s Energy Portal, “Bulgaria Price Report”, see <https://www.energy.eu/historical-prices/Bulgaria/>, accessed 24 March 2015.

criteria defined in the tender”.⁷⁰³ However, it transpired that the tender was irrelevant, as a key issue for new-build is the level of state support, and in February 2014, then Prime Minister Bohuslav Sobotka stated: “The new government is not willing to provide guarantees for purchasing prices of electricity that could be a big financial burden for households and firms in the next decades.”⁷⁰⁴ CEZ Chief Executive Daniel Benes subsequently said: “If there is no certainty and a guarantee in legislation, it is impossible to decide about the construction at Temelín under the current market conditions.”⁷⁰⁵ Then in April 2014, CEZ simply cancelled its call for tenders for the two new units at Temelín, citing the low electricity market price and the lack of government guarantees.

Despite this, the Czech Industry and Finance ministries continue to promote nuclear power, but there is little incentive or rationale for pushing for new construction in the short term. Rather, it is suggested that new capacity will be build some time in the next 20 years.⁷⁰⁶ Czech news agency České Noviny said an investment of between CZK250 billion (US\$10.4 billion) and CZK300 billion (US\$12.4 billion) would be needed before the state could consider whether or not to provide guarantees for new nuclear power projects.⁷⁰⁷ In these plans, new capacity is foreseen for both locations, Dukovany and Temelín, to maintain employment after the closure of existing reactors.

Hungary has only one nuclear power plant, at Paks, where four VVER 440-213 reactors that provided 14.8 TWh or 53.6 percent of the country’s electricity 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, until the 2030s, accompanied by a 20 percent increase in capacity. The first unit received permission to operate for another 10 years after a periodic safety review in 2013, the second unit in 2014.⁷⁰⁸

In March 2009, the Parliament approved a government decision-in-principle to build additional reactors at Paks.⁷⁰⁹ Even at this time, Russian assistance seemed to be the preferred option, and the Foreign Minister indicated that expansion of the Paks plant would be part of a “package deal” on outstanding economic issues with Russia.⁷¹⁰ But it was still a shock to nuclear vendors⁷¹¹ when in January 2014, unexpectedly abandoning the previously promised international tender process, an agreement was reached between Hungary and Russia through direct negotiation between their heads of government. This was followed by an engineering, procurement, and construction

⁷⁰³ CEZ, “Areva Failed to Comply with Public Contract Requirements Defined for Building Temelin NPP Units 3 and 4: CEZ had to Disqualify this Bidder”, 5 November 2014, see <http://www.cez.cz/en/investors/inside-information/1499.html>, accessed 13 June 2014.

⁷⁰⁴ Ceskenoviny, “Government won’t guarantee electricity prices for Temelin—PM Sobotka”, 6 February 2014.

⁷⁰⁵ Reuters, “Czech CEZ boss says prefers dividend predictability”, 31 March 2014.

⁷⁰⁶ NIW, “Prague’s Vague NewBuild Plans”, 23 February 2015.

⁷⁰⁷ WNN, “CEZ should fund new reactor projects, says government report”, 20 January 2015, see <http://www.world-nuclear-news.org/NP-CEZ-should-fund-new-reactor-projects-says-government-report-20011501.html>, accessed 18 May 2015.

⁷⁰⁸ WNN, “Paks unit 2 gets 20-year life extension”, 27 November 2015, see <http://www.world-nuclear-news.org/RS-Paks-unit-2-gets-20-year-life-extension-27111401.html>, accessed 18 May 2015.

⁷⁰⁹ John Shepherd, “Hungary’s Parliament Paves Way to Build New Reactor Unit”, *NucNet*, 31 March 2009.

⁷¹⁰ Realdeal.hu, “Hungary, Russia Seek to Resolve All Outstanding Issues in One Package, Says FM”, 21 January 2011.

⁷¹¹ NIW, “Newbuild: Hungary Ditches Tender in Favor of Rosatom Deal”, 17 January 2014.

contract in December 2014 worth €12.5 billion (US\$13.2 billion). It is said that this will be a “turn-key” contract, including a 20-year fuel contract and spent fuel return.⁷¹²

The loan deal has been criticized⁷¹³ because it was agreed just five days before a general election, and only a few of the crucial terms and conditions of the deal have been made public.⁷¹⁴ According to a version of the loan contract leaked by the Russian side, the loan rate will be significantly below the market norm for such a project, with reports suggesting variable rates of 3.95-4.95 percent interest to cover 80 percent of the project’s costs. However, penalty conditions are said to have the possibility to bankrupt the Hungarian State, and opposition parliamentarians have called for the Government to cancel the project. The Government is nonetheless determined to proceed and has even modified proposed legislation to increase the period for which contract terms would remain secret from 15 years to 30. The scope of the confidentiality is that it “may deny publishing any data connected to the project, if their publication would engage either the national security interests of Hungary, or intellectual property rights.”⁷¹⁵ The secrecy of the project has raised significant national and international protest as by keeping everything confidential, there will be little opportunity to keep track of costs. The project represents a U-turn for the ruling party, which had fiercely criticized previous socialist governments for failing to diversify away from reliance on Russian energy. Russia already provides about three-quarters of the country’s oil and gas supplies.⁷¹⁶ However, the nuclear fuel supply contract was rejected initially by the Euratom Supply Agency and subsequently by the European Commission, as it would “not comply with the European policy on diversification”.⁷¹⁷ It is still unclear how far the fuel contract can or will be re-negotiated and whether the European Commission will further investigate the implications of the financial model for State Aid violations.

Romania has one nuclear power plant at Cernovoda, where two Canadian-designed CANDU reactors began operating in 1996 and 2007. In 2014, they provided 10.7 TWh or 18.5 percent of the country’s electricity and achieved the second highest annual load factor in the world with 95.2 percent (partly because CANDU reactors refuel whilst online). Construction started in the 1980s, with the initial intention of five units. The first two units were partly funded by the Canadian Export Development Corporation, the second also partly by Euratom. Over the past decade, numerous foreign firms have been linked to the completion of additional Cernavoda units, including AECL and SNC-Lavalle (Canada), Ansaldo (Italy), AtomTechnoProm (Russia), CEZ (Czech Republic), Electrabel (Belgium), ENEL (Italy), GDF Suez (France), Iberdrola (Spain), KHNP (South Korea), RWE (Germany), and Arcelor Mittal (France).⁷¹⁸ In December 2013, Arcelor Mittal and ENEL, as the last foreign partners, sold back their shares in the project to the Romanian state. The latest attempt involves China General Nuclear Power Group (CGN), which signed a letter of intent in November 2013 with the Societatea Nationala Nuclearelectrica (SNN) to complete the projects in 2019 and 2020. In March 2014, it was announced that an extension would be granted to the letter of intent, which was set to expire on 25 May 2014.⁷¹⁹ In October 2014, SNN and CGN

⁷¹² NIW, “Newbuild, EPC Contract Signed for Russian VVER1200s at Paks”, 12 December 2014.

⁷¹³ NIW, “Hungary: Secrecy, Political Risk Cloud Prospects for Paks Expansion”, 20 February 2015.

⁷¹⁴ *Politics.hu*, “Hungary signs EUR 10 billion Paks agreement with Russia”, 1 April 2014.

⁷¹⁵ NIW, “EU Hungary doubles down on Paks 2 secrecy”, 27 February 2015.

⁷¹⁶ *Financial Times*, “Russia builds clout in eastern Europe with €10bn loan to Hungary”, 14 January 2014.

⁷¹⁷ NIW, “Hungary Questioning the Paks 2 Fuel Contract”, 13 March 2015.

⁷¹⁸ WNA, “Nuclear Power in Romania”, Updated December 2013.

⁷¹⁹ *Telgraf*, “Construction of NPP units 3 and 4, the petty cash”, 22 March 2014.

signed a binding agreement that made the latter the “selected investor”. However, with SNN proposing to invest in the life extension of the first two units at Cernavoda at €1.2–1.5 billion (US\$1.4–1.7 billion) per unit, it is looking for 100 percent investment in the completion of the third unit. This raises questions about whether the rising costs at Hinkley Point C in the UK, in which CGN is also a proposed partner, would affect its ability to invest in Romania.⁷²⁰

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 2014, these produced 14.4 TWh or 56.8 percent of the country’s electricity—behind France, the second largest nuclear share in the world. In October 2004, the Italian national utility ENEL 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. However, 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, including from CEZ, Finland’s Fortum, EPH, and a Hungarian consortium of the utility MVM and Mol.⁷²¹ The Slovak State has also expressed interest in increasing its share⁷²², but it has demanded from ENEL that Mochovce-3 and -4 be finished before a sale, in order to prevent further delays or even the cancellation of the project.⁷²³

In February 2007, SE announced that it was proceeding with the construction of Mochovce-3 and -4 and that ENEL had agreed to invest €1.8 billion (US\$2.6 billion). Construction restarted on 3 December 2008, and at the time the units were expected to start operation in 2012 and 2013.⁷²⁴ However, the project was beset with problems, and in 2013 the Slovak Government announced that the cost of completion had risen by €250 million (US\$260 million). Then in April 2014, at the Annual Shareholders meeting for SE, it was revealed that another €400 million (US\$424 million) would be needed to complete the units, taking the total costs of completion to €3.8 billion (US\$4 billion), with startup rescheduled for the end of 2014 and 2015.⁷²⁵ In June 2014, it was announced that the Russian Bank Sberbank would give SE an €800 million (US\$850 million) loan for 7.5 years; €300 million (US\$380 million) of the loan are to be spent on nuclear exports from Russia, including for the supply of nuclear fuel and for equipment for Mochovce.⁷²⁶ In 2014, it was then announced that the project completion would be delayed, with startup of unit 1 envisaged by the end of 2016 and unit 2 in 2017. The project is therefore at least four years behind schedule and €2 billion (US\$2.1 billion) over budget.

⁷²⁰ *NIW*, “Romania’s Struggle to lock in CGN”, 20 February 2015.

⁷²¹ *Reuters*, “ENEL expects four bids for Slovak utility stake-sources”, 3 March 2015, see <http://www.reuters.com/article/2015/03/03/enel-ma-slovakia-idUSI6N00Z01620150303>, accessed 18 March 2015.

⁷²² *Slovak Spectator*, “Finnish firm eyes Slovenske Elektrarne shares”, 20 February 2015, see <http://spectator.sme.sk/c/20056311/finnish-firm-eyes-slovenske-elektrarne-shares.html>, accessed April 2015.

⁷²³ *Bloomberg*, “Enel to proceed with Slovak Sale in Face of Premier’s Opposition”, 20 March 2015, see <http://www.bloomberg.com/news/articles/2015-03-26/enel-to-proceed-with-slovak-sale-in-face-of-premier-s-opposition>, accessed April 2015.

⁷²⁴ ENEL, “ENEL Starts Site Works at Mochovce 3–4”, 3 November 2008, see https://www.enel.com/en-GB/investors/press_releases/enel-starts-site-works-at-mochovce-3-4/r/1594888, accessed March 2015.

⁷²⁵ *Spectator*, “Shareholders approve additional funding for Mochovce plant”, 9 April 2014.

⁷²⁶ *WSJ*, “Sberbank to lend \$1.1 billion to Slovakia’s Largest Power Company”, 10 June 2014.

In addition to the delays and cost overruns, concerns have been raised about the state of the power market and electricity demand due to 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 ENEL and SE will recover their ever-increasing investment seems slim.

Slovenia jointly owns the Krsko nuclear power plant with **Croatia**—a 696-MW Westinghouse PWR. In 2014, it provided 6 TWh or 37.3 percent of the Slovenia’s electricity (down from a maximum of 42.4 percent in 2005). The load factor reached a remarkable 100 percent in 2014. The reactor was started in 1981 with an initial operational life of 40 years, but, the operator intends to seek a 20-year life extension. In 2010, a proposal was put forward for the construction of another reactor. However, developments are hindered by the negative seismic assessment by IRSN, the Technical Support Organization (TSO) of the French Nuclear Safety Authorities. In a December 2013 presentation⁷²⁷, IRSN released excerpts of its January 2013 letter to owner-operator GEN Energija concluding that “GEN should consider revising its strategy for the Krsko II project and further examine the possibility to search for an alternative site”.⁷²⁸ The nuclear regulator, however, denied these conclusions and brought forward further assessments.

Former Soviet Union

Armenia has one remaining reactor at the Medzamor (Armenian-2) nuclear power plant, which is situated within 30 kilometers of the capital Yerevan. This unit provided 2.2 TWh or 30.6 percent of the country’s electricity in 2014, down from a maximum of 45 percent in 2009.

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. The reactor is an early Soviet design, a VVER 440-230, and in 1995, a U.S. Department of Energy document stated: “In the event of a serious accident...the reactor’s lack of a containment and proximity to Yerevan could wreak havoc with the lives of millions.”⁷²⁹ In October 2012, the Armenia Government announced that it would operate the Medzamor unit 2026. This led to the Turkish authorities’ calling for the immediate closure of the power station.⁷³⁰ In March 2014, the Turkish energy minister said of the plant: “The nuclear plant, which was put online in 1980, has had a lifespan of 30 years. This plant has expired and should be immediately closed.”⁷³¹ In December 2014, an intergovernmental agreement was signed that would see the Russian Government finance a program of upgrading to

⁷²⁷ Oona Scotti, “Presentation of IRSN report on possible NPP Krsko II site. What are the implications of this report?”, IRSN, Event on nuclear in Ljubljana, Slovenia, 2 December 2013.

⁷²⁸ IRSN, Letter to GEN Energija, dated 9 January 2013.

⁷²⁹ Office on Energy Intelligence, “Most Dangerous Reactors: A Worldwide Compendium of Reactor Risk”, DOE, Washington, DC, May 1995.

⁷³⁰ USAID, “Turkey renews demands for ‘immediate closure’ of Armenian nuke plant”, 5 November 2012.

⁷³¹ *Hurriyet Daily*, “Turkey wants nuclear plant in Armenia to be shut down”, 22 March 2014.

let the reactor operate until 2026.⁷³² An application for the life extension license will be launched in September 2016, with the upgrade work expected to be completed by 2019. The work is to be funded by a Russian state loan.

In March 2015, the European Commission released the “Implementation of the European Neighborhood Policy (ENP) in Armenia”, which stated: “The early closure and decommissioning of the MNPP [Medzamor Nuclear Power Plant] remain a key objective for the EU and under the ENP Action Plan. Since the power plant cannot be upgraded to meet current internationally recognized nuclear safety standards, it should be closed as soon as possible”.⁷³³

For years, Armenia has been negotiating with Russia for the construction of a new 1000 MW unit, and signed an intergovernment agreement in August 2010. The plant was estimated by a U.S.-funded feasibility study that to cost US\$5 billion.⁷³⁴ In March 2014, the energy minister admitted that it was having difficulty in attracting funds to start construction.⁷³⁵ In July 2014, the energy minister said that Russia was expected to provide plant worth US\$4.5 billion out of the total US\$5 billion.⁷³⁶ In December 2014, an intergovernmental agreement was signed for the Russian Government to finance a program of upgrading to enable the reactor to operate until 2026.⁷³⁷ However, in June 2015, the IAEA said that, following an Integrated Regulatory Review Service, it was concerned that no application for life extension had been received by the national regulatory authority, despite the operating license’s expiring in 2016.⁷³⁸

In **Russia**, the industry is seeking to increase its domestic production as well as its global influence, through the export of reactors backed by cheap finance. The year 2014 saw the completion of a new reactor at Rostov, the first for four years, bring the total up to 34 reactors that provided 169 TWh or 18.6 percent of the Russian Federation’s electricity over the year. Russia’s average annual load factor was 80.8 percent in 2014, but the lifetime load factor remains very low at 66.8 percent. In the absence of a major and successful new-build program, the Russian reactor fleet is aging continuously and currently averages 30.7 years (see Figure 35), exactly like the EU28.

Problems of cost over-runs and delays continue to blight the industry. Two other reactors, the BN800 and the AES2006 at Novovoronezh, failed to make their end-of-year completion deadline.⁷³⁹

⁷³² *Diario Armenia*, “Armenia and Russia signed an agreement to extend the life of Medzamor nuclear power plant”, 27 December 2014, see <http://www.diarioarmenia.org.ar/armenia-y-rusia-firman-un-acuerdo-para-extender-la-vida-util-de-la-central-atomica-de-medzamor/>, accessed 25 March 2015.

⁷³³ European Commission 2015, “Joint Staff Working Document—Implementation of the European Neighbourhood Policy in Armenia—Progress in 2014 and recommendations for Actions”, 25 March 2015, http://eeas.europa.eu/enp/pdf/2015/armenia-enp-report-2015_en.pdf, accessed 4 June 2015.

⁷³⁴ USAID, “Government extends service life of Metsamor NPP for another ten years”, 19 October 2012.

⁷³⁵ *Business New Europe*, “Armenia denies plans to abandon nuclear power plant project”, 28 March 2014.

⁷³⁶ Rosatom, “Russia and Armenia agree to unit 2 life extension”, Press Release, 24 December 2014.

⁷³⁷ *Diario Armenia*, “Armenia and Russia signed an agreement to extend the life of Metsamor nuclear power plant”, 27 December 2014, see <http://www.diarioarmenia.org.ar/armenia-y-rusia-firman-un-acuerdo-para-extender-la-vida-util-de-la-central-atomica-de-medzamor/>, accessed 25 March 2015.

⁷³⁸ *NucNet*, “IAEA Expresses Concern Over Lack of Progress on Armenian-2 Licence Extension”, 12 June 2015, see <http://www.nucnet.org/all-the-news/2015/06/12/iaea-expresses-concern-over-lack-of-progress-on-armenian-2-licence-extension>, accessed 16 June 2015.

⁷³⁹ *NIW*, “Russia, preparing for triple reactor launch in 2014”, 20 June 2014.

According to the IAEA-PRIS database, Russia has nine reactors under construction, second only to China. Two of these are “floating reactors” (*Akademik Lomonosov*-1 and -2), which are nominally 32 MWe each. These were ordered in February 2009 and were expected to be delivered to the customer at the end of 2012.⁷⁴⁰ The latest official start-up date is said to be 6 September 2016,⁷⁴¹ although other reports suggest the vessels will be launched only in 2019.⁷⁴² 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 to the elements, subject to threats of piracy, and if deployed widely will increase the risks of nuclear material proliferation.⁷⁴³

Figure 35: Age Distribution of Russian Reactor Fleet



Sources: IAEA-PRIS, MSC, 2015

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. Despite no indication that construction will restart in 2015, the project remains “under construction” in IAEA statistics. However, given the ongoing problems in electricity markets with low market prices and sluggish demand, there is little incentive for construction to restart.

Commissioning work is said to be continuing at the Beloyarsk-4 fast breeder reactor that was expected to be completed in 2014. Construction of the 880 MW unit began initially in 1986 but was subsequently suspended and then restarted in July 2006. Fuel was said to be being loaded into the reactor in June 2014⁷⁴⁴, and according to Rosatom, Beloyarsk-4 is expected to reach full power in the second half of 2015⁷⁴⁵. Two VVER-1200 MW units are being built at the Leningrad nuclear power plant near St. Petersburg, where construction started in 2008 and 2010. At the

⁷⁴⁰ NEI, “KLT-40S nuclear barge project still afloat”, 9 March 2010.

⁷⁴¹ WNN, “Reactors installed on floating plant”, 1 October 2013.

⁷⁴² U.S.EIA, “Russia”, 12 March 2014, see <http://www.eia.gov/countries/cab.cfm?fips=RS>, accessed 12 May 2015.

⁷⁴³ NTI, “Floating nuclear reactors could fall prey to terrorist, experts say”, *Global Security Newswire*, 13 August 2010, see <http://www.nti.org/gsn/article/floating-nuclear-reactors-could-fall-prey-to-terrorists-experts-say/>, accessed 12 May 2015.

⁷⁴⁴ WNN, “Rosatom targets growth”, 3 June 2014.

⁷⁴⁵ Rosatom, “Russia expects to ramp up to full power unit 4 of Beloyarsk NPP in the second half of 2015”, 3 March 2015, see http://www.rosatom.ru/en/presscentre/nuclear_industry/faacab004781fc808116f36578d50f5d, accessed 25 June 2015.

time of ordering, the reactors were expected to start up in 2013 and 2016; startup is now expected respectively in December 2016 and 2018.⁷⁴⁶

Two VVER-1200 reactors are also under construction at Novovoronezh; one is now four years late and expected to be completed in 2016, and the second, according to WNA, in 2019,⁷⁴⁷ four years later than announced a year ago. Another reactor is being constructed at the Rostov nuclear power plant, expected to be completed in 2017.

A report by Russia's Audit Chamber found that seven out of the nine units under construction are 12–38 months behind schedule—probably an underestimate. The report also noted with concern the financial situation of Rosenergoatom's construction program with lower state budgets, which fell 18 percent during 2009–2015. Furthermore, Rosenergoatom, due to lower electricity prices, was forced to take out further loans to enable construction to proceed, and, as a result, had to use 68 percent of its reserves to cover interest costs.⁷⁴⁸ The report also refers to alarming environmental and safety implications of the current situation, with construction taking place in the absence of a passing review by Russia's Directorate-General for State Environmental Reviews. Furthermore, construction at the Leningrad-2 station lacks a synchronized schedule of equipment delivery and installation, so by the time some equipment comes online, it will be out of warranty.⁷⁴⁹

All these delays, financial and technical problems have continually downgraded targets for the deployment of new units. In September 2006, Rosatom announced a target for nuclear power to provide 23 percent of Russia's electricity by 2020 from 44 GW of capacity (compared to 24 GW in 2014). By July 2012, this had been scaled back to suggest that there would be 30.5 GW of nuclear nuclear in 2020. That would require just the completion of the nine reactors currently under construction, taking into account the closure of the first two RBMK units at Leningrad.

Therefore, a key issue for the industry is how to manage its aging reactors. There are three major classes of reactors in operation: the RBMK (a graphite-moderated reactor of the Chernobyl type), the VVER440, and the VVER1000. Both the RBMKs and VVER440 have been granted a 15-year life extension to enable them to operate for 45 years, while the VVER1000s are expected to work for up to 50 years. As of the middle of 2015, 19 have operated for over 30 years, of which four have run for over 40 years.

Russia is attempting to be an increasingly important player on the world nuclear power market, but serious questions have to be asked about the ability for Russia to finance its nuclear export plans. Russian finance is currently being used in reactors being built in Belarus, China, and India. However, finance has been pledged or is being negotiated for many other countries, including Armenia, Bangladesh, Finland, Hungary, Iran, Jordan, South Africa, Turkey, Ukraine, and Vietnam.

Funding for these projects comes from Russia's National Wealth Fund. A rough estimate of the funding Russia has pledged is US\$24 billion for plants now under construction and an additional US\$64 billion for future agreements—a total of US\$88 billion over the next decade or two.⁷⁵⁰

⁷⁴⁶ NIW, "Weekly roundup", 20 February 2015.

⁷⁴⁷ WNA, "Nuclear Power in Russia", Updated March 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/>, accessed 26 March 2015.

⁷⁴⁸ NIW, "Auditor Report Illuminates Rosatom's Financial Challenges", 23 January 2015.

⁷⁴⁹ Charles Digges, "Russian Audit Chamber cites ballooning budgets in domestic nuke projects", *Bellona*, 27 January 2015, see <http://bellona.org/news/nuclear-issues/nuclear-russia/2015-01-russian-audit-chamber-cites-ballooning-budgets-domestic-uke-projects>, accessed 26 March 2015.

⁷⁵⁰ C. Rofer, "Can Russia Afford Its Reactor Exports ?", *Nuclear Dinner.com*, 18 February 2015, see <http://nucleardinner.com/2015/02/18/can-russia-afford-its-reactor-exports/>, accessed 26 March 2015

However, the National Wealth Fund is also being used for stabilizing the Russian economy. With falling oil and gas prices, the falling value of the Rouble, and ongoing sanctions, the nuclear export program will be disrupted for political and economic reasons. The credit-rating agencies are not optimistic. In February 2015, Moody's downgraded Atomenergoprom—a 100 percent subsidiary of Rosatom, which as an integrated nuclear group also building reactors is comparable to the French AREVA—to “junk” (Ba1) and assigned a negative outlook.⁷⁵¹

The ongoing dispute between Russia and **Ukraine** over Crimea and the eastern Ukraine conflict has made energy an even more high-profile political and economic issue. Ukraine has been and remains heavily dependent on Russia for its oil, two-thirds of its natural gas (which Russia cut off in June 2014 and June 2015), and nearly all its nuclear fuel, though it is largely self-sufficient in coal. As Russia is the main manufacturer of the nuclear fuel used in Ukraine's VVER reactors, it poses a particular, but not necessarily acute, problem. Consequently, the Government of Ukraine has begun to diversify and is seeking to increase the share of its fuel that it obtains from Westinghouse, which in 2014 stood at just 6 percent, the rest coming from Rosatom's TVEL.⁷⁵² However it is not just fresh fuel that might cause problems, as Ukraine has historically been sending its used fuel to Russia for storage or reprocessing and it has no long-term storage facility for high-level waste. Ukraine has 15 operating reactors, two of the VVER440 designs and the rest VVER1000s. They provided 83.1 TWh or 49.4 percent of power in 2014. Many of the reactors were built in the 1980s, with twelve reactors over 25 years old.

This raises important questions for aging of components and the lifetime management of the facility. In March 2013, the European Bank for Reconstruction and Development (EBRD) awarded the state-owned nuclear operator, Energoatom, a €300 million (US\$338 million) loan for an upgrading program at all the country's reactors. The total cost of the program is expected to be €1.45 billion (US\$1.65 billion), with further funding, also of around €300 million, to come from the EU through the Euratom loan facility.⁷⁵³ The project is expected to be completed by 2017. Energoatom claims that the upgrading program “will impact only the future scope of works concerning the lifecycle extension of the operating power units, but will not influence the decision of life extension.”⁷⁵⁴ This is an artificial separation, as the upgrading program is not economic without extending the operating lives, and many of the reactors would have to close before the upgrading program was complete. In 2014, Ukraine lost a complaint procedure under the Espoo Convention about the lack of an environmental impact assessment for the life extension of the Rivne units 1 and 2⁷⁵⁵—a decision that will also affect Ukraine's other upcoming reactor life extensions.

Two reactors, Khmelnytsky-3 and -4, are officially under construction. Building work started in 1986 and 1987 but stopped in 1990. In February 2011, Russia and Ukraine signed an

⁷⁵¹ Moody's, “Rating Action: Moody's takes rating actions on six Russian utility and infrastructure GRIs; assigns negative outlook”, 25 February 2015, see https://www.moody.com/research/--PR_319091, accessed 4 June 2015.

⁷⁵² *NIW*, “Fuel Fabrication, Ukraine set on Diversifying away from Russia”, 13 March 2015.

⁷⁵³ EBRD, “Nuclear Power Plant Safety Upgrade Programme”, see <http://www.ebrd.com/english/pages/project/psd/2011/42086.shtml>, accessed March 2013

⁷⁵⁴ Energoatom, “Ecological Assessment Report, main report”, 31 January 2012.

⁷⁵⁵ UNECE, “Report on the Implementation Committee of its thirteen session”, 14 August 2014, see http://www.unece.org/fileadmin/DAM/env/documents/2014/EIA/IC/ece.mp.eia.ic.2014.2.as_resubmitted.pdf, accessed 7 July 2015.

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 coming from Russia. It is unclear how much work has been completed, with the documentation for the Environmental Impact Assessment stating the units were 35–40 percent and 5–10 percent complete respectively, while the operator NNEGC “Energoatom” stated on its website that construction of units 3 and 4 is reaching 75 percent and 28 percent completion.⁷⁵⁶ However, once again the project was delayed at the end of 2013, and the energy minister said that construction might resume only in 2015.⁷⁵⁷ In August 2014, it was announced that Ukraine would not cooperate with Russia on construction of the units. In October 2014, Prime Minister Arseniy Yatsenyuk told Energoatom management to speed up construction of new nuclear reactors and to enlist the help of “European partners” rather than Russia, which in the case of Khmelnytsky could mean the Czech company Škoda.⁷⁵⁸

⁷⁵⁶ Oda Becker, et al., “Khmelnytsky NPP Construction of Units 3 and 4—Expert Statement to the Information and Analytical Survey (IAS) of the Feasibility Study (FS) and the EIA Report of the FS”, Umweltbundesamt (Environment Agency Austria), Federal Ministry of Agriculture, Forestry, Environment and Water Management, 2013, see <http://www.umweltbundesamt.at/fileadmin/site/publikationen/REP0441.pdf>, accessed 12 May 2015.

⁷⁵⁷ WNA, “Nuclear Power in Ukraine”, Update January 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Ukraine/>, accessed March 2015.

⁷⁵⁸ WNN, “Energoatom and Skoda extend Links”, 28 October 2014, see <http://www.world-nuclear-news.org/C-Energoatom-and-Skoda-extend-links-28101401.html>, accessed 26 March 2015.

Annex 2: Japanese Nuclear Reactor Status

(as of 1 July 2015)

Table 9: Japanese Nuclear Reactor Status (as of 1 July 2015)

Owner	Reactor (Type)	Capacity (MWe)	Startup - Age (Years) (1)	Shutdown (2)	NRA Guidelines Compliance		Shutdown Duration (Years)
					Application ⁷⁵⁹	Approval ⁷⁶⁰	
Kyushu Electric	Sendai-1 (PWR)	890	1983 – 31	10/05/11	08/07/13	27/05/15	4.2
	Sendai-2 (PWR)	890	1985 – 29	01/09/11	08/07/13	27/05/15	3.8
	Genkai-2 (PWR)	559	1980 – 34	29/01/11			4.5
	Genkai-3 (PWR)	1180	1993 – 21	11/12/10	12/07/13		4.6
	Genkai-4 (PWR)	1180	1996 – 18	25/12/11	12/07/13		3.6
Shikoku Electric	Ikata-1 (PWR)	556	1977 – 37	04/09/11			3.8
	Ikata-2 (PWR)	556	1981 – 33	13/01/12			3.5
	Ikata-3 (PWR)	890	1994 – 20	29/04/11	08/07/13		4.3
Hokkaido Electric	Tomari-1 (PWR)	579	1988 – 26	22/04/11	08/07/13		4.3
	Tomari-2 (PWR)	579	1990 – 24	26/08/11	08/07/13		3.9
	Tomari-3 (PWR)	912	2009 – 5	05/05/12	08/07/13		3.2
	Shimane-2 (BWR)	820	1988 – 26	27/01/12	25/12/13		3.5

⁷⁵⁹ All dates from NRA, “Status of Applications for Review of Commercial Power Reactors”, 1 April 2015, see <http://www.nsr.go.jp/data/000067275.pdf>, accessed 13 June 2015.

⁷⁶⁰ All dates from JAIF, “Nuclear Power Plants in Japan—In operation and under construction”, as of 10 June 2014, see http://www.jaif.or.jp/english/news_images/pdf/ENGNEWS02_1402531967P.pdf, accessed 13 June 2014.

Owner	Reactor (Type)	Capacity (MWe)	Startup - Age (Years)	Shutdown	NRA Guidelines Compliance		Shutdown Duration (Years)
					Application	Approval	
Kansai Electric	Takahama-1 (PWR)	826	1974 – 40	10/01/11	17/03/15		4.5
	Takahama-2 (PWR)	826	1975 – 39	25/11/11	17/03/15		3.7
	Takahama-3 (PWR)	870	1984 – 30	20/02/12	08/07/13		3.4
	Takahama-4 (PWR)	870	1984 – 30	21/07/11	08/07/13		4.0
	Ohi-1 (PWR)	1175	1977 – 37	10/12/10			4.6
	Ohi-2 (PWR)	1175	1978 – 36	16/12/11			3.6
	Ohi-3 (PWR)	1180	1991 – 23	02/09/13	08/07/13		1.8
	Ohi-4 (PWR)	1180	1992 – 22	15/09/13	08/07/13		1.8
	Mihama-3 (PWR)	826	1976 – 38	14/05/11	17/03/15		4.2
Tokyo Electric	Kashiwazaki-Kariwa-1 (BWR)	1100	1985 – 29	06/08/11			3.9
	Kashiwazaki Kariwa-2 (BWR)	1100	1990 – 24	19/02/07			8.4
	Kashiwazaki Kariwa-3 (BWR)	1100	1992 – 22	16/07/07			8.0
	Kashiwazaki Kariwa-4 (BWR)	1100	1993 – 21	16/07/07			8.0
	Kashiwazaki Kariwa-5 (ABWR)	1100	1989 – 25	25/01/12			3.5
	Kashiwazaki Kariwa-6 (ABWR)	1365	1996 – 18	23/06/12	27/09/13		3.3
	Kashiwazaki Kariwa-7 (BWR)	1365	1996 – 18	23/08/11	27/09/13		3.9
JAPC	Tsuruga-2 (PWR)	1160	1986 – 28	29/08/11			3.9
	Tokai-2 (BWR)	1100	1978 – 36	21/05/11	20/05/14		4.2

Owner	Reactor (Type)	Capacity (MWe)	Startup - Age (Years)	Shutdown	NRA Guidelines Compliance		Shutdown Duration (Years)
					Application	Approval	
Chubu Electric	Hamaoka-3 (BWR)	1100	1987 – 27	29/11/10	15/06/15 ⁷⁶¹		4.7
	Hamaoka-4 (BWR)	1137	1993 – 21	13/05/11	14/02/14		4.2
	Hamaoka-5 (ABWR)	1380	2005 – 9	14/05/11	30/05/14		4.2
Tohoku Electric	Higashidori-1 (BWR)	1100	2005 – 9	06/02/11	20/06/14		4.4
	Onagawa-1 (BWR)	524	1983 – 31	10/09/11			3.8
	Onagawa-2 (BWR)	825	1994 – 20	06/11/10	27/12/13		4.7
	Onagawa-3 (BWR)	825	2001 – 13	10/09/11			3.8
Hokuriku Electric	Shika-1 (BWR)	540	1993 – 21	01/03/11			4.3
	Shika-2 (ABWR)	1358	2005 – 9	11/03/11	12/08/14		4.3
JAEA	Monju (FBR)	280	1995 – 19	08/12/95			19.6

Notes: (1) Grid connection year

(2) The shutdown dates are from Japan Atomic Industrial Forum (JAIF), “Nuclear Power Plants in Japan - In operation and under construction”, as of 10 June 2014, see http://www.jaif.or.jp/english/news_images/pdf/ENGNEWS02_1402531967P.pdf, accessed 13 June 2014.

(3) NRA Draft Review Report on Sendai.

Comments

WNISR considers that the 10 Fukushima units are shut down and will never restart. All of the remaining 40 reactors (including Monju) fall under the criteria of the WNISR Long Term Outage (LTO) category since none of them has generated any electricity in 2014 nor in the first half of 2015.

All these units should also be included in the Long-term Shutdown (LTS) under the criteria set by the International Atomic Energy Agency (IAEA).⁷⁶² However, the Japanese government and the

⁷⁶¹ According to WNN, “Safety review sought for Hamaoka 3”, 17 June 2015, see <http://www.world-nuclear-news.org/RS-Safety-review-sought-for-Hamaoka-3-1706154.html>, accessed 17 June 2015.

⁷⁶² IAEA, Power Reactor Information System, “Glossary of Terms in PRIS Reports”, see <http://www.iaea.org/pris/Glossary.aspx>, accessed 6 June 2014.

IAEA have chosen to limit the LTS classification to only one reactor (Monju) and consider all of the other reactors as “in operation”.

In March 2015, five units were officially closed and thus taken off the list of units in LTO. These are Mihama-1 and -2 and Tsuruga-1 on 17 March 2015 and Genkai-1 and Shimane-1 on 18 March 2015.

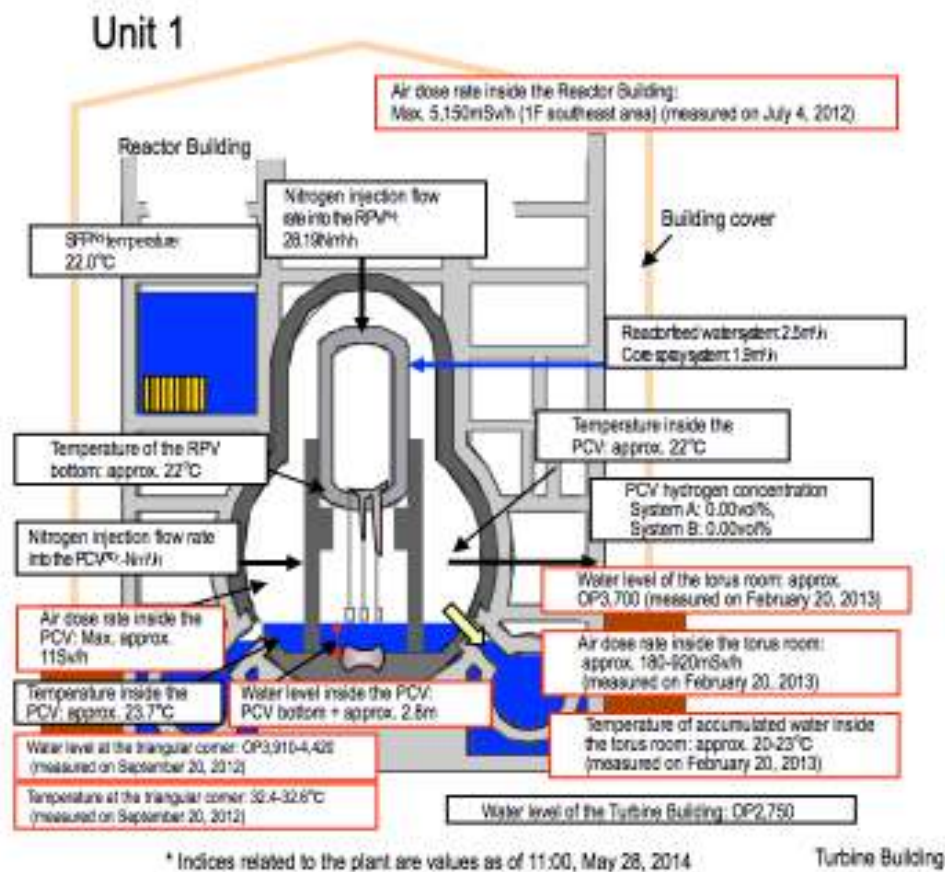
In July 2013, the NRA established a three-step review process for any company planning a reactor restart, designed to ensure that facilities meet the new regulatory requirements. The three steps of this process, are summed up as: “Permission for change in reactor installation license”, “Approval of plan for construction works”, and “Approval of operational safety programs”.

The NRA received Applications for Review for 25 reactors from 11 power companies. Half were submitted in July 2013, immediately after the regulation was first issued. As of 1 July 2015, only Sendai-1 and -2, on 27 May 2015, received Final Approval for Operation.⁷⁶³ Takahama-3 and -4, on 12 February 2015, passed the first of the three approval levels.

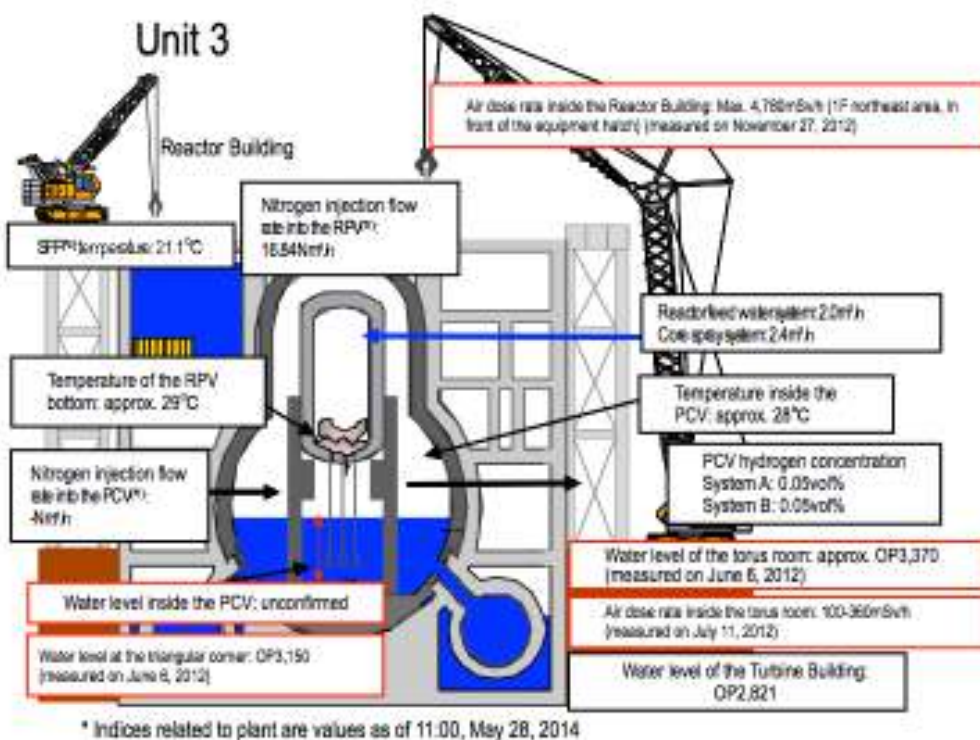
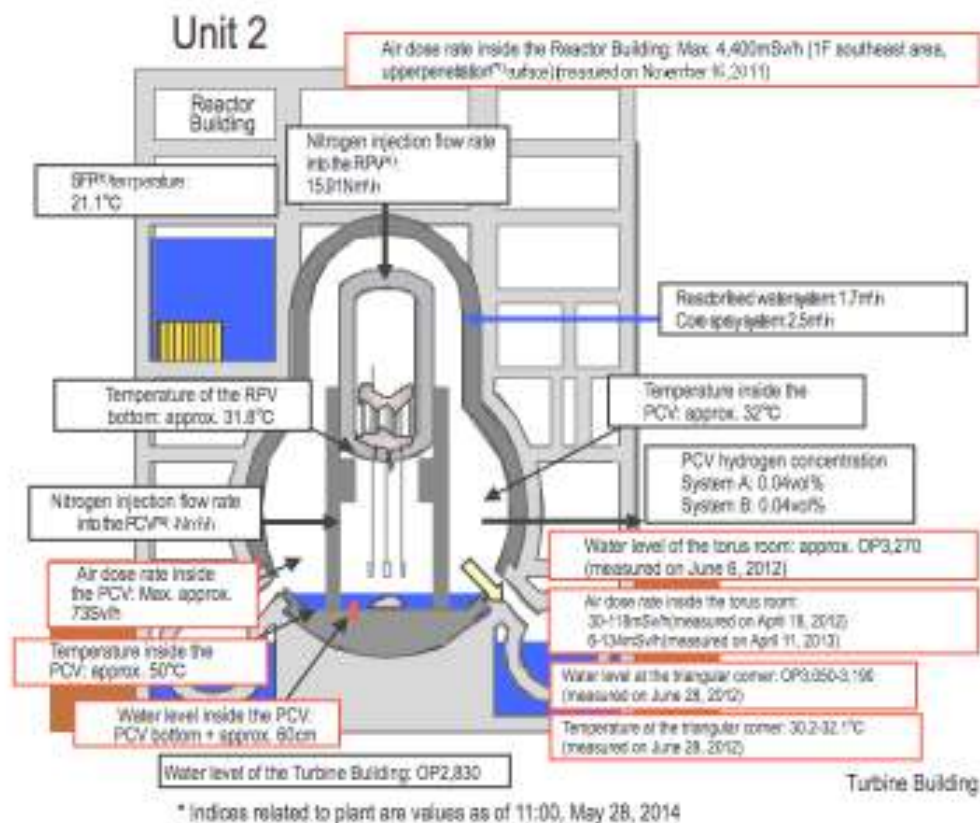
⁷⁶³ NRA, "Approval of Operational Safety Programs for Kyushu Electric Power Company's Sendai Nuclear Power Station Units 1 and 2", 27 May 2015, see <http://www.nsr.go.jp/data/000108443.pdf>, accessed 9 July 2015.

Annex 3: Schematic View and Various Indicators of the Fukushima Daiichi Units 1 to 3

Figure 36: Fukushima: Schematic View and Various Indicators of Units 1 to 3



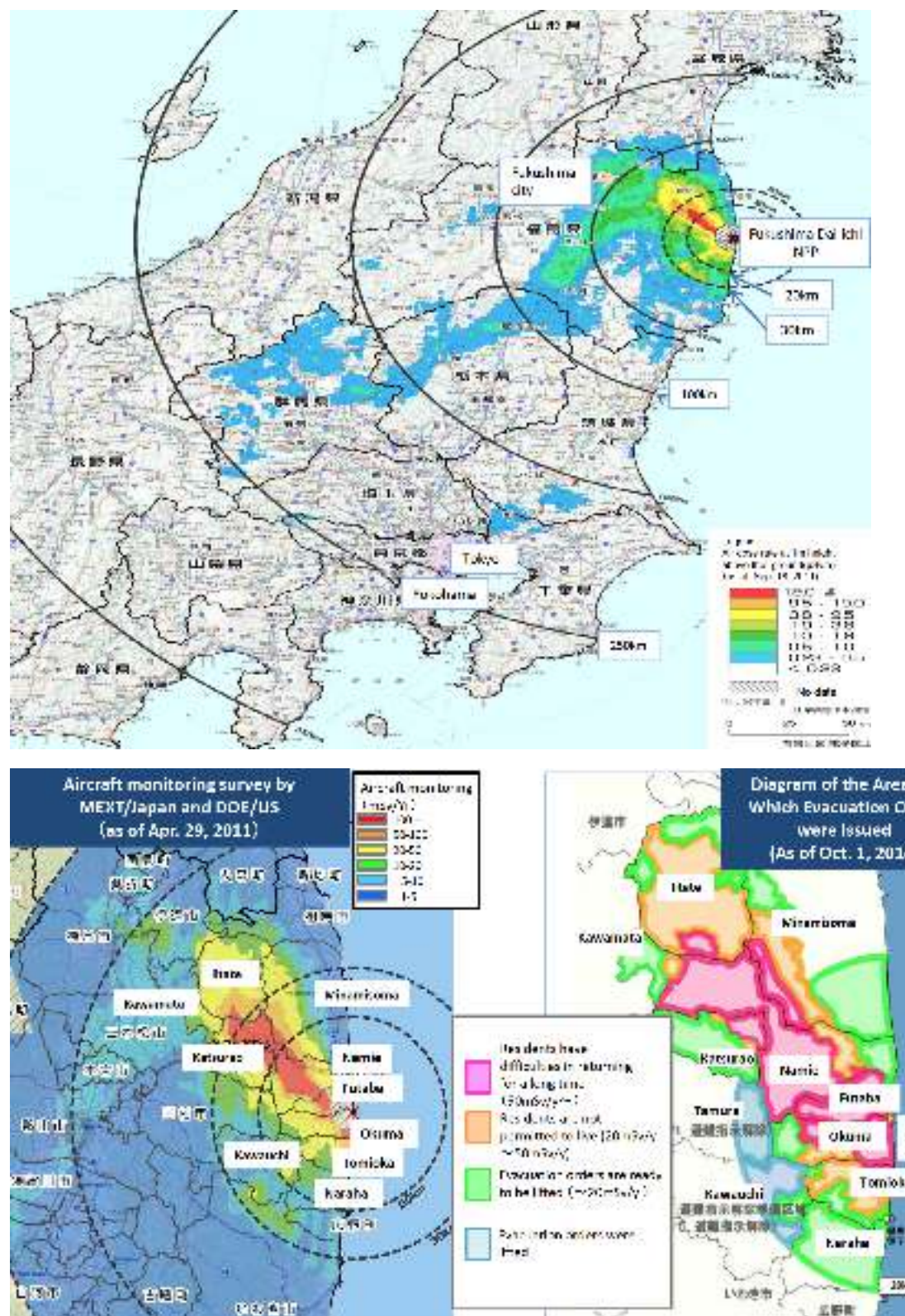
Source: METI, "Progress Status and Future Challenges of the Mid-and-Long-Term Roadmap toward the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1-4 (Outline)", 29 January 2015.



Note: SFP: Spent Fuel Pool, RPV: Reactor Pressure Vessel, PCV: Primary Containment Vessel

Annex 4: Fukushima—Radioactive Contamination and Current Evacuation Zones

Figure 37: Fukushima: Radioactive Contamination and Current Evacuation Zones



Source: Ministry of the Environment, "Progress on Off-site Cleanup Efforts in Japan", April, 2015.

Notes: **Top:** Air dose at 1 m height above the ground (as of 18 September 2011)

Bottom left: Aircraft monitoring survey by MEXT/Japan and DOE/US (as of 29 April 2011)

Bottom right: Diagram of the areas to which evacuation orders were issued (as of 1 October 2014)

Annex 5: Definition of Credit Rating by the Main Agencies

Table 10: 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+		
Baa2	P-3	BBB	A-3	BBB	F3	Lower medium grade
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		

Note: S&P=Standard & Poor's

Source: Wikipedia, 2012

Annex 6: Status of Lifetime Extensions in the U.S.

(as of 15 June 2015)

Table 11: Submitted and Expected Applications for Lifetime Extensions of U.S. Nuclear Power Plants

Plant	Grid Connection	Extension Application	Extension Granted
Calvert Cliffs 1, 2	1/75, 12/76	4/98	3/00
Oconee 1, 2, 3	5/73, 12/73, 9/74	7/98	5/00
Arkansas 1 (Ano-1)	8/74	2/00	6/01
Hatch 1, 2	11/74, 9/78	3/00	1/02
Turkey Point 3, 4	11/72, 6/73	9/00	6/02
Surry 1, 2	7/72, 3/73	5/01	3/03
North Anna 1, 2	4/78, 8/80	5/01	3/03
McGuire 1, 2	9/81, 5/83	6/01	12/03
Catawba 1, 2	1/85, 5/86	6/01	12/03
Peach Bottom 2, 3	2/74, 9/74	7/01	5/03
St Lucie 1, 2	5/76, 6/83	11/01	10/03
Fort Calhoun	8/73	1/02	11/03
Robinson 2	9/70	6/02	4/04
Ginna	12/69	8/02	5/04
Summer	11/82	8/02	4/04
Dresden 2, 3	4/70, 7/71	1/03	10/04
Quad Cities 1, 2	4/72, 5/72	1/03	10/04
Farley 1, 2	8/77, 5/81	9/03	5/05
Arkansas 2 (Ano-2)	12/78	10/03	6/05
Cook 1, 2	2/75, 3/78	11/03	8/05
Browns Ferry 1, 2, 3	10/73, 8/74, 9/76	1/04	5/06
Millstone 2, 3	11/75, 2/86	1/04	11/05
Point Beach 1, 2	11/70, 8/72	2/04	12/05
Nine Mile Point 1, 2	11/69, 8/87	5/04	10/06
Brunswick 1, 2	12/76, 4/75	10/04	6/06

Plant	Grid Connection	Extension Application	Extension Granted
Monticello	3/71	3/05	11/06
Palisades	12/71	3/05	1/07
Oyster Creek	9/69	7/05	4/09
Pilgrim	7/72	1/06	5/12
Fitzpatrick	2/75	8/06	9/08
Susquehanna 1, 2	11/82, 7/84	9/06	11/09
Wolf Creek	6/85	10/06	11/08
[Shearon] Harris	1/87	11/06	12/08
Indian Point 2, 3	6/73, 4/76	4/07	
Vogtle 1, 2	3/87, 4/89	6/07	6/09
Beaver Valley 1, 2	6/76, 8/87	8/07	11/09
Three Mile Island 1	6/74	1/08	10/09
Prairie Island 1, 2	12/73, 12/74	4/08	6/11
Cooper	5/74	9/08	11/10
Duane Arnold	5/74	10/08	12/10
Palo Verde 1, 2, 3	6/85, 5/86, 11/87	12/08	4/11
Hope Creek	8/86	8/09	7/11
Salem 1, 2	12/76, 6/81	8/09	6/11
Diablo Canyon 1, 2	11/84, 10/85	11/09	
Columbia	5/84	1/10	5/12
Seabrook	5/90	6/10	
Davis-Besse	8/77	8/10	
South Texas 1, 2	3/88, 4/89	10/10	
Limerick 1, 2	4/85, 9/89	6/11	10/14
Grand Gulf	10/84	11/11	
Callaway	10/84	12/11	3/15
Sequoyah 1, 2	7/80, 12/81	1/13	
Braidwood 1, 2	7/87, 5/88	5/13	
Byron 1, 2	3/85, 2/87	5/13	

Plant	Grid Connection	Extension Application	Extension Granted
Fermi 2	9/86	4/14	
LaSalle 1, 2	9/82, 4/84	Expected 12/14	
Perry 1	12/86	Expected 9/15	
Waterford 3	3/85	Expected 1-3/16	
River Bend 1	12/85	Expected 1-3/17	
Comanche Peak 1, 2	4/90, 4/93	Expected 7-9/18	
Clinton 1	4/87	Expected 1-3/21	

Sources:

- For grid connection dates:

<https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US>,

- For life extension dates: <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-reactor-license-renewal.html>, updated 12 December 2014, accessed 16 June 2015 and <http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html>, reviewed 21 April 2015, accessed 16 June 2015.

Notes:

(1) Pairs of reactors marked † have significantly different designs.

(2) The STARS Alliance of nuclear power plant owners has informed the NRC it will submit applications for life extensions for two unnamed units in 2016 and 2018. The Comanche Peak reactors are the only ones owned by STARS members that have not already applied for life extension or have had it granted, so it is assumed the application refers to these two units.

(3) Nine Mile Point 2 applied for and received a license extension before its 20th birthday.

(4) Kewaunee and Vermont Yankee facilities both applied for Lifetime Extensions which were granted in February 2011 and June 2011, before Kewaunee was shut down on 7 May 2013 and Vermont Yankee on 29 December 2014.

(5) Crystal River's Unit 3 was first connected to the grid January 1977. An application for a lifetime extension was submitted in December 2008, then withdrawn on 6 February 2013. Crystal River-3 was permanently shut down on 20 February 2013.

Annex 7: Chinese Nuclear Reactor Status

(as of 10 June 2015)⁷⁶⁴

Table 12: Chinese Nuclear Power Plants *in Operation* and *under Construction*

1. Chinese Nuclear Power Plants *in Operation*

Status	Reactor ⁷⁶⁵	Reactor Type	Rated Power (gross MWe)	Construction Start	Grid Connection	Commercial Operation ⁷⁶⁶
Operating	CEFR ⁷⁶⁷	FBR	25	10/05/00	21/07/2011	
	Daya Bay-1	PWR	984	07/08/87	31/08/93	01/02/94
	Daya Bay-2	PWR	984	07/04/88	07/02/94	06/05/94
	Fangjiashan-1	PWR	1089	26/12/08	04/11/14	15/12/14
	Fangjiashan-2	PWR	1089	17/07/09	12/01/15	12/02/15
	Fuqing-1	PWR	1089	21/11/08	20/08/14	22/11/14
	Hongyanhe-1	PWR	1119	18/08/07	17/02/13	06/06/13
	Hongyanhe-2	PWR	1119	28/03/08	23/11/13	13/05/14
	Hongyanhe-3	PWR	1119	07/03/09	23/03/15 ⁷⁶⁸	
	Ling Ao-1	PWR	990	15/05/97	26/02/02	28/05/02
	Ling Ao-2	PWR	990	28/11/97	14/09/02	08/01/03
	Ling Ao-3	PWR	1086	15/12/05	15/07/10	20/09/10
	Ling Ao-4	PWR	1086	15/06/06	03/05/11	07/08/11
	Ningde-1	PWR	1089	18/02/08	28/12/12	15/04/13
	Ningde-2	PWR	1089	03/11/08	04/01/14	21/04/14
	Ningde-3	PWR	1089	08/01/10	21/03/15 ⁷⁶⁹	10/06/15

⁷⁶⁴ Data from China Nuclear Energy Association (CNEA), “China: List of Nuclear Power Plants in Operation (and under Construction)”, in Chinese, 10 June 2015. Unless noted otherwise.

⁷⁶⁵ Nomenclature IAEA-PRIS.

⁷⁶⁶ Dates from China Nuclear Energy Association, “China: List of Nuclear Power Plants in Operation (and under Construction)”, (in Chinese), 10 June 2015. They are not always identical with the dates given by the IAEA-PRIS.

⁷⁶⁷ CNEA does not list the CEFR (China Experimental Fast Reactor) as “in operation”. While it has hardly generated any electricity, it has operated at full power for 72 hours in December 2014. See Xinhua in China Securities Journal, “China experimental fast reactor runs at full capacity”, 19 December 2014, see http://www.cs.com.cn/english/ei/201412/t20141219_4595461.html, accessed 18 June 2015.

⁷⁶⁸ CNEA lists this reactor as “under construction” as of 10 June 2015. However, reportedly grid connection took place on 23 March 2015; see CGN, “Ningde 3, Hongyanhe 3 Connected to Power Grid”, 23 March 2015, see <http://en.cgnpc.com.cn/n1017152/n1017227/c1027996/content.html>, accessed 20 June 2015.

Status	Reactor	Reactor Type	Rated Power (gross MWe)	Construction Start	Grid Connection	Commercial Operation
Operating	Qinshan-1	PWR	310	20/03/85	15/12/91	01/04/94
	Qinshan-2-1	PWR	650	02/06/96	06/02/02	15/04/02
	Qinshan-2-2	PWR	650	01/04/97	11/03/04	03/05/04
	Qinshan-2-3	PWR	660	28/04/06	01/08/10	05/10/10
	Qinshan-2-4	PWR	660	28/01/07	25/11/11	08/04/12
	Qinshan-3-1	CANDU	728	08/06/98	19/11/02	31/12/02
	Qinshan-3-2	CANDU	728	25/09/98	12/06/03	24/07/03
	Tianwan-1	PWR	1060	20/10/99	12/05/06	17/05/07
	Tianwan-2	PWR	1060	20/09/00	14/05/07	16/08/07
	Yangjiang-1	PWR	1086	16/12/08	23/12/13	25/03/14
	Yangjiang-2	PWR	1086	04/06/09	10/03/15 ⁷⁷⁰	05/06/15
Total	27 Units Operating		24,714			

⁷⁶⁹ CGN, “Ningde 3, Hongyanhe 3 Connected to Power Grid”, 23 March 2015, see <http://en.cgnpc.com.cn/n1017152/n1017227/c1027996/content.html>, accessed 20 June 2015.

⁷⁷⁰ No date given by CNEA. This date from IAEA-PRIS.

2. Chinese Nuclear Power Plants *Under Construction*

Status	Reactor	Reactor Type	Rated Power (gross MWe)	Construction Start
Under Construction	Changjiang-1	PWR	650	25/04/10
	Changjiang-2	PWR	650	21/11/10
	Fangchenggang-1	PWR	1080	30/07/10
	Fangchenggang-2	PWR	1080	23/12/10
	Fuqing-2	PWR	1089	17/06/09
	Fuqing-3	PWR	1089	31/12/10
	Fuqing-4	PWR	1089	17/11/12
	Fuqing-5	PWR	1200	07/05/15
	Haiyang-1	PWR	1250	24/09/09
	Haiyang-2	PWR	1250	20/06/10
	Hongyanhe-4	PWR	1119	15/08/09
	Hongyanhe- 5	PWR	1119	29/03/15
	Ningde-4	PWR	1089	29/09/10
	Sanmen-1	PWR	1250	29/03/09
	Sanmen-2	PWR	1250	17/12/09
	Shidao Bay	HTG	211	09/12/12
	Taishan-1	PWR	1750	18/11/09
	Taishan-2	PWR	1750	15/04/10
	Tianwan-3	PWR	1060	27/12/12
	Tianwan-4	PWR	1060	27/09/13
	Yangjiang-3	PWR	1086	15/11/10
	Yangjiang-4	PWR	1086	17/11/12
	Yangjiang-5	PWR	1086	18/09/13
	Yangjiang-6	PWR	1086	23/12/13
Total	24 Units Under Construction		26,429	
General Total	27 Units in Operation + 24 Under Construction 51 Reactors			24,714 MWe +26,429 MWe 51,143 MWe

Annex 8: About the Authors

Mycle Schneider is an independent international consultant on energy and nuclear policy based in Paris. He 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). Mycle 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, the European Parliament's Scientific and Technological Option Assessment Panel, and the French Institute for Radiation Protection and Nuclear Safety. Mycle has given evidence and held briefings at national Parliaments in fourteen countries and at the European Parliament. Between 2004 and 2009, he was in charge of the Environment and Energy Strategies lecture of an International MSc at the French Ecole des Mines in Nantes. He has given lectures at 20 universities and engineering schools around the globe. He founded the Energy Information Agency WISE-Paris in 1983 and directed it until 2003. In 1997, along with Japan's Jinzaburo Takagi, he received the Right Livelihood Award, also known as the "Alternative Nobel Prize".

Antony Froggatt works as independent European energy consultant based in London. Since 1997, he has worked as a freelance researcher and writer on energy and nuclear policy issues in the EU and neighboring states. He has worked extensively on EU energy issues for European governments, the European Commission and Parliament, environmental NGOs, commercial bodies, and media. He has given evidence to inquiries and hearings in the parliaments of Austria, Germany, and the EU. He is a part time senior research fellow at the Royal Institute of International Affairs—Chatham House in London. He is a regular speaker at conferences, universities, and training programs across the region. Prior to working freelance, Antony served for nine years as a nuclear campaigner and coordinator for Greenpeace International.

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. Since 1992, she has maintained a world nuclear reactors database and undertakes data modeling work for the World Nuclear Industry Status Report. From 1983 to 2006, she worked in various positions at WISE-Paris, an independent information service on energy and environment issues that she co-founded. Starting in 1989, she developed the computerization of the library and electronic information products. Her responsibilities covered database development, specialized translation, and project management, as well as research activities for specific projects. She is a member of négaWatt (France). She develops EnerWebWatch in the framework of the Coopaname Co-op.

Tadahiro Katsuta holds a PhD in plasma physics from Hiroshima University (1997). He is currently an Associate Professor at Meiji University, Tokyo, Japan. During 2014–15 he is 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

2006–08, he carried out research at the University of Tokyo on separated plutonium issues linked to the Rokkasho reprocessing plant. During 1999–2005, he worked as a researcher at the Citizens Nuclear Information Center (CNIC) in Tokyo.

Jonathon Porritt, Co-Founder & Trustee of [Forum for the Future](#), is an eminent writer, broadcaster and commentator on sustainable development. Forum for the Future is the U.K.'s leading sustainable development charity, with over 100 partner organizations globally. He is a Non-Executive Director of [Willmott Dixon Holdings](#), a Trustee of the Ashden Awards for Sustainable Energy, a Director of Collectively (an online platform celebrating sustainable innovation), and the [Chancellor](#) of Keele University. His previous roles include Director of Friends of the Earth, Co-Chair of the Green Party, Chairman of UNED-UK, Chairman of Sustainability South West, Trustee of World Wildlife Fund (WWF) U.K., Member of the Board of the South West Regional Development Agency, and Chairman of the [U.K. Sustainable Development Commission](#).

M.V. Ramana received his Ph.D. in theoretical physics from Boston University. He is currently with the Nuclear Futures Laboratory and the Program on Science and Global Security at the Woodrow Wilson School of Public and International Affairs, Princeton University, U.S., where he has been assessing nuclear power programs around the world. Ramana is the author of *The Power of Promise: Examining Nuclear Energy in India* (Penguin Books, 2012) and co-editor of *Prisoners of the Nuclear Dream* (Orient Longman, 2003). He is a member of the International Panel on Fissile Materials (IPFM) and the recipient of a Guggenheim Fellowship and a Leo Szilard Award from the American Physical Society.

Steve Thomas is Professor of Energy Policy and Director of Research for the Business School, University of Greenwich. He holds a BSc (honors) degree in Chemistry from Bristol University and has been working in energy policy analysis since 1976. His main research interests are reforms of energy industries, economics and policy towards nuclear power, and corporate policies of energy industry companies. Recent clients include Public Services International, the European Federation of Public Service Unions, the Nonproliferation Policy Education Center (U.S.), Energywatch (U.K.), and Greenpeace International.

Annex 9: Abbreviations

ABB – Asea Brown Boveri

ABWR – Advanced Boiling Water Reactor

AHWR – Advanced Heavy Water Reactor

AEA – Atomic Energy Act

AECL – Atomic Energy Canada Limited

AFP – Agence France Presse

AGR – Advanced Gas cooled Reactor

ALPS – Advanced Liquid Processing System

ANRE – Ministry of Economics, Trade and Industry's Agency for Natural Resources and Energy, Japan

APWR – Advanced Pressurized Water Reactor

ARENH – Accès Régulé à l'Electricité Nucléaire Historique

ASN – Nuclear Safety Authority, France

B&W – Babcock & Wilcox

BNDES – Brazilian National Development Bank

BNEF – Bloomberg New Energy Finance

BP – Beyond Petroleum

BWR – Boiling Water Reactor

CANDU – Canadian Deuterium Uranium

CB&I – Chicago Bridge & Iron

CEA – French Atomic Energy Commission

CEFR – China Experimental Fast Reactor

CEIP – Carnegie Endowment for International Peace

CEO – Chief Executive Officer

CEZ – České Energetické Závody

CFD – Contract for Difference

CFSI – Counterfeit, Fraudulent and Suspect Items

CGN or CGNPC – Chinese General Nuclear Power Company

CNEA – Comisión Nacional de Energía Atómica, Argentina or China Nuclear Energy Association

CNIC – Citizens Nuclear Information Center

CNNC – Chinese National Nuclear Company

CNSC – Canadian Nuclear Safety Commission

COL – Construction and Operation License

COLA – Combined Operating License Applications

DAE – Department of Atomic Energy, India

DECC – Department of Energy and Climate Change, U.K.

DOE – Department of Energy, U.S. or South Africa

EBRD – European Bank for Reconstruction and Development

ECJ – European Court of Justice

EDF – Électricité de France

EIA – U.S. Energy Information Administration, or Environmental Impact Assessment

EITB – Euskal Irrati Telebista

ENEC – Emirates Nuclear Energy Corporation

ENEL – Ente Nazionale per l'energia Elettrica — National Agency for Electric Energy, Italy

ENP – European Neighborhood Policy

ENSI – Eidgenössische Nuklearsicherheitsinspektorat

ENTSO-E – European Network of Transmission System Operator for Electricity

EPR – European Pressurized Water Reactor (EU), or Evolutionary Pressurized Water Reactor (U.S.)

ERD – Economic Relations Division of Bangladesh

ESBWR – Economic Simplified Boiling Water Reactor

EU – European Union

EU15 – the 15 Western European countries of the EU

EU28 – European Union 28 Member States

EVN – Electricity of Vietnam

EWEA – European Wind Energy Association

FANC – Federal Agency for Nuclear Control, Belgium

FANR – Federal Authority for Nuclear Regulation, United Arab Emirates

FEPCO – Federation of Electric Power Companies

FL3 – Flamanville-3

FOAK – first-of-a-kind

FPU – Floating Point Unit

FS – Feasibility Study, or Frankfurt School

FY(2014) – Financial Year

GDF – Gaz de France

GDA – Generic Design Assessment

GDP – Gross Domestic Product

GE – General Electric

GEIS – Generic Environmental Impact Statement

GWEC – Global Wind Energy Council

HSE’ND – Health and Safety Executive’s Nuclear Directorate, U.K.

HTR – High Temperature Reactor

I&C – Instrumentation and Control

IAB – International Advisory Board

IAEA – International Atomic Energy Agency

IAS – Information and Analytical Survey

ICRP – International Commission on Radiological Protection

IEA – International Energy Agency (OECD)

IEAC – International Energy Advisory Council

IEEE – Institute of Electrical and Electronics Engineers

IISS – International Institute for Strategic Studies

INDC – Intended Nationally Determined Contribution

INES – International Nuclear Event Scale

INPRO – International Project on Innovative Nuclear Reactors and Fuel Cycles

INS – Indian Nuclear Society

INSAC – Indian Nuclear Society Annual Conference

IPFM – International Panel on Fissile Materials

IRID – International Research Institute for Nuclear Decommissioning

IRIS – International Reactor Innovative and Secure (Design)

IRPA – International Radiation Protection Association

IRSN – Institut de Radioprotection et de Sûreté Nucléaire — Institute for Radiological Protection and Nuclear Safety, France

ISIS – Institute for Science and International Security

JAEC – Japan Atomic Energy Commission or Jordanian Atomic Energy Commission

JAIF – Japan Atomic Industrial Forum

JAPC – Japan Atomic Power Company

JAPEIC – Japan Power Engineering And Inspection Corporation

JETRO – Japan External Trade Organization

JNTO – Japan National Tourism Organization

JSC – Joint Stock Company

JSW – Japan Steel Works

KA-CARE – King Abdullah City for Atomic and Renewable Energy

KEPCO – Korea Electric Power Corporation, South Korea or Kansai Electric Power Corporation, Japan

KGHM – Copper Mining and Smelting Industrial Complex, Poland

KHNP – Korea Hydro and Nuclear Power

KINS – Korean Institute of Nuclear Safety

LCOE – Levelized Cost of Electricity

LNG – Liquefied Natural Gas

LOCA – Loss-of-Coolant-Accident

LTO – Long Term Outage

LTS – Long Term Shutdown

METI – Ministry of Economics, Trade and Industry, Japan

MEXT – Ministry of Education, Culture, Sports, Science and Technology

MHI – Mitsubishi Heavy Industries

MNPP – Medzamor Nuclear Power Plant, Armenia

MOE – Ministry of Environment, Japan

MoU – Memorandum of Understanding

MOX – Mixed Oxide Fuel

MSC – Mycle Schneider Consulting

NCA – Nuclear Cooperation Agreement

NDF – Nuclear Damage Compensation and Decommissioning Facilitation Corporation

NEA – Nuclear Energy Agency

NEI – *Nuclear Engineering International* or Nuclear Energy Institute

NERI – Nuclear Energy Research Initiative of the U.S. DOE

NEXI – Nippon Export and Investment Insurance

NGO – Non-Governmental Organization

NISA – Nuclear And Industrial Safety Agency

NIW – Nuclear Intelligence Weekly

NNEGC – National Nuclear Energy Generating Company, Ukraine

NNSA – National Nuclear Safety Administration, China

NPAD – New Politics Alliance for Democracy

NPCIL – Nuclear Power Corporation of India Ltd

NPP – Nuclear Power Plant

NPS – National Policy Statement, U.K.

NPT – Non-Proliferation Treaty

NRA – Nuclear Regulation Authority, Japan

NRC – Nuclear Regulatory Commission, U.S.

NRN – Nuclear Reactor Regulation

NSG – Nuclear Suppliers Group

NSSC – Nuclear Safety and Security Commission, Korea

NTI – Nuclear Threat Initiative

NW – *Nucleonics Week* (McGraw Hill)

OECD – Organisation for Economic Development and Co-operation

OKG – Oskarshamns Kraftgrupp AB, Sweden

OL3 – Olkiluoto-3

OL4 – Olkiluoto-4

O&M – Operation & Maintenance

ONR – Office for Nuclear Regulation, U.K.

OPG – Ontario Power Generation

PAEC – Pakistan Atomic Energy Commission

PBMR – Pebble Bed Modular Reactor

PCV – Primary Containment Vessel

PFBR – Prototype Fast Breeder Reactor

PGE – Polska Grupa Energetyczna, Poland

PJM – Pennsylvania-New Jersey-Maryland Interconnection LLC

PLEC – Nuclear Power Plant Life Engineering Center, Japan

PLEX – Plant Life Extension

PPA – Power Purchase Agreement

PRIS – Power Reactor Information System

PSC – Public Service Commission, (Georgia) USA

PSGS – Program on Science and Global Security

PTI – Press Trust of India

PV – Photovoltaic

PWR – Pressurized Water Reactor

R&D – Research & Development

RBMK – Light water cooled, graphite moderated reactor (Soviet design)

RCPs – Reactor Coolant Pumps

RE – Renewable Energy

RPS – Renewable Portfolio Standards

RPV – Reactor Pressure Vessel

RTE – Réseau de Transport d'Électricité, France

RWE – Rheinisch-Westfälisches Elektrizitätswerk

S&P – Standard & Poor's

SCRO – State Council Research Office, China

SCE&G – South California Electric & Gas

SE – Slovenské Elektrárne ; Slovak Electric

SEA – Strategic Environmental Assessment

SES – Schweizerische Energie-Stiftung

SFP – Spent Fuel Pool

SFR – Sodium-cooled Fast Reactor

SIEAC – Seoul International Advisory Council

SMR – Small Modular Reactor

SNN – Societatea Nationala Nuclearelectrica — Power Generating, and Nuclear Fuel Manufacturing National Society, Romania

SNPTC – State Nuclear Power Technology Corporation, China

STUK – Finnish Radiation and Nuclear Safety Authority

TEPCO – Tokyo Electric Power Company

TMMOB – Chamber of Turkish Engineers and Architects

TSO – Technical Support Organization (of the French Nuclear Safety Authorities)

TVA – Tennessee Valley Authority

TVO – Teollisuuden Voima Tyj

UAE – United Arab Emirates

UBS – Union Bank of Switzerland

UNECE – United Nations Economic Commission for Europe

UNEP – United Nations Environment Programme

UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation

VAT – Value Added Tax

VEB – Vnesheconombank

Voimaosakeyhtiö SF – Voimaosakeyhtiö Suomi Finland

VVER – Light Water Reactor – Soviet/Russian design

WNA – World Nuclear Association

WNISR – *World Nuclear Industry Status Report*

WNN – *World Nuclear News*

WRI – World Resources Institute

WSJ – *Wall Street Journal*

WWF – World Wildlife Fund

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)

mSv – millisievert

mSv/h – millisievert per hour

Sv – Sievert

Sv/h – Sievert per hour

Sv/y – Sievert per year

Annex 10: Status of Nuclear Power in the World

Table 13: Status of Nuclear Power in the World (as of 1 July 2015)

Country	Nuclear Reactors ⁷⁷¹				Power ⁷⁷²	Energy ⁷⁷³
	Operate (Reactors)	Capacity (MWe)	Average Age (Years)	Under Construction ⁷⁷⁴ (Reactors)	Share of Electricity	Share of Commercial Primary Energy
Argentina	3	1 627	25	1	4% (=)	1.5% (-)
Armenia	1	375	35		31% (+)	?%
Belarus				2		
Belgium	6	5 480	34		47.5% (-)	13% (-)
Brazil	2	1 884	24	1	3% (=)	1% (=)
Bulgaria	2	1 926	26		32% (+)	20% (=)
Canada	19	13 500	32		17% (=)	7% (=)
China	27	23 079	7	24	2% (=)	1% (=)
Czech Republic	6	3 904	24		36% (=)	17% (=)
Finland	4	2 752	36	1	35% (+)	21% (=)
France	58	63 130	30	1	77% (+)	41.5% (+)
Germany	8	10 799	29		16% (=)	7% (=)
Hungary	4	1 889	30		54% (+)	18% (=)
India	20	5 215	19	6	3.5% (=)	1% (=)
Iran	1	915	4		1.5% (=)	<1% (=)
Japan ⁷⁷⁵					0.0% (-)	0.0% (-)
Mexico	2	1 330	24		6% (+)	1% (=)
Netherlands	1	482	42		4% (+)	1% (=)
Pakistan	3	690	21	2	4% (=)	1% (=)

⁷⁷¹ Mycle Schneider Consulting, based on IAEA-PRIS database, July 2015, and others.

⁷⁷² BP, "Statistical Review of World Energy", June 2015.

⁷⁷³ BP, "Statistical Review of World Energy", June 2015.

⁷⁷⁴ As of 1 July 2015.

⁷⁷⁵ The average age of the Japanese fleet is 26 years. Currently all reactors are in Long Term Outage (LTO).

Country	Operate (Reactors)	Capacity (MWe)	Average Age (Years)	Under Construction (Reactors)	Share of Electricity	Share of Commercial Primary Energy
Romania	2	1 300	14		18.5% (-)	8% (=)
Russia	34	24 654	31	8	19% (+)	6% (=)
Slovakia	4	1 816	24	2	57% (+)	23% (+)
Slovenia	1	688	34		37% (+)	?
South Africa	2	1 860	31		6% (=)	3% (=)
South Korea	24	21 670	19	4	30% (+)	13% (+)
Spain	7	7 121	31		20% (=)	10% (=)
Sweden	9	9 012	36		41.5% (-)	29% (=)
Switzerland	5	3 333	40		38% (+)	22% (+)
Taiwan	6	5 032	34		19% (=)	9% (=)
Ukraine	15	13 107	27	2	49% (+)	20% (+)
UAE				3		
United Kingdom	16	9 373	32		17% (-)	8% (=)
USA	99	98 639	36	5	19.5% (=)	8% (=)
EU28	128	119 672	30.6	4	28%(=) ⁷⁷⁶	12% (=)
World Total	391	336 582	28.8	62	11%(=)	4.4%(=)

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⁷⁷⁶ Eurostat, “EU-28 Electricity Production by Source, 2014”, May 2015, see [http://ec.europa.eu/eurostat/statistics-explained/index.php/File:EU-28_Electricity_production_by_source_2014_\(in%25\).png](http://ec.europa.eu/eurostat/statistics-explained/index.php/File:EU-28_Electricity_production_by_source_2014_(in%25).png), accessed 8 July 2015.

Annex 11: Nuclear Reactors in the World “Under Construction”

Table 14: Nuclear Reactors in the World "Under Construction" (as of 1 July 2015)

Country	Units	MWe (net)	Construction Start	Planned Grid Connection
Argentina	1	25		
Carem25			08/02/14	2018 ¹
Belarus	2	2218		
Belarusian-1		1109	06/11/13	2019 ²
Belarusian-2		1109	03/06/14	2020 ³
Brazil	1	1245		
Angra-3			01/06/10	5/2018 ⁴
China⁵	24	24 738		
Changjiang-1		610	25/04/10	4/2015
Changjiang-2		610	21/11/10	2/2016
Fangchenggang-1		1000	30/07/10	6/2015
Fangchenggang-2		1000	23/12/10	2/2016
Fuqing-2		1000	17/06/09	1/2015
Fuqing-3		1000	31/12/10	9/2015
Fuqing-4		1000	01/10/12	7/2017
Fuqing-5		1000	07/05/2015	2019
Haiyang-1		1000	24/09/09	3/2016
Haiyang-2		1000	21/06/10	9/2016
Hongyanhe-4		1000	15/08/09	3/2015
Hongyanhe-5		1000	29/03/2015	2021
Ningde-4		1018	29/09/10	8/2015
Sanmen-1		1000	19/04/09	12/2015
Sanmen-2		1000	17/12/09	6/2016

Country	Units	MWe (net)	Construction Start	Planned Grid Connection
Shandong Shidaowan		200	01/12/12	2/2017
Taishan-1		1660	28/10/09	6/2015
Taishan-2		1660	15/04/10	9/2015
Tianwan-3		990	22/12/12	2/2018
Tianwan-4		990	27/09/13	11/2018
Yangjiang-3		1000	15/11/10	9/2015
Yangjiang-4		1000	01/11/12	7/2017
Yangjiang-5		1000	18/09/13	11/2017
Yangjiang-6		1000	31/12/13	7/2019
Finland	1	1 600		
Olkiluoto-3			12/08/05	2018 ⁶
France	1	1 600		
Flamanville-3			03/12/07	2017 (“marketable production”) ⁷
India	6	3 907		
Kakrapar-3		630	22/11/10	2017 (completion) ⁸
Kakrapar-4		630	22/11/10	2018 (completion) ⁹
Kudankulam-2		917	04/07/02	9/2015 (first criticality) ¹⁰
PFBR		470	23/10/04	2015-2016 (“completion date”) ¹¹
Rajasthan-7		630	18/11/11	2018 (“completion date”) ¹²
Rajasthan-8		630	30/09/11	2019 (“completion date”) ¹³
Pakistan¹⁴	2	630		
Chasnupp-3		315	28/05/11	12/2016 (commercial operation)
Chasnupp-4		315	18/12/11	10/2017 (commercial operation)

Country	Units	MWe (net)	Construction Start	Planned Grid Connection
Russia¹⁵	8	6 262		
BN-800		789	01/01/85	2015 ¹⁶
Leningrad-2-1		1085	25/10/08	2016 (startup) ¹⁷
Leningrad-2-2		1085	15/04/10	2018 (startup) ¹⁸
Novovoronezh-2-1		1114	24/06/08	2016 ¹⁹
Novovoronezh-2-2		1114	12/07/09	2019 ²⁰
Rostov-4		1011	01/01/83	06/2017 ²¹
Severodvinsk Lomonosov-1		32	15/04/07	31/12/19 (commercial operation) ²²
Severodvinsk Lomonosov-2		32	15/04/07	01/12/19 (commercial operation) ²³
Slovakia	2	880		
Mochovce-3		440	01/01/85	11/2016 (first power) ²⁴
Mochovce-4		440	01/01/85	late 2017 (first power) ²⁵
South Korea²⁶	4	5 360		
Shin-Hanul-1		1340	10/07/12	04/2017 (commercial operation) ²⁷
Shin-Hanul-2		1340	19/06/13	04/2018 (commercial operation) ²⁸
Shin-Kori-3		1340	31/10/08	03/2016 (commercial operation) ²⁹
Shin-Kori-4		1340	15/09/09	05/2016 (commercial operation) ³⁰
Ukraine³¹	2	1 900		
Khmelnitski-3		950	01/03/86	2019?
Khmelnitski-4		950	01/02/87	2019?
United Arab Emirates³²	3	4 035		
Barakah-1		1345	01/07/12	2017
Barakah-2		1345	30/05/13	2018
Barakah-3		1345	24/09/14	2019

Country	Units	MWe (net)	Construction Start	Planned Grid Connection
USA	5	5 633		
Virgil C. Summer-2		1117	09/03/13	2019 ³³
Virgil C. Summer-3		1117	02/11/13	2020 ³⁴
Vogtle-3		1117	12/03/13	June 2019 (substantial completion) ³⁵
Vogtle-4		1117	19/11/13	June 2020 (substantial completion) ³⁶
Watts Bar-2		1165	01/12/72	June 2016 (commercial operation) ³⁷
TOTAL	62	59 033	1972-2014	2014-2020

Sources: IAEA-PRIS, MSC, 2015, unless noted otherwise

¹ No startup date in IAEA/PRIS. Commercial operation from WNA, “Nuclear Power in Argentina”, updated May 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Argentina/>, accessed 17 May 2015

² No startup date in IAEA/PRIS. This commercial operation date from WNA, “Nuclear Power in Belarus”, Updated June 2014, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Belarus/>, accessed 7 June 2015.

The Directorate for Nuclear Power Plant Construction (DSAE) indicates a “commissioning date” of 2018. DSAE, “Belarusian Nuclear Power Plant Construction Project Progress at 20%”, 22 April 2015, see <http://www.dsae.by/en/news/official-news/belarusian-nuclear-power-plant-construction-project-progress-at-20-i-0000000904.html>, accessed 8 June 2015.

³ No startup date in IAEA/PRIS. Ibidem.

⁴ Delayed numerous times. Latest “commissioning” estimate from NIW, “Potential and Global Nuclear Newbuild Projects”, 25 April 2014. By the end of 2013, the unit was said to be about half complete.

⁵ Delays officially acknowledged for all 15 pre-2012 construction starts. All dates from Shan Sun, “Challenges during construction of new NPPs”, Huaneng Shandong Shidao Bay Nuclear Power Company, 4 February 2014, see http://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-02-04-02-07-TM-INIG/Presentations/37_S7_China_Sun.pdf, accessed 31 May 2014; table translated in NIW, “China—Sanmen—Two Year Delay Pushes Costs Higher”, 14 March 2014.

⁶ Delayed. After numerous revisions of the original planned commissioning in 2009, the date refers to “commercial operation”. In 2013, Teollisuuden Voima (TVO) was preparing for the possibility that the start of regular electricity production of Olkiluoto 3 may be postponed until year 2016, see TVO, “Information About the Start-up of Olkiluoto 3 Nuclear Power Plant Unit”, 11 February 2013, see <http://www.tvo.fi/news/32>, accessed 11 February 2013. In 2014, TVO decided not to provide any new startup date, TVO, “TVO Does Not Provide an Estimate of the Start-up Time of Olkiluoto 3 Nuclear Power Plant”, see <http://www.tvo.fi/news/190>, accessed 12 February 2014. AREVA, “Updated Schedule for Olkiluoto 3”, 1 September 2014, see <http://www.aveva.com/EN/news-10288/updated-schedule-for-olkiluoto-3.html>; and TVO, “Olkiluoto 3 ready for electricity production in 2018, according to the plant supplier”, 1 September 2014, accessed 1 September 2014.

⁷ Delayed numerous times from the original planned startup date in 2012. EDF’s “Reference Document 2014”, April 2015, states: “In November 2014, the project schedule was revised, with the first marketable production scheduled for 2017”.

⁸ Delayed two years from previous estimates. DAE (Department of Atomic Energy of India) indicates an anticipated completion date of 2017-2018 for Kakrapar 3 & 4. DAE, in Rajya Sabha, “Statement Referred to in Reply to Rajya Sabha Starred Question n°14 for Answer on 23.04.2015 by Shri K.C. Tyagi Regarding Generation of Power by Nuclear Plants”, 23 April 2015, see <http://www.dae.nic.in/writereaddata/parl/budget2015/rssq14.pdf>, accessed 1 May 2015. Earlier planned grid connection (31 March 2015) and commercial operation dates deleted from IAEA/PRIS in August 2013. Expected commercial operation still “June 2015” in NPCIL, “Plants Under Construction, Kakrapar”, see <http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=91>, accessed 8 June 2015.

⁹ Delayed 3 years from previous estimates. DAE indicates an anticipated completion date of 2017-2018 for Kakrapar 3 & 4. DAE, in Rajya Sabha, "Statement Referred to in Reply to Rajya Sabha Starred Question n°14 for Answer on 23.04.2015 by Shri K.C. Tyagi Regarding Generation of Power by Nuclear Plants", 23 April 2015, see <http://www.dae.nic.in/writereaddata/parl/budget2015/rssq14.pdf>, accessed 1 May 2015. Grid Connection (30 September 2015) and commercial operation dates deleted from IAEA/PRIS in August 2013. Expected commercial operation date still "December 2015" in NPCIL, "Plants Under Construction, Kakrapar", see <http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=91>, accessed 8 June 2015.

¹⁰ Delayed numerous times. Construction at least seven years behind schedule. No IAEA/PRIS startup date. This "First Criticality" date from NPCIL, "Plants Under Construction, Kudankulam", see <http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=77>, accessed 6 June 2015.

¹¹ Delayed numerous times. No IAEA start-up date. DAE indicates an anticipated completion date of 2015-2016 for PFBR, in Rajya Sabha, "Statement Referred to in Reply to Rajya Sabha Starred Question n°14 for Answer on 23.04.2015 by Shri K.C. Tyagi Regarding Generation of Power by Nuclear Plants", 23 April 2015, see <http://www.dae.nic.in/writereaddata/parl/budget2015/rssq14.pdf>, accessed 1 May 2015.

¹² Delayed. Startup date (31 March 2016) was deleted from IAEA/PRIS. DAE indicates an anticipated completion date of 2018-2019 for Rajasthan 7 & 8. DAE, in Rajya Sabha, "Statement Referred to in Reply to Rajya Sabha Starred Question n°14 for Answer on 23.04.2015 by Shri K.C. Tyagi Regarding Generation of Power by Nuclear Plants", 23 April 2015, see <http://www.dae.nic.in/writereaddata/parl/budget2015/rssq14.pdf>, accessed 1 May 2015. Expected date of Commercial operation still "June 2016" according to NPCIL, "Plants Under Construction, Rajasthan", see <http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=87>, accessed 6 June 2015.

¹³ Delayed. Startup date (30 September 2016) was deleted from IAEA/PRIS. DAE indicates an anticipated completion date of 2018-2019 for Rajasthan 7 & 8. DAE, in Rajya Sabha, "Statement Referred to in Reply to Rajya Sabha Starred Question n°14 for Answer on 23.04.2015 by Shri K.C. Tyagi Regarding Generation of Power by Nuclear Plants", 23 April 2015, see <http://www.dae.nic.in/writereaddata/parl/budget2015/rssq14.pdf>, accessed 1 May 2015. Expected date of Commercial Operation still "December 2016", according to NPCIL, "Plants Under Construction, Rajasthan", see <http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=87>, accessed 6 June 2015.

¹⁴ Delayed by three months. Dates were deleted from IAEA/PRIS. These dates from WNA, "Nuclear Power in Pakistan", Updated April 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Pakistan/>, accessed 12 June 2015.

¹⁵ No dates for Russian reactors in IAEA/PRIS. All dates ("Start") and other information from WNA, "Nuclear Power in Russia", Updated May 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/>, accessed 6 June 2015, unless otherwise noted.

¹⁶ Delayed numerous times. Criticality in June 2014. Grid connection by the end of 2015 according to a deputy director of Rosatom, quoted by NIW, "Weekly Roundup—Reactor Delays in Russia and South Korea", 24 April 2015. Commercial operation 1/2016 according to IAEA, "Nuclear Reactors in the World 2015", May 2015.

¹⁷ NIW, "Weekly roundup", 20 February 2015. WNA says commercial operation in 2017. Delayed from original startup date in October 2013 (see WNISR 2009).

¹⁸ NIW, "Weekly roundup", 20 February 2015. WNA says commercial operation in 2019.

¹⁹ Delayed from original start-up date on 31 December 2012 (see WNISR2009).

²⁰ Previously announced to start up in 2016.

²¹ Delayed numerous times.

²² Delayed several times. This estimate from WNA Reactor Database, "Akademik Lomonosov 1", see <http://world-nuclear.org/NuclearDatabase/reactordetails.aspx?id=27570&rid=E4152D64-0C6B-475E-86ED-BDADF73D9C19&country=Russian%20Federation>, accessed 8 June 2015.

²³ Delayed several times. This estimate from WNA Reactor Database, "Akademik Lomonosov 2", see <http://world-nuclear.org/NuclearDatabase/reactordetails.aspx?id=27570&rid=A0D78EB7-B62A-48FF-9D78-21A8E4534D90>, accessed 8 June 2015.

²⁴ Delayed numerous times. Latest IAEA/PRIS date was deleted. This estimate from WNA, "Nuclear Power in Slovakia", Updated January 2015, see <http://world-nuclear.org/info/Country-Profiles/Countries-O-S/Slovakia/>, accessed 23 May 2015.

²⁵ Delayed numerous times. Latest IAEA/PRIS date was deleted. WNA, “Nuclear Power in Slovakia”, Updated January 2015, see <http://world-nuclear.org/info/Country-Profiles/Countries-O-S/Slovakia/>, accessed 23 May 2015.

²⁶ No IAEA startup date for any Korean reactor. Dates from KHNP (Korean Hydro and Nuclear Power Co) for Shin-Hanul-1 & 2, and WNA for Shin-Kori-3 & 4 WNA, “Nuclear Power in South Korea”, Updated June 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/South-Korea/>, accessed 8 June 2015.

²⁷ KHNP, “Shin-Hanul #1, 2”, as of 30 April 2015, see <http://cms.khnp.co.kr/eng/shin-ulchin-12/>, accessed 8 June 2015.

²⁸ Previous commercial operation date as of 30 April 2014 was 2/2018. As of July 2014, commercial operation is delayed by two extra months (April 2018). Unchanged since. KHNP, “Shin-Hanul #1, 2”, see <http://cms.khnp.co.kr/eng/shin-ulchin-12/>, accessed 11 June 2015.

²⁹ Delayed again in 2015. Cumulated delay at least 20 months. KHNP, “Shin-Kori #3, 4”, see <http://cms.khnp.co.kr/eng/shin-kori-34/>, accessed 11 June 2015.

³⁰ Delayed in 2014 by at least 3 months. KHNP, “Shin-Kori #3,4”, see <http://cms.khnp.co.kr/eng/shin-kori-34/>, accessed 11 June 2015.

³¹ Delayed numerous times. Latest IAEA/PRIS grid connection dates were deleted. Commercial operation dates from WNA, “Nuclear Power in Ukraine”, Updated 21 May 2015, see <http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Ukraine/>, accessed 8 June 2015.

³² No IAEA startup dates. Dates for three reactors from Emirates Nuclear Energy Corporation (ENEC), “ENEC Submits Operating License Application to FANR for Barakah Units 1 & 2”, 26 March 2015, see <http://www.enec.gov.ae/media-centre/news/content/enec-submits-operating-license-application-to-fanr-for-barakah-units-1>, accessed 23 May 2015.

³³ Delayed again. This date is from NRC, “Quarterly Nuclear Power Deployment Summary—April 2015”, April 2015.

³⁴ Ibidem.

³⁵ Ibidem.

³⁶ Ibidem.

³⁷ Delayed numerous times. This date is from NRC, “Quarterly Nuclear Power Deployment Summary—April 2015”, April 2015.