World Nuclear Industry Status Report 2013

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Steve Thomas
Yukio Yamaguchi
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foreword Peter Bradford

A Mycle Schneider Consulting Project

Paris, London, Kyoto, July 2013

With the support of

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SCHWEIZERISCHE ENERGIE-STIFTUNG
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The World Nuclear Industry Status Report 2013

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MYCLE SCHNEIDER CONSULTING
Project

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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 suggestions of improvement.

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Foreword

By **Peter A. Bradford***

Nuclear power requires obedience, not transparency. The gap between nuclear rhetoric and nuclear reality has been a fundamental impediment to wise energy policy decisions for half a century now. For various reasons in many nations, the nuclear industry cannot tell the truth about its progress, its promise or its perils. Its backers in government and in academia do no better.

Rhetorical excess from opponents of nuclear power contributes to the fog, but proponents have by far the heavier artillery. During the rise and fall of the bubble formerly known as “the nuclear renaissance” in the U.S. many of their tools have been on full display.

Academic and governmental studies a decade ago understated the likely cost of new reactors and overstated their potential contribution to fighting climate change. By 2006 a few U.S. state legislatures had been enticed to expose utility customers to all the risks of building new reactors. Industry-sponsored conferences persuaded businesses and newspapers of an imminent jobs bonanza, ignoring job losses resulting from high electric rates and passing up cheaper, more labor intensive alternatives. These local groups added to the pressure on Congress for more subsidies.

France and Japan were held out as examples of countries that had avoided the timidity and overregulation that had stalled nuclear construction in the U.S. Indeed, it was argued, these nations had even solved the waste problem through their commitment to reprocessing spent fuel.

At times inconsistent tales were told simultaneously. Thus the U.S. Congress was told that the new licensing process and the new generic designs were so untried and environmental opposition so formidable that loan guarantees were needed to lay the risks off on taxpayers. At the same time Wall Street and state legislatures were assured that these new features had chloroformed public opposition and otherwise laid to rest the terrifying industry ghosts embodied by the nine figure dollar losses at Shoreham, Seabrook, WPPSS, and Midland, sites that resonate in U.S. nuclear folklore like Civil War battlefield names.

The renaissance story line was hard to resist. By early 2009, applications for 31 new reactors were pending at the U.S. Nuclear Regulatory Commission. The promises came garnished with tales of remorseful changes of heart from oft-obscure nuclear converts. With few exceptions, the news media - especially television with its thirst for the short and the simple - fell for the renaissance story line.

It is all in ruins now. The 31 proposed reactors are down to four actually being built and a few others lingering on in search of a license, which is good for 20 years. Those four are hopelessly uneconomic but proceed because their state legislatures have committed to finish them as long as a dollar remains to be taken from any electric customer’s pocket. Operating reactors are being closed as uneconomic for the first time in fifteen years.

Still the band plays on. President Obama recently touted new reactors as part of his “all of the above” policy on climate change. But is “all of the above” really a policy? Do we build palaces to avert housing shortages? Don’t we instead prioritize, based on the best information available? U.S. secretaries of energy enthuse that the four new reactors will be completed “on time and on budget”, never mind that they are already behind and over and that “on budget” will mean “well above the cost of creating equivalent low carbon energy more sensibly”.

As always in the face of failure, the industry puts forth new designs as a basis for new promises, now touting small modular reactors with the same fervor that it touted large partially modular reactors a decade ago. Congress finds a few hundred million to preserve these dreams even as its cutbacks shatter so many others.

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A new movie, *Pandora's Promise* (no filmmaker familiar with nuclear history would include "promise" in a title intended to be pronuclear[1]), recently screened at Sundance.

Featuring the same old converts and straw men, it opened in theaters a few weeks ago to tiny audiences and generally unenthusiastic reviews, especially from reviewers knowledgeable about nuclear power[2].

In the astonishing persistence of the global appetite for false nuclear promises lies the critical importance of the *World Nuclear Industry Status Report*.

The Report sets forth in painstaking detail the actual experience and achievements of nuclear energy around the world. It is based for the most part on generally accepted data distinctively graphed for clearer understanding. Where the authors introduce judgment, they explain what they have done and why. The Report has a track record stretching back years. It is much better than the embarrassing exuberances of the International Atomic Energy Agency, the World Nuclear Association or the pronouncements of most national governments. If more journalists would use it for reference, their readers would be spared much of the foolishness that they must now consume.

Most of the myths on which the purported nuclear renaissance rested founder on the rocks of the information presented here.

Is new nuclear power cheaper than alternative ways of meeting energy needs? Of course not. What about low carbon "baseload" alternatives? See page 73ff. Can a country grow its economy by building nuclear reactors? What don't you understand about the employment consequences of imposing rate shock on industrial and commercial customers? Are the consequences of the Fukushima meltowns really being overstated by antinuclear activists? Maybe, but see the chapter on the status of Fukushima.

In short, the nuclear renaissance –whatever it may be called throughout the world - has always consisted entirely of the number of reactors whose excess costs governments were prepared to make mandatory for either customers or taxpayers. Investor capital cannot be conscripted. Investors of the sort that nuclear power must attract study risks carefully. They know the information in this report, and so should everyone else with responsibility for energy decisions that allocate nuclear risk.

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[1] A more accurate use of the word is in M.V. Ramana's aptly titled and excellent history of India's nuclear follies, *The Power of Promise* (Penguin Viking, 2012).

[2] For an insightful example, see Victor Gilinsky and Henry Sokolski, "Pandora's Promise: Is the Issue Really Environmental", Nuclear Intelligence Weekly, June 21, 2013, http://www.npolicy.org/article.php?aid=1219&rtid=1.

Executive Summary and Conclusions

Two years after the Fukushima disaster started unfolding on 11 March 2011, its impact on the global nuclear industry has become increasingly visible. Global electricity generation from nuclear plants dropped by a historic 7 percent in 2012, adding to the record drop of 4 percent in 2011. This *World Nuclear Industry Status Report 2013 (WNISR)* provides a global overview of the history, the current status and the trends of nuclear power programs worldwide. It looks at nuclear reactor units in operation and under construction. Annex 1 provides 40 pages of detailed country-by-country information. A specific chapter assesses the situation in potential newcomer countries. For the second time, the report looks at the credit-rating performance of some of the major nuclear companies and utilities. A more detailed chapter on the development patterns of renewable energies versus nuclear power is also included. Annex 6 provides an overview table with key data on the world nuclear industry by country.

The 2013 edition of the *World Nuclear Industry Status Report* also includes an update on nuclear economics as well as an overview of the status, on-site and off-site, of the challenges triggered by the Fukushima disaster. However, this report's emphasis on recent post-Fukushima developments should not obscure an important fact: as previous editions (see www.WorldNuclearReport.org) detail, the world nuclear industry already faced daunting challenges long before Fukushima, just as the U.S. nuclear power industry had largely collapsed before the 1979 Three Mile Island accident[3]. The nuclear promoters' invention that a global nuclear renaissance was flourishing until 3/11[4] is equally false: Fukushima only added to already grave problems, starting with poor economics.

The performance of the nuclear industry over the year from July 2012 to July 2013 can be summed up as follows:

Operation and Construction Data (1 July 2013)[5]

Operation. There are 31 countries operating nuclear power plants in the world.[6] A total of 427 reactors have a combined installed capacity of 364 GWe[7]. These figures assume the final shutdown of the ten reactors at Fukushima-Daiichi and -Daini. It should be noted that as of 1 July 2013 only two (Ohi-3 and -4) of the 44 remaining Japanese reactors are operating and their future is highly uncertain. In fact, even if four utilities are expected to submit restart requests in July 2013, many observers believe that a large share of the suspended Japanese units will likely never restart.

The nuclear industry is in decline: The 427 operating reactors are 17 lower than the peak in in 2002, while, the total installed capacity peaked in 2010 at 375 GWe before declining to the current level, which was last seen a decade ago. Annual nuclear electricity generation reached a maximum in 2006 at 2,660 TWh, then dropped to 2,346 TWh in 2012 (down 7 percent compared to 2011, down 12 percent from 2006). About three-quarters of this decline is due to the situation in Japan[8], but 16 other countries, including the top five nuclear generators, decreased their nuclear generation too.

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[3] See Nathan Hultman, Jonathan Koomey, "Three Mile Island: The driver of US nuclear power's decline", Bulletin of the Atomic Scientists, May-June 2013, see http://bos.sagepub.com/content/69/3/63, accessed 7 July 2013.

[4] 3/11 refers to the triple disaster earthquake-tsunami-nuclear accident on 11 March 2011.

[5] See Annex 7 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.

[6] Unless otherwise noted, the figures indicated are as of 1 July 2013.

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

[8] The continuing debacle of the Japanese reactors led to the provisional categorization as "in long-term shutdown", see main text for details.

The nuclear share in the world's power generation declined steadily from a historic peak of 17 percent in 1993 to about 10 percent in 2012. Nuclear power's share of global commercial primary energy production plunged to 4.5 percent, a level last seen in 1984.[9] Only one country, the Czech Republic, reached its record nuclear contribution to the electricity mix in 2012.

Age. In the absence of major new-build programs, the unit-weighted average age of the world nuclear reactor fleet continues to increase and in mid-2013 stands at 28 years. Over 190 units (45 percent of total) have operated for 30 years of which 44 have run for 40 years or more.

Construction. Fourteen countries are currently building nuclear power plants, one more than a year ago as the United Arab Emirates (UAE) started construction at Barrakah. The UAE is the first new country in 27 years to have started building a commercial nuclear power plant.

As of July 2013, 66 reactors are under construction (7 more than in July 2012) with a total capacity of 63 GW. The average construction time of the units under construction, as of the end of 2012, is 8 years. However:

- Nine reactors have been listed as "under construction" for more than 20 years and four additional reactors have been listed for 10 years or more.
- Forty-five projects do not have an official planned start-up date on the International Atomic Energy Agency's (IAEA) database.
- At least 23 have encountered construction delays, most of them multi-year. For the remaining 43 reactor units, either construction began within the past five years or they have not yet reached projected start-up dates, making it difficult or impossible to assess whether they are on schedule or not.
- Two-thirds (44) of the units under construction are located in three countries: China, India and Russia.

The average construction time of the 34 units that started up in the world between 2003 and July 2013 was 9.4 years.

Reactor Status and Nuclear Programs

- **Startups and Shutdowns.** Only three reactors started up in 2012, while six were shut down[10] and in 2013 up to 1 July, only one started up, while four shutdown decisions—all in the U.S.—were taken in the first half of 2013.[11] Three of those four units faced costly repairs, but one, Kewaunee, Wisconsin, was running well and had received a license renewal just two years ago to operate up to a total of 60 years; it simply became uneconomic to run. As of 1 July 2013, there were only two reactors operating in Japan and how many others will receive permission to restart and over what timeframe remains highly uncertain.
- **Newcomer Program Delays.** Engagement in nuclear programs has been delayed by most of the potential newcomer countries, including Bangladesh, Belarus, Jordan, Lithuania, Poland, Saudi Arabia and Vietnam.

[9] According to BP, "Statistical Review of World Energy", June 2013.

[10] Shutdown is defined as definitively taken off the grid. The shutdown date is the last day when the reactor generated electricity.

[11] The operator decided in June 2013 to shut down the two San Onofre units in California. However, they have not generated electricity for over a year. So in the WNISR database the units have been withdrawn for the year 2012 rather than 2013.

Construction & New Build Issues

• **Construction Cancellation.** In Russia, one reactor, which had just started construction in 2012 (Baltic-1), was abandoned in May 2013.

• **Construction Starts.** In 2012, construction began on six reactors and on three so far in 2013, including on two units in the U.S. for the first time in three and a half decades. Those two units have been offered over $8 billion in federal loan guarantees and other subsidies whose total rivals their construction cost, and special laws have transferred financial risks to the taxpayers and customers.

• **Certification Delays.** The certification of new reactor designs has continued to be delayed, in the U.S. certification of the Franco-German-designed EPR[12] was pushed back again, this time to 2015. Only the Westinghouse AP1000 has received full generic design approval in the U.S.

• **Construction Start Delays.** In various countries firmly planned construction starts were delayed, most notably in China, where for almost two years, between December 2010 and November 2012, not a single new reactor building site was opened. Furthermore, in the first half of 2013 it did not start any further constructions.

Economics & Finances

• **Capital Cost Increases.** Construction costs are a key determinant of the final nuclear electricity generating costs and many projects are significantly over budget. Cost estimates have increased in the past decade from $1,000 to $7,000 per kW installed. The U.S. Vogtle project, now officially under construction, is built by the same firm whose two previous reactors at that site were originally budgeted at $660 million and were later estimated to have cost $9 billion.

• **State Aid.** The U.K. model of Contract for Difference (CFD), a kind of feed-in tariff agreement for nuclear electricity that is aimed at providing a subsidy scheme for new-build, in the view of many observers, is likely to violate current EU competition rules.

• **Operating Cost Increases.** In some countries, especially the U.S. illustrated by the Kewaunee case, historically low inflation-adjusted operating costs—especially for major repairs—have escalated so rapidly that the average reactor's operating costs is barely below the normal band of wholesale power prices.

• **Post-Fukushima Costs.** Additional costs arising from upgrading and backfitting measures following the lessons of the Fukushima crisis are only beginning to surface. They are likely to have substantial impact on investment as well as operational costs.

• **Income and Debt.** Nine out of 14 major utilities assessed saw their earnings decline over the past five years while 13 constantly increased their debt level.

• **Credit Rating.** Over the past five years, of 15 assessed nuclear utilities, 10 were downgraded by credit rating agency Standard and Poor's, four companies remained stable, while only one was upgraded over the same period. Rating agencies consider nuclear investment risky and the abandoning of nuclear projects explicitly "credit positive".

• **Share Value.** The share value of the world's largest nuclear operator, French state utility EDF, went down by 85 percent over the past five years, while the share price of the world's largest nuclear builder, French state company AREVA, dropped by up to 88 percent.

[12] European Pressurized Water Reactor (in Europe) or Evolutionary Pressurized Water Reactor (in the U.S. and elsewhere).

Fukushima Status Report

This assessment includes analyses of on-site and off-site challenges that have arisen from the 3/11 disaster. To what extent the disaster was triggered by the earthquake or the tsunami or by both in combination cannot yet be conclusively elucidated.

• **On-site Challenges.** Radiation readings inside the reactor buildings of units 1–3 vary between 5 mSv/h and 73 Sv/h[13], which makes human intervention almost impossible. Massive amounts of water, about 360 tons per day, are still pumped into the destroyed reactors via makeshift vinyl tubes that frequently leak. This water, together with a similar additional amount of groundwater, seeps into the basements of the reactor buildings, some of it decontaminated to some degree and re-injected. The amount of radioactive water that cannot be re-used is constantly increasing and has reached 380,000 tons in precarious storage of which 90,000 tons in the basements. It is estimated that 27 times the amount of cesium-137 released into the air in the first three weeks or more than 2.5 times the total amount released at the Chernobyl accident is contained in this water.

• **Off-site Challenges.** More than 150,000 people remain in forced evacuation. About 130,000 compensation claims have been filed. A total of 101 municipalities in 8 prefectures were designated as a "Scheduled Contamination Survey Zone", where annual doses between 1 and 20 mSv are predicted and local authorities are responsible for decontamination work. In addition, the central government is in charge of decontamination efforts in 11 municipalities in Fukushima Prefecture covering 235 km^2, where annual doses exceed 20 mSv. Less than 5 percent of the surface has seen any decontamination efforts.

The worst-case scenario, as depicted by the Chairman of the Japan Atomic Energy Commission in the middle of the crisis in March 2011, remains the collapse of the spent fuel pool of unit 4[14] and a subsequent fuel fire, potentially requiring evacuation of up to 10 million people in a 250 km radius of Fukushima, including a significant part of Tokyo.

Nuclear Power vs. Renewable Energy Deployment

In spite of a slight decrease in global investment in 2012, partly reflecting rapidly falling equipment prices, renewable energy development continues its rapid expansion in both, capacity and generation. China, Germany and Japan, three of the world's four largest economies, as well as India, now generate more power from renewables than from nuclear power.

- **Investment.** Global investment in renewable energy totaled $268 billion[15] in 2012, down from $300 billion the previous year[16] but still five times the 2004 amount. China increased spending by 20 percent to $65 billion and was by far the largest investor. While some big investors (U.S., Germany, Italy) reduced their spending considerably, some smaller players boosted their investments and reached the top ten, including South Africa, which skyrocketed spending by a factor of 200 to reach $5.5 billion, and Japan, which added 75 percent to reach $16 billion.
- **Installed Capacity.** Globally, since 2000, the annual growth rates for onshore wind power have averaged 27 percent and for solar photovoltaics 42 percent. This has resulted in 2012 in 45 GW of wind and 32 GW of solar being installed, compared to a net addition of 1.2 GW of nuclear. China has a total of 75 GW of operating wind power capacity, roughly doubled in each of the past five years.
- **Electricity Generation.** In 2012 wind produced almost 500 TWh and solar power about 100 TWh more than in 2000, while nuclear power generated 100 TWh less. For the first time in 2012

[13] Without massive radiation protection a lethal dose would be reached within minutes.

[14] Pools are above the reactor vessels between the 4th and the 5th floor. The pool of unit 4 contains as much fuel as the 3 others combined.

[15] Does not include any investments in large hydropower projects, but a very small percentage on Carbon Capture and Storage (CCS).

[16] The figure had been corrected upwards from $260 billion after publication of WNISR 2012.

China and India generated more power from wind than from nuclear plants, while in China solar electricity generation grew by 400 percent in one year.

Introduction

On 29 June 2013, the Director General of the International Atomic Energy Agency (IAEA) declared at the Ministerial Conference in St. Petersburg, Russia that “nuclear power will make a significant and growing contribution to sustainable development in the coming decades”. [17] The future will show whether or not nuclear power *will* play an increasing role. In the meantime, the *World Nuclear Industry Status Report 2013* (WNISR) provides a reality check of the current situation and trends of an industry that in the past has rarely been able to fulfill its own promises. The 2012 edition of the WNISR demonstrated that the IAEA consistently overestimated the development of nuclear power in the world[18], a side-effect of “the leading role of the IAEA in promoting peaceful uses of nuclear energy”.[19]

Contrary to the IAEA’s hopes for the future, this edition of the WNISR shows that nuclear power generation experienced a drop of 7 percent in 2012, larger even than the previous year’s record 4 percent decline. As in previous editions, this report provides many diverse health indicators of the nuclear industry, including numbers of reactors operating, under construction, installed capacities, and extensive country-by-country assessments of nuclear programs around the world. As in the past two editions, a chapter is included that compares certain trends in the nuclear industry with developments in the renewable energy industry.

A greatly extended economic chapter provides data on key strategic markets, especially the U.S. and the U.K., and financial indicators (e.g. share value and credit-rating developments). Professor Steve Thomas once again shares his insights in this area.

In addition, now more than two years after the Fukushima disaster started unfolding, also included is a concise overview of the key issues that continue to raise serious concerns among international experts and the Japanese population. Two independent Japanese experts, Professor Komei Hosokawa from Kyoto and Professor Yukio Yamaguchi from Tokyo have contributed their analysis.

The *World Nuclear Industry Status Report* has turned into a major international reference on nuclear issues. Over the past year, numerous mainstream publications[20] use the WNISR as their information source for analysis and/or as statistical reference for graphic work, rather than solely relying on IAEA or World Nuclear Association (WNA) data.

The international team that has collaborated to make this project work sincerely hopes that the WNISR 2013 will meet the increasingly high expectations.

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[17] International Ministerial Conference, “Nuclear Power in the 21st Century”, St. Petersburg, 27-29 June 2013, Concluding Statement by the President of the Conference, see http://www.iaea.org/newscenter/statements/stpclosing.pdf, accessed 30 June 2013.

[18] “Unrealistic Projections”, in Mycle Schneider et al., “World Nuclear Industry Status Report 2012”, see http://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status.html#unpro.

[19] International Ministerial Conference, op.cit.

[20] For a selection of media citations, see http://www.worldnuclearreport.org/-In-the-media-.html.

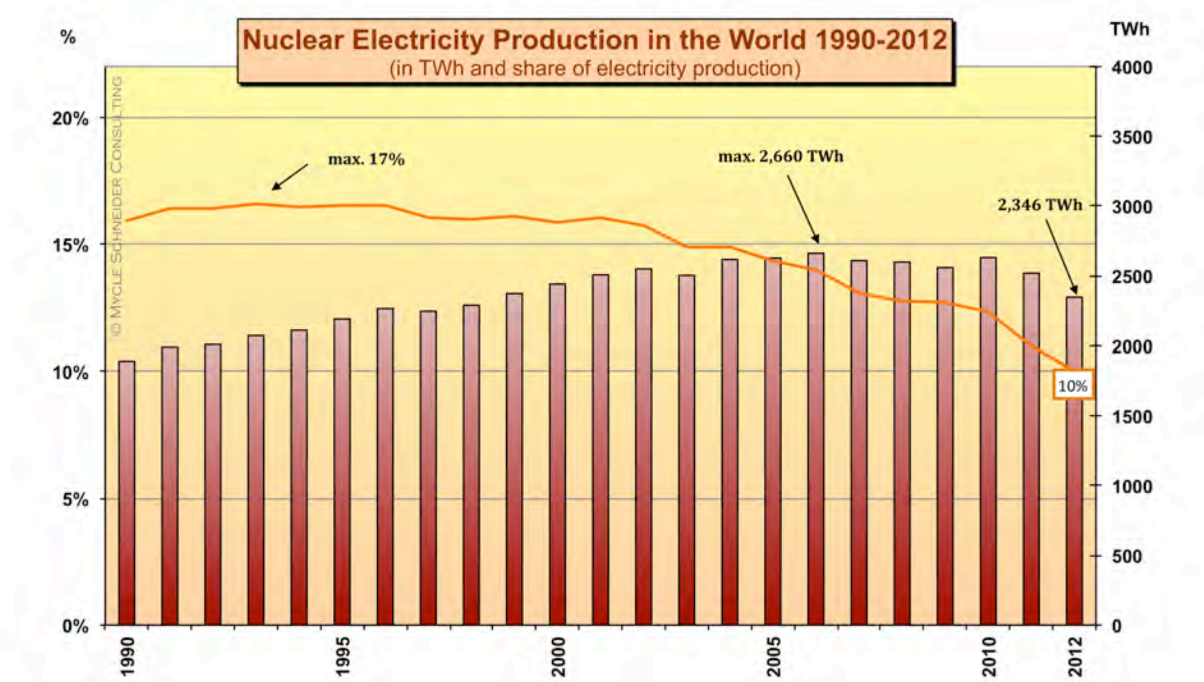
General Overview Worldwide

I would like to begin by congratulating the Kingdom of Swaziland on becoming the 159th Member State of the IAEA.

Yukiya Amano
IAEA, Director General
Introductory Statement to Board of Governors
4 March 2013

As of the middle of 2013, a total of 31 countries were operating nuclear fission reactors for energy purposes. Nuclear power plants generated 2,346 terawatt-hours (TWh or billion kilowatt-hours) of electricity in 2012[21], less than in 1999 and a 172 TWh or 6.8 percent decrease compared to 2011 as well as 11.8 percent below the historic maximum nuclear generation in 2006. The maximum contribution of nuclear power to commercial electricity generation worldwide was reached in 1993 with 17 percent (see figure 1). It has dropped to 10.4 percent in 2012, a level last seen in the 1980s. According to BP, the nuclear share in commercial primary energy consumption dropped to 4.5 percent, "the lowest since 1984".[22]

Figure 1: Nuclear Electricity Generation in the World



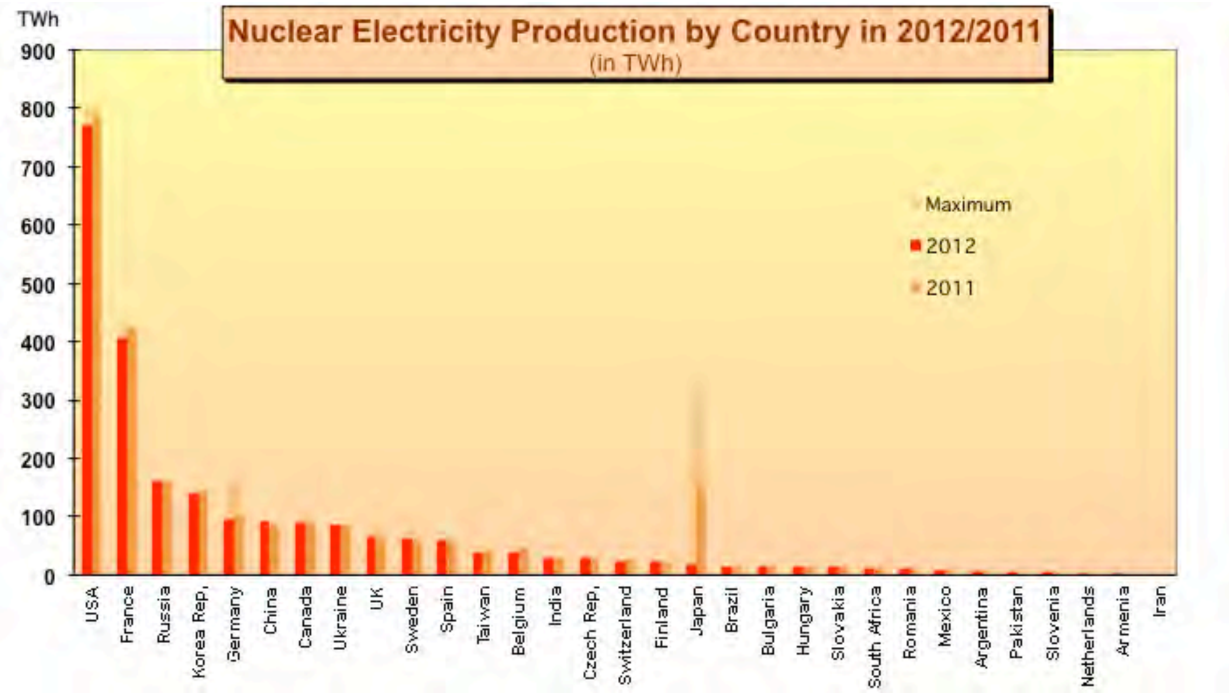
Source : IAEA-PRIS, BP, MSC, 2013

About three-quarters of the decrease is due to the continuing and substantial generation drop in Japan (–139 TWh or –50 percent over the previous year), which in three years fell back from the 3rd to the 18th position of nuclear generators. Production also decreased for differing reasons in all top five nuclear generating countries: United States (–20 TWh or –2.5 percent), France (–16 TWh/–4 percent), Germany (–8 TWh/–10 percent), South Korea (–7 TWh/5 percent) and Russia with an insignificant drop (–0.8 TWh/–0.5 percent).

[21] 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, www.iaea.org/programmes/a2/index.html.
[22] BP, "Statistical Review of World Energy", June 2013.

Nuclear generation declined in a total of 17 countries, while in 14 countries it increased or remained stable[23]. Seven countries[24] generated their historic maximum in 2012.

Figure 2. Nuclear Power Generation by Country, 2012/2011 and Historic Maximum



Sources: IAEA-PRIS, MSC, 2013

The "big five" nuclear generating countries—by rank: the United States, France, Russia, South Korea and Germany—generated 67 percent of all nuclear electricity in the world. The three countries that have phased out nuclear power (Italy, Kazakhstan, Lithuania), and Armenia, 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 peaked their nuclear generation between 2001 and 2005: Bulgaria, France, Germany, South Africa, Spain, and Sweden. Among the countries with a steady increase in nuclear generation are China, the Czech Republic and Russia. However, even where countries are increasing their nuclear electricity production this is in most cases not keeping pace with overall increases in electricity demand leading to a reduced and declining role for nuclear power.

Only one country in the world, the Czech Republic, peaked its nuclear share in 2012 with 35 percent. In fact, all other countries—except Iran, which started up its first nuclear plant in 2011—reached their maximum share of nuclear power prior to 2010. While three countries peaked in 2008 (China) or 2009 (Romania, Russia), the other 26 countries saw their largest nuclear share by 2005. In total, nuclear power played its largest role in ten countries during the 1980s[25], in 12 countries each in the 1990s and in the 2000s.

Increases in nuclear generation are mostly a result of higher productivity and uprating[26] at existing plants rather than due to new reactors. According to the latest assessment by *Nuclear Engineering International*[27], the global annual load factor[28] of nuclear power plants decreased from 77 percent in

[23] Less than 1 TWh variation from the previous year

[24] Brazil, China, Czech Republic, Hungary, India, Iran, Pakistan

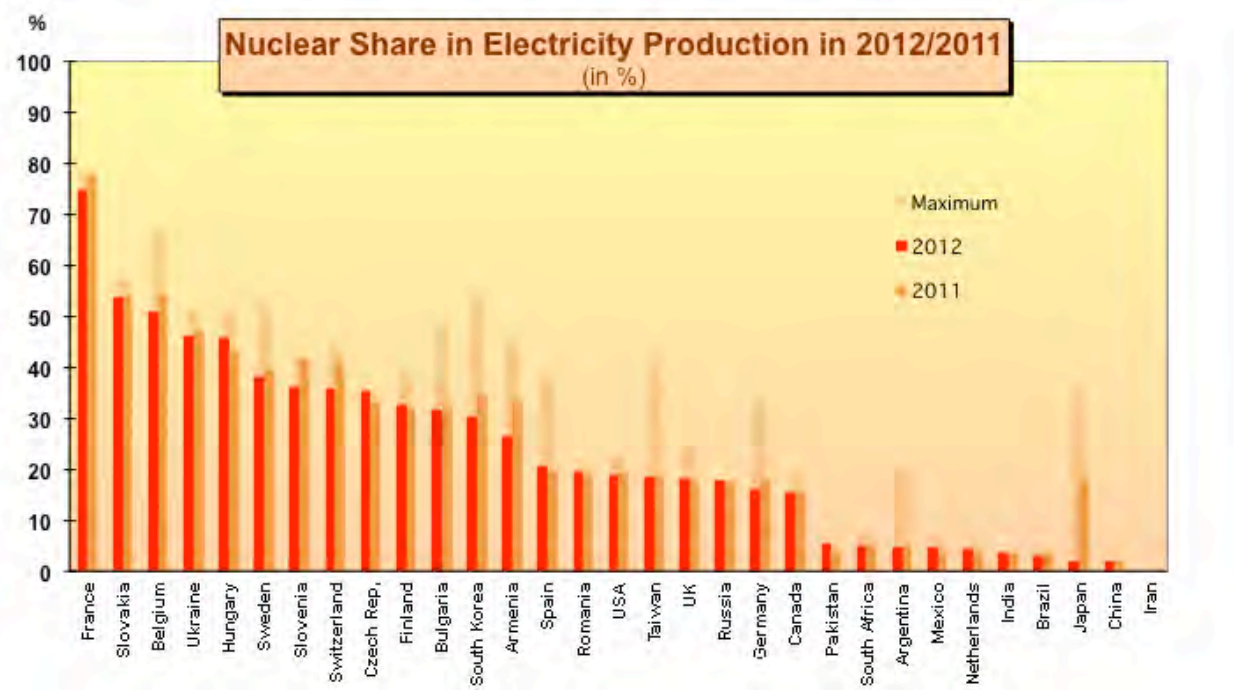
[25] Armenia, Hungary, India, Germany, Italy, Netherlands, South Africa, South Korea, Spain, Taiwan.

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

[27] Nuclear Engineering International, "Load Factors to end December 2012", May 2013.

2011[29] to 70 percent in 2012. Not surprisingly the biggest change was seen in Japan, where the load factor plunged from 69.5 percent in 2010 to 39.5 percent in 2011 to 3.7 percent in 2012. This is also due to the fact that officially 50 of the 54 pre-3/11 units in Japan are still counted as operational—even though some reactors have not generated electricity for years (see box hereunder).

Figure 3. Nuclear Share in Electricity Mix by Country, 2012/2011 and Historic Maximum



Sources: IAEA-PRIS, MSC, 2013

Although both countries decreased performance, as in 2011, Romania and Taiwan had the highest load factors in 2012 with 92.8 and 90.8 percent respectively. The most dramatic reductions in load factor outside Japan were in Belgium (–11.8 percentage points), Mexico (–20 percentage points) and South Korea (–9.5 percentage points). Belgium had two of its seven reactors off-line for much of the year because of thousands of cracks discovered in their pressure vessels. They only restarted in June 2013. Mexico is carrying out major uprating work on both of its units. South Korea had a series of scandals involving quality control issues that kept a number of units down. Other major nuclear countries saw their load factors deteriorate to some degree: the U.S. by 3.1 percentage points to reach 83.2 percent, France by 2.3 percentage points, now down to 73.6 percent and remaining at the lower end of global performance.

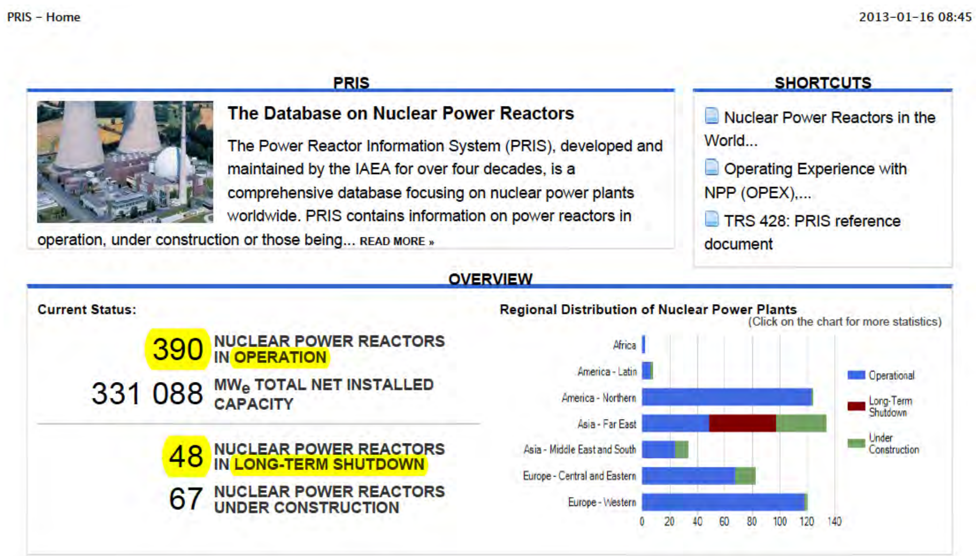
[28] Nuclear Engineering International load factor definition: "Annual load factors are calculated by dividing the gross generation of a reactor in a one-year period by the gross capacity of the reactor (sometimes called output), as originally designed, multiplied by the number of hours in the calendar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

[29] NEI revised the 2011 figure from 76 to 77 percent.

Japanese Reactors "in Operation" or "in Long-Term Shutdown"?

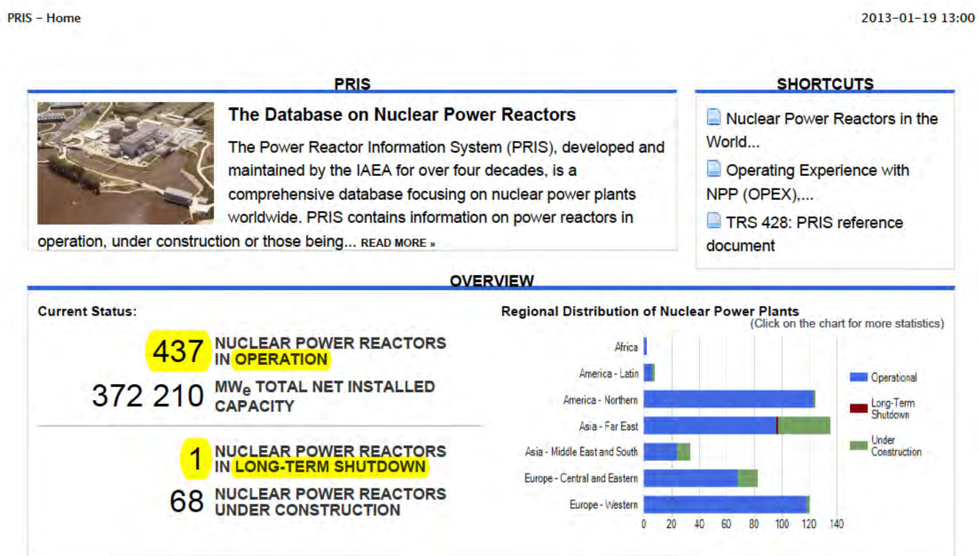
In an unprecedented move, on 16 January 2013, the IAEA shifted 47 Japanese nuclear reactors from the category "In Operation" to the category "Long-term Shutdown" (LTS) in its web-based Power Reactor Information System (PRIS)[30]. The number of nuclear reactors listed as "In Operation" in the world thus dropped to 390, a level last seen in 1986, the year of the Chernobyl accident. The move was a dramatic step by the IAEA in its official statistics by acknowledging the the current industrial reality in Japan. Coming from the IAEA this was without doubt a unique revision of world operational nuclear data.

Screen Capture 1 : The IAEA's Online Database on Nuclear Power Reactors on 16 January 2013



Note: Yellow highlighting added. *Source: IAEA, 2013, see http://www.iaea.org/pris/*

Screen Capture 2 : The IAEA's Online Database on Nuclear Power Reactors on 19 January 2013



Note: Yellow highlighting added. *Source: IAEA, 2013, see http://www.iaea.org/pris/*

This historic revision however, did not last. Only two days later, the Japanese government requested the reversal of the reactor status of the 47 Japanese reactors from the IAEA's LTS category to "In operation". The modification was thus reversed on 18 January and commented on by the IAEA in a press release on 19 January 2013.[31]

[30] See http://www.iaea.org/pris/.

[31] IAEA, "Japan corrects error in IAEA nuclear power database", press release, 19 January 2013,

An IAEA representative explained by email: "In communication with the Government of Japan, it was identified that this status is not applicable for [the] time being and our Japanese counterpart changed the decision and the status was put back."[32] Another IAEA representative identified the "IAEA counterpart" in a phone interview as the Japan Nuclear Energy Safety Organization (JNES). This was confirmed in the IAEA press release. According to the IAEA, JNES, an incorporated Administrative Agency, modified the raw country data in the online Power Reactor Information System (PRIS) of the IAEA. The modification was then automatically integrated into the World Overview pages of the Agency's website.

Any correspondent or counterpart to the IAEA's online database has to be authorized by its respective government. In addition, it is understood that modifications of the reactor status are controlled by the respective government. However, it is unclear what happened in this case, as it is hard to believe that such a significant modification of the reactor status of the Japanese reactor fleet happened at the initiative of an individual at JNES. If this was indeed the case, the question remains why this was done. The IAEA stated that the Japanese counterparts advised the Agency that the "changes resulted from a clerical error".

The explanation given of a "clerical error" is surprising and unconvincing. The reactor-by-reactor changes were precise and made perfect sense. In fact, all of the 47 reactors could well fall within the IAEA definition for LTS status[33]:

> Reactor is considered in long-term shutdown status from the Long-term Shutdown date to the Restart Date, if it has been shut down for an extended period (usually more than one year) and any of the following conditions has occurred in early period of shutdown:
>
> 1. restart is not being aggressively pursued (there is no vigorous onsite activity to restart the unit) or
>
> 2. no firm restart date or recovery schedule has been established, but there is the intention to re-start the unit eventually.
>
> This status may be for example due to technical, economical, strategic or political reasons. This status does not apply to long-term maintenance outages, including unit refurbishment, if the outage schedule is consistently followed, or to long-term outages due to regulatory restrictions (licence suspension), if restart (licence recovery) term and conditions have been established. Such units are still considered 'operational' (in a long-term outage).
>
> If an intention not to restart the shutdown unit has been officially announced by the owner, the unit is considered 'permanently shut-down'.

Furthermore, if this incident was due to a simple "clerical error", why would it take JNES two days to notify the Agency?

The incident raises the question of the operational rules of the PRIS database. It seems astounding that representatives of individual governments, utilities, research or safety organizations can actually directly modify the IAEA's public website. The IAEA explained that it "runs the PRIS database with input from its Member States, which own the information provided". However, as a consequence of the Japan incident, the Agency decided to change the procedures[34]:

> The Nuclear Energy Department of the IAEA, which runs the PRIS database, is implementing a software upgrade that in future would prevent status changes being entered into the system without the agreement of the system administrators, and would require clear justification from the national counterparts.

Any outside observer would have expected this to be the rule *before* the incident. The overall information management by the IAEA and the Japanese authorities—with very significant changes in reactor statistics, one way or the other, without any public explanation for three days—puts serious doubts on the reliability of the information provided.

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see http://www.iaea.org/press/?p=3250, accessed 30 June 2013.

[32] Email to Mycle Schneider, dated 18 January 2013 as a reply to our request from 16 January, prior to the release of the first story on the issue on www.WorldNuclearReport.org, "Historic Move: IAEA Shifts 47 Japanese Reactors Into 'Long-Term Shutdown' Category", 16 January 2013, see http://www.worldnuclearreport.org/Historic-Move-IAEA-Shifts-47.html.

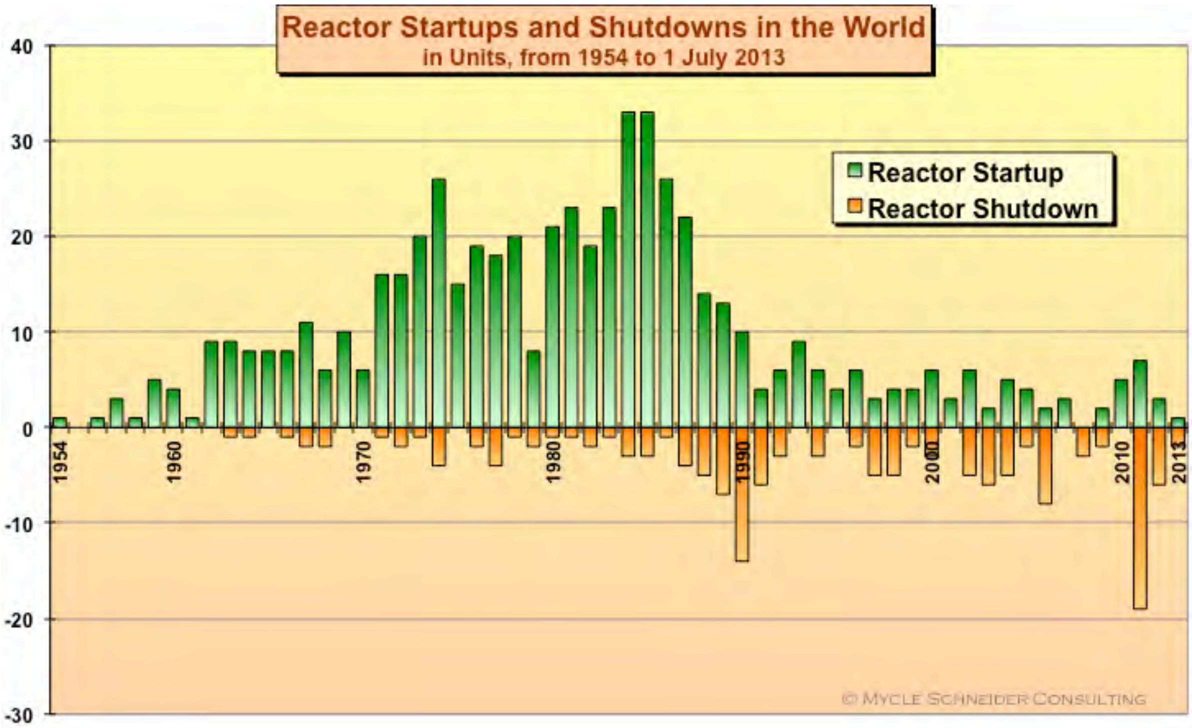
[33] See IAEA Glossary http://www.iaea.org/pris/Glossary.aspx.

[34] IAEA, "Japan corrects error in IAEA nuclear power database", press release, 19 January 2013, see http://www.iaea.org/press/?p=3250, accessed 30 June 2013.

Overview of Operation, Power Generation, Age Distribution

Since the start of the commercial nuclear power age in the mid-1950s there have been two major waves of grid connections (see Figure 4). A first wave peaked in 1974, with 26 reactor startups in that year. The second wave 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 1992-2001 decade showed twice as many startups than shutdowns (51/23), while in the past decade 2003-2012 the trend reversed (31/51). Six reactors (including two units at San Onofre, California, that did not generate any power anymore in 2013) were shut down in 2012, while only three started up. In the first half of 2013, another two units were closed (also in the U.S.), while only one unit started up (in China).

Figure 4. Nuclear Power Reactor Grid Connections and Shutdowns, 1956–2013



Source: IAEA-PRIS, MSC, 2013

As of 1 July 2013, under the Baseline Scenario (see hereunder), a total of 427 nuclear reactors were considered operating in 31 countries, down 17 from the maximum of 444 in 2002. The current world reactor fleet has a total nominal electric net capacity of about 364 gigawatts (GW or thousand megawatts). However, there are large uncertainties in these figures, mainly stemming from the undefined future of the 50 Japanese nuclear reactors that are officially still operating but, except for two units, are all shut down as of 1 July 2013. We have therefore considered three scenarios:

• **The Baseline Scenario**. Only the 10 Fukushima reactors are permanently closed. Many industry analysts now consider this as unrealistically optimistic. However, it remains unclear, *which* units will remain closed. Utilities were awaiting the Nuclear Regulatory Authority's new safety rules that were released on 8 July 2013. Four utilities have announced "early applications for restart" for 10 reactors[35], whatever that means in practice.

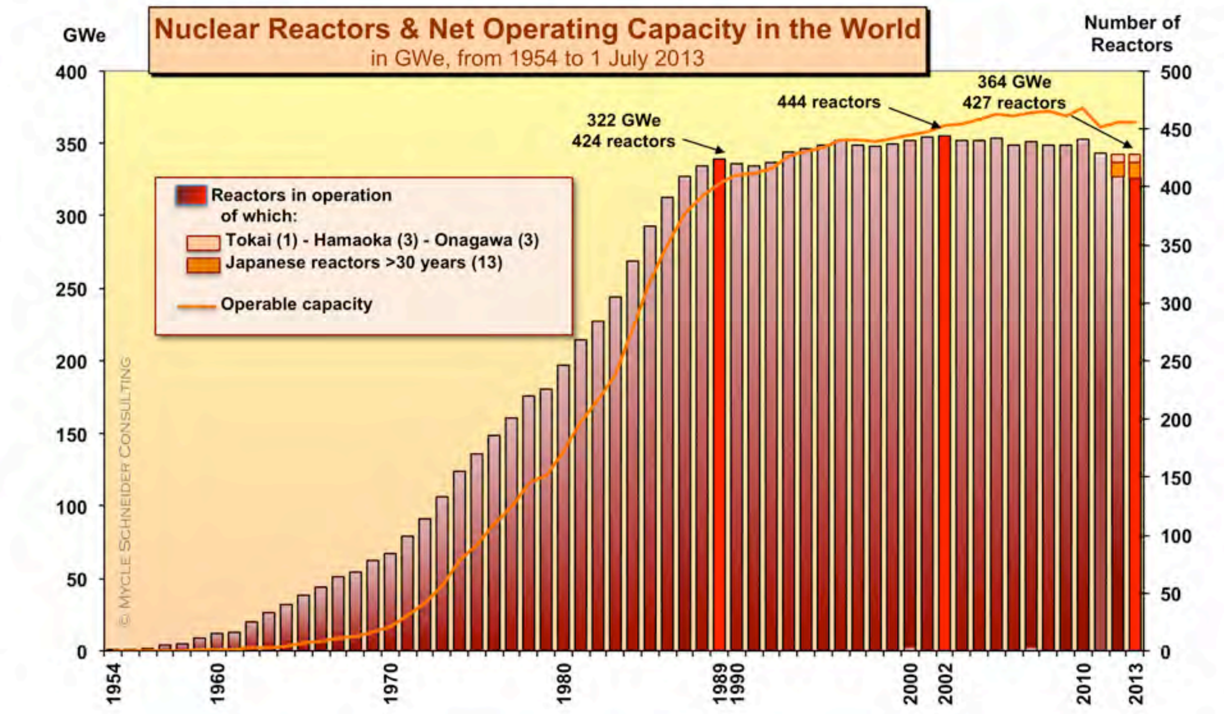
• **The East Coast Scenario**. In addition to the Fukushima units, the seven reactors affected directly or indirectly by 3/11 events remain closed. These include three Onagawa reactors that were closest to the 3/11 epicenter, the three remaining Hamaoka units shut down at the request of former Prime Minister

[35] JAIF, "Nuclear Power Plants in Japan (in operation and under construction)", 19 June 2013.

Naoto Kan because of high earthquake risk estimates and the Tokai reactor, the nuclear plant closest to the Tokyo Metropolitan area (ca. 100 km). Under this scenario, the total number of operating units in the world would drop to 420 and the installed capacity to 354 GWe.

• **The German Scenario.** In addition to the units considered closed under the Baseline and East Coast Scenarios the 13 reactors in Japan with an operational age in excess of 30 years will remain shut down. The German government decided in the wake of 3/11 to permanently shut down the eight reactors down that had operated for over three decades. That would leave Japan with 24 operating reactors, the worldwide figure would drop to 407, last seen in 1987, and the installed capacity to 349 GWe, not experienced since the mid-1990s.

Figure 5. World Nuclear Reactor Fleet, 1954–2013



Sources: IAEA-PRIS, MSC, 2013

Considering the opposition to nuclear power in Japan, especially by local authorities under the influence of an increasingly vocal public opinion, against the restart of any nuclear reactor, it is possible—even under a strongly pro-nuclear central government—that there will be the short-term closure of the majority of the nuclear program in the country. This would not be a "phase-out" scenario but rather the simple "abandoning" of nuclear power. Every authorization of restart will be subject to intense battles between promoters and opponents of the nuclear option. The continuous instability of the Fukushima site could also lead to further incidents and additional releases of large amounts of radioactivity, especially following strong aftershocks, of which a substantial risk persists. Under these circumstances, the scenarios above are likely to prove quite conservative.

The total world installed nuclear capacity has decreased six times since the beginning of the commercial application of nuclear fission, all in the past 15 years—in 1997, 2003, 2007, 2008, 2009 and 2011. Despite 15 fewer units operating in early 2012 compared to 2002, the generating capacity is still about identical and as of late June 2013, with two fewer units operating, the installed capacity is identical to its value a year ago. This is a result of the combined effects of larger units replacing smaller ones and, mainly, technical alterations at existing plants, a process known as uprating. In the United States, the Nuclear Regulatory Commission (NRC) has approved 148 uprates since 1977. These included, in 2012, six uprates between 1.6 percent (Harris 1) and 13.1 percent (Grand Gulf 1).

The cumulative approved uprates in the United States total 6.9 GW.[36] Most of these have already been implemented. A similar trend of uprates and lifetime extensions of existing reactors can be seen in Europe. The main incentive for lifetime extensions is their considerable economic advantage over new-build, but upgrading and extending the operating lives of older reactors have lower safety margins than replacement with more modern designs.

It appears however that the incentives for power uprates are waning as in 2012 the number of units with pending applications dropped from 20 in the previous year to 14 and the total capacity increase that would occur from 1.5 GW to 1 GW.[37] The increasing challenge for existing U.S. reactors to compete with wholesale market prices set by the operating costs of gas-fired and wind generators led nuclear giant Exelon to abandon planned uprates for four older units.[38]

Adding together uprates, new-build capacity, and substracting closures, the capacity of the global nuclear fleet increased by about 30 GWe between 1992 and 2002 to reach 362 GWe; it peaked in 2010 at 375 GWe before falling back to the level achieved a decade ago.

The use of nuclear energy has been limited to a small number of countries, with only 31 countries, or 16 percent of the 193 members of the United Nations, operating nuclear power plants in early 2013 (see Figure 2). Half of the world's nuclear countries are located in the European Union (EU), and in 2012 they accounted for 36 percent of the world's nuclear production. France alone generated about half (48 percent) of the EU's nuclear production.

Overview of Current New Build

Currently, 14 countries are building nuclear power plants. With the United Arab Emirates (UAE) concreting the base-slab for two units at Barakah in July 2012 and May 2013, one country was added to the list compared to the last edition of the WNISR. Japan halted work at two units following the 3/11 events, Ohma and Shimane-3, which had been under construction since 2007 and 2010 respectively. Officially construction resumed at Ohma on 1 October 2012 and Shimane-3 has remained "under construction", according to Japan Atomic Industrial Forum (JAIF)[39] and IAEA statistics. However, in view of the current situation in Japan, we consider it very unlikely that these plants will be completed; it will be hard enough for the industry to get its stranded plant restarted.

In the previous WNISR edition, the Russian Kursk-5 unit was removed from the list, following reports that the builder, Rosatom, confirmed that the project was abandoned. The unit finally disappeared from the IAEA's data base early July 2013. So, as of early July 2013, 66 reactors are defined here as under construction, seven more than a year ago. However, 28 of these are in China, leaving the total in the rest of the world being 38. The current number compares with a peak of 234 units in building progress—totaling more than 200 GW—in 1979. However, many of those projects (48) were never finished (see Figure 6.) The year 2004, with 26 units under construction, marked a record low for construction since the beginning of the nuclear age in the 1950s.

After a near two year freeze on nuclear plant construction following the events of March 2011, when no new building site was opened, China resumed construction on on 17 November 2012.[40] The *World*

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[36] Nuclear Regulatory Commission (NRC), "Approved Applications for Power Uprates", updated 29 March 2012, at www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/approved-applications.html, accessed on 22 June 2013.

[37] Nuclear Regulatory Commission (NRC), "Pending Applications for Power Uprates", updated 30 April 2012, at www.nrc.gov/reactors/operating/licensing/power-uprates/status-power-apps/pending-applications.html, accessed on 22 June 2013.

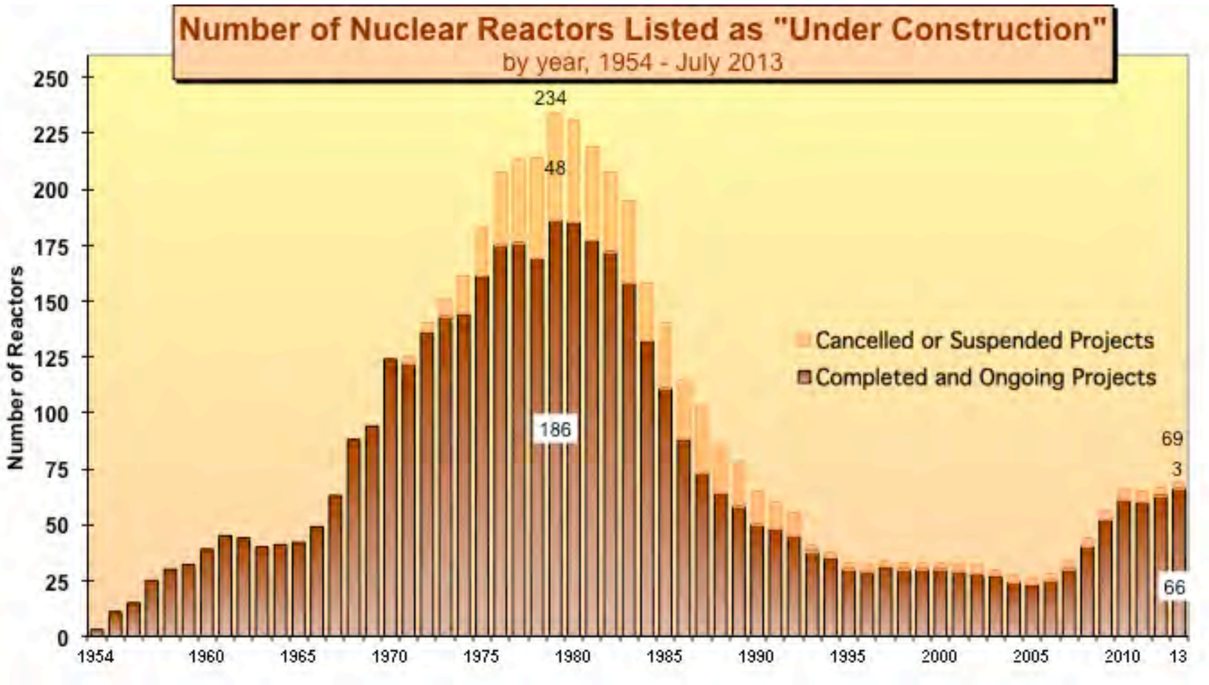
[38] Platts, "Exelon cancels power uprates for LaSalle, Limerick nuclear plants", 12 June 2013, see http://www.platts.com/latest-news/electric-power/Washington/Exelon-cancels-power-uprates-for-LaSalle-Limerick-21152061, accessed 7 July 2013.

[39] JAIF, "Nuclear Power Plants in Japan", 22 May 2013.

[40] The previous construction start dated from 31 December 2010.

Nuclear Association assumes that at least five authorized construction starts did not happen, with at least another ten in the pipeline for 2011 alone.[41]

Figure 6. Number of Nuclear Reactors under Construction



Source: IAEA-PRIS, MSC 2013

The total capacity of units now under construction in the world is about 63 GWe, up by about 7 GWe compared to a year ago, with an average unit size of 960 MW (see Table 1 and Annex 7 for details). A closer look at currently listed projects illustrates the level of uncertainty associated with reactor building, especially given that most constructors assume a five-year construction period:

- Nine reactors have been listed as "under construction" for more than 20 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 the latest startup date in 2012 and is now scheduled to be connected to the grid in 2015. Other long-term construction projects include three Russian units, two Mochovce units in Slovakia, and two Khmelnitski units in Ukraine. The construction of the Argentinian Atucha-2 reactor started 32 years ago.
- Four reactors have been listed as "under-construction" for over 10 years. These are two Taiwanese units at Lungmen for about 14 years and two Indian units at Kudankulam for around 10 years.
- Forty-five projects do not have an IAEA planned start-up date.
- At least 23 of the units listed by the IAEA as "under construction" have encountered construction delays, most of them significant. All of the 43 remaining units were started within the last five years or have not reached projected start-up dates yet. This makes it difficult to assess whether or not they are on schedule.
- Two thirds (44) of the units under construction are located in just three countries: China, India and Russia. Historically, none of these countries have historically been very transparent or reliable about information on the status of their construction sites. It is nevertheless known that half of the Russian units listed are experiencing multi-year delays (see Annex 7 for details).

[41] www.world-nuclear.com/info/inf63.html, accessed 3 May 2012.

Table 1: Nuclear Reactors "Under Construction" (as of 1 July 2013)[42]

Country	Units	MWe (net)	Construction Start	Grid Connection
China	28	27,790	2008-2013	2013-2017
Russia	9	7,273	1983-2019	2014-2019
India	7	4,824	2002-2011	2013-2016
South Korea	5	6,320	2008-2013	2013-2017
USA	3	3,399	1972-2013	2015-2017
Pakistan	2	630	2011	2016-2017
Slovakia	2	880	1985	2014-2015
Taiwan	2	2,600	1999	2014-2015
UAE	2	2,690	2012-2013	2017-2018
Ukraine	2	1,900	1986-1987	2015-2016
Argentina	1	692	1981	2013
Brazil	1	1,245	2010	2016
Finland	1	1,600	2005	2016
France	1	1,600	2007	2016
Total	66	63,443	1972-2013	2013-2019

Source : IAEA-PRIS, MSC, 2013

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.

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 for grid connection and power production. The French Atomic Energy Commission (CEA) statistics on "cancelled orders" through 2002 indicate 253 cancelled orders in 31 countries, many of them at an advanced construction stage (see also Figure 6). The United States alone accounted for 138 of these cancellations.[43] Many U.S. utilities incurred significant financial harm because of cancelled reactor-building projects.

Operating Age

In the absence of any significant new-build *and* grid connection over many years, the average age (since grid connection) of operating nuclear power plants has been increasing steadily and now stands at about 28 years.[44] 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. Nuclear operators can request a license renewal for an additional 20 years from the NRC. As of June 2013, 72 of the 100 operating U.S. units have received an extension, and another 18 applications are under NRC review.[45] However, these applications are currently on hold pending completion of a review of the management of commercial nuclear reactor spent fuel, with no license extension decision to be granted until completion of this process.[46]

Even license renewal does not guarantee longer operating life. None of the 32 units that have been shut down in the U.S. had reached 40 years on the grid. In other words, at least a quarter of the reactors built in the U.S. never reached their design lifetime. On the other hand, of the 100 currently operating plants 24 units have operated for 40 years or more.

[42] For further details see Annex 8.

[43] CEA, "Elecnuc – Nuclear Power Plants in the World", 2002.

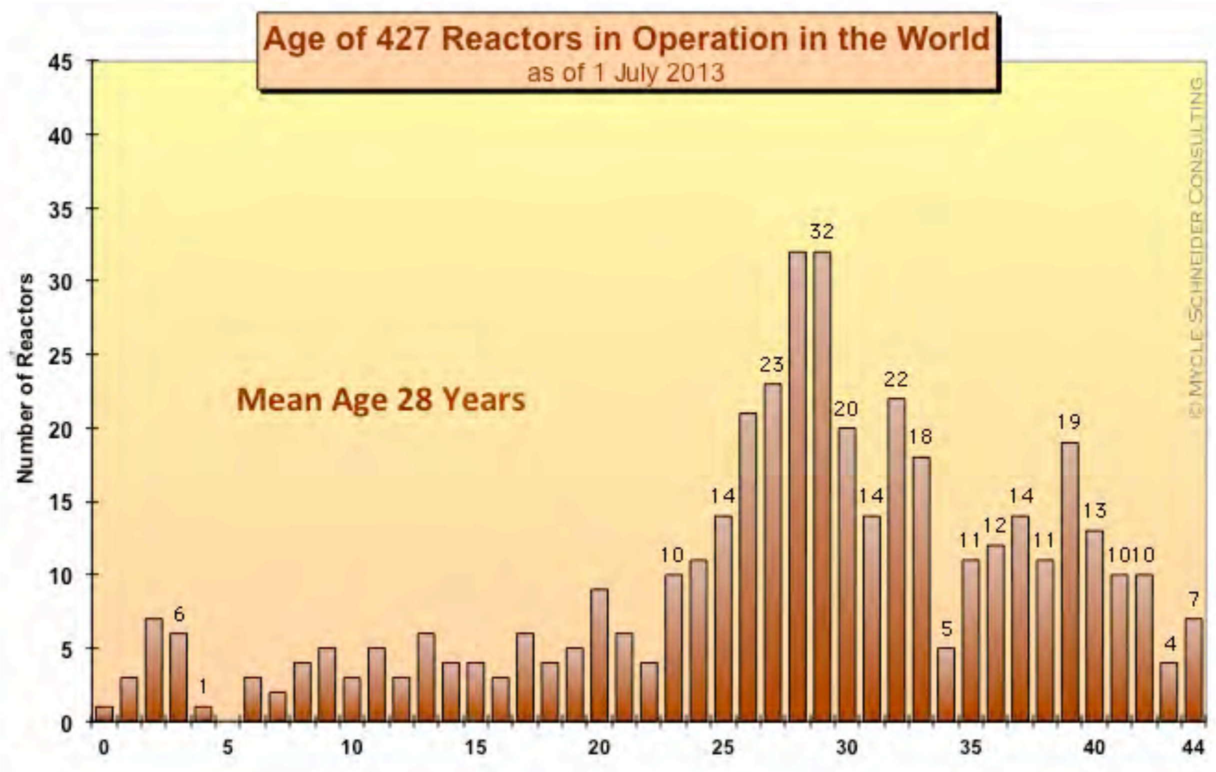
[44] Here, reactor age is calculated from grid connection to final disconnection from the grid. In this report, "startup" is synonymous with grid connection and "shutdown" with withdrawal from the grid.

[45] U.S.NRC, "Status of License Renewal Applications and Industry Activities", updated 17 June 2013, see http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 23 June 2013.

[46] U.S.NRC, "Waste Confidence", see http://www.nrc.gov/waste/spent-fuel-storage/wcd.html, accessed 10 July 2013.

Many other countries, however, have no time limitations on operating licenses. In France, where the country's first operating PWR started up in 1977, reactors must undergo in-depth inspection and testing every decade. The French Nuclear Safety Authority (ASN) evaluates on a reactor-by-reactor basis whether a unit can operate for more than 30 years. At this point, ASN considers the issue of lifetimes beyond 40 years to be irrelevant, although the French utility EDF has clearly stated that, for economic reasons, it plans to prioritize lifetime extension over large-scale new-build. However, only a few plants have so far received a permit to extend their operational life from 30 to 40 years, but only under the condition of significant upgrading. President François Hollande vowed to close down the country's oldest reactors at Fessenheim by the end of 2016 and to engage on a path leading to the reduction of the nuclear share in power generation from 75 to 50 percent by 2025. These decisions were confirmed in September 2012 by the *Conseil de Politique Nucléaire,* the highest nuclear decision-making body chaired by the President himself.[47] However, even if ASN gave the go-ahead for all of the oldest units to operate for 40 years, 22 of the 58 French operating reactors will reach that age by 2020.

Figure 7. Age Distribution of Operating Nuclear Reactors, 2013



Sources: IAEA-PRIS, MSC, 2013

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 Figures 7 and 8). As of mid-2013, 31 of the world's operating reactors have exceeded the 40-year mark.[48] As the age pyramid illustrates, that number will rapidly increase over the next few years. A total of 190 units have already reached age 30 or more.

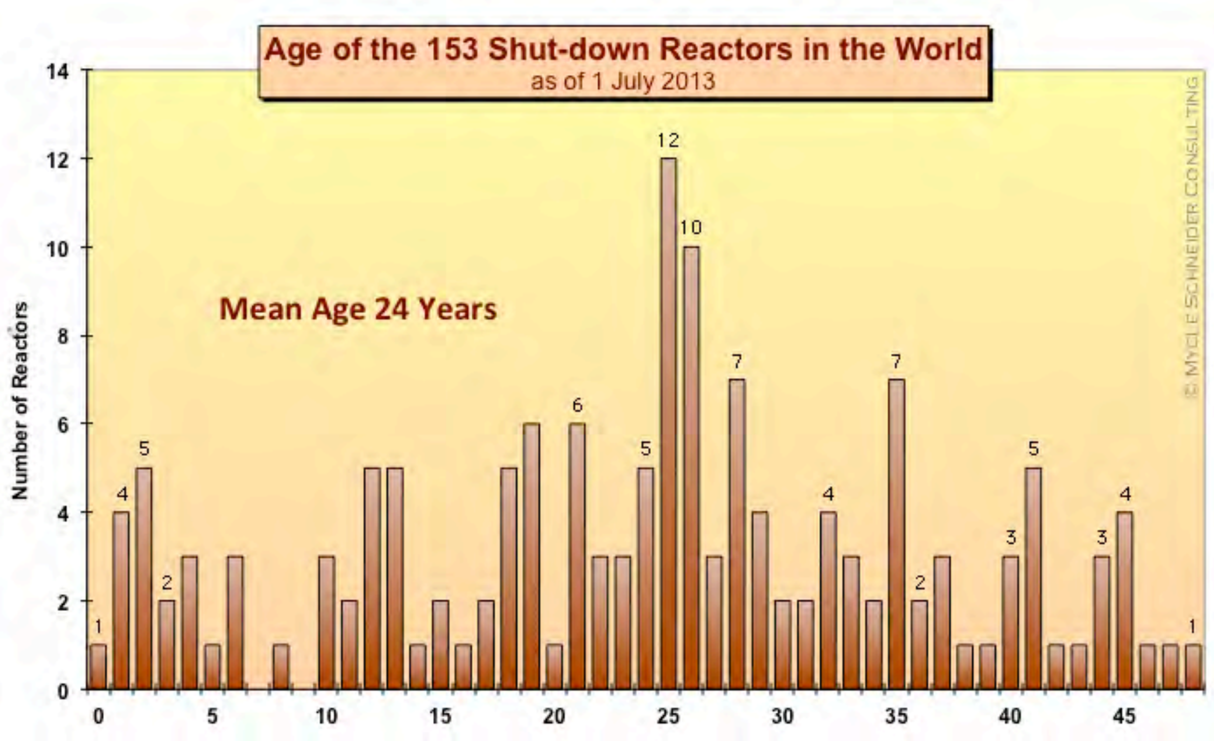
The age structure of the 153 units already shut down confirms the picture. In total, 47 of these units operated for 30 years or more and of those, 20 reactors operated for 40 years or more (see Figure 8). The majority of these were Magnox reactors located in the U.K. As they were designed to produce weapons-grade plutonium, these were all small reactors (50–490 MW) that had operated with very low

[47] Conseil de Politique Nucléaire, 28 September 2012, press release issued on 15 October 2012, see http://www.elysee.fr/communiques-de-presse/article/conseil-de-politique-nucleaire/, accessed 23 June 2013.
[48] We count the age starting with grid connection, and figures are rounded by half-years.

burn-up fuel and very low power density (watts of heat per liter of core volume). Therefore there are significant differences from the large 900 MW or 1,300 MW commercial reactors whose high burn-up fuel and high power density generate significantly more stress on materials and equipment. Many units of the first generation have operated for only a few years. Considering that the average age of the 153 units that have already shut down is about 24 years—with 8 more units shut down over the past year the figure did not change—plans to extend the operational lifetime of large numbers of units to 40 years and beyond seem rather optimistic.

As a result of the Fukushima nuclear disaster questions have been raised about the wisdom of operating older reactors. The Fukushima-I units (1 to 4) were connected to the grid between 1971 and 1974. The license for unit 1 was extended for another 10 years in February 2011. Four days after the accidents in Japan, the German government ordered the shutdown of seven reactors that had started up before 1981. These reactors, together with another unit that was closed at the time, never restarted. The sole selection criterion was operational age. Other countries did not adopt the same approach, but it is clear that the 3/11 events had an impact on previously assumed extended lifetimes in other countries as well, including in Belgium, Switzerland and Taiwan.

Figure 8. Age Distribution of Shutdown Nuclear Reactors, 2013



Sources: IAEA-PRIS, MSC, 2013

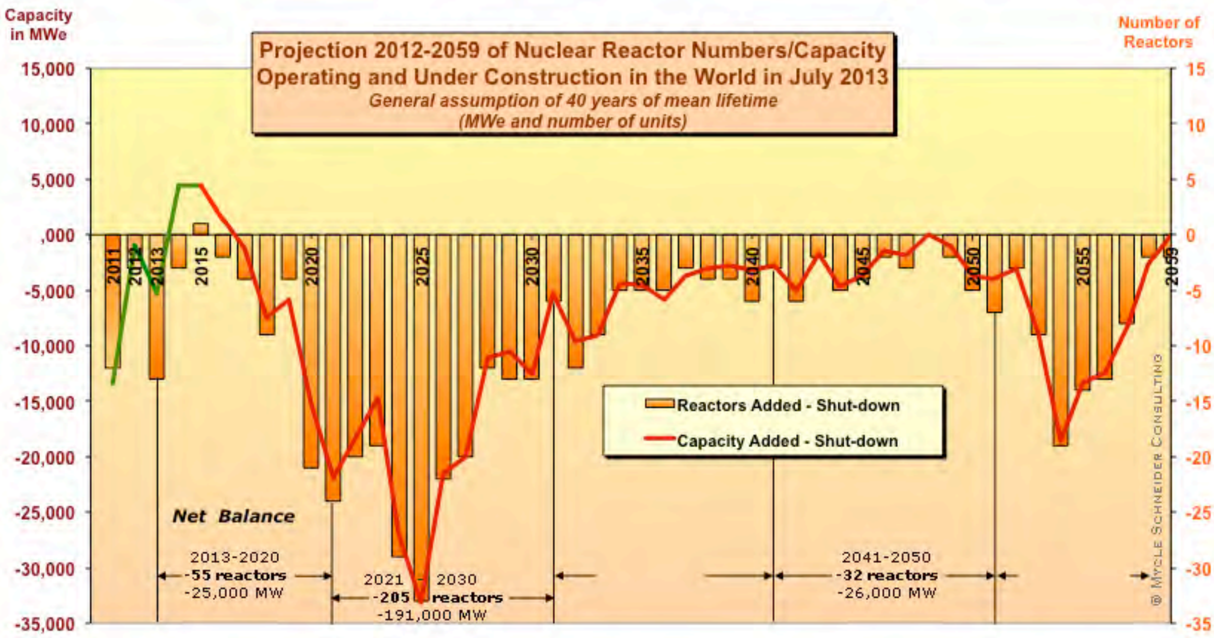
For the purposes of capacity projections, in a first scenario (40-Year Lifetime Projection, see Figure 9), we have assumed a general lifetime of 40 years for worldwide operating reactors, with a few adjustments, while we take into account already-authorized lifetime extensions in a second scenario (PLEX Projection). There are several individual cases where continued operation or lifetime extensions are in question and an official decision to shutdown earlier has been made[49] (see Figure 10).

The lifetime projections make possible an evaluation of the number of plants that would have to come on line over the next decades to offset closures and simply maintain the same number of operating plants. Even with 66 units under construction—as of 1 July 2013, all of which are considered online

[49] The Japanese reactors constitute the largest contingency of uncertainty. In this scenario all but the 10 Fukushima reactors would return to operation. A highly conservative assumption.

by 2020—installed nuclear capacity would drop by 25 GW. Therefore in total 55 additional reactors would have to be finished and started up prior to 2020 in order to maintain the status quo. This corresponds to between eight and nine new grid connections per year, with an additional 205 units (191 GW) over the following 10-year period—one every 18 days. This compares to 33 grid connections over the past 10-year period.

Figure 9. The 40-Year Lifetime Projection



Sources: IAEA-PRIS, WNA, MSC 2013

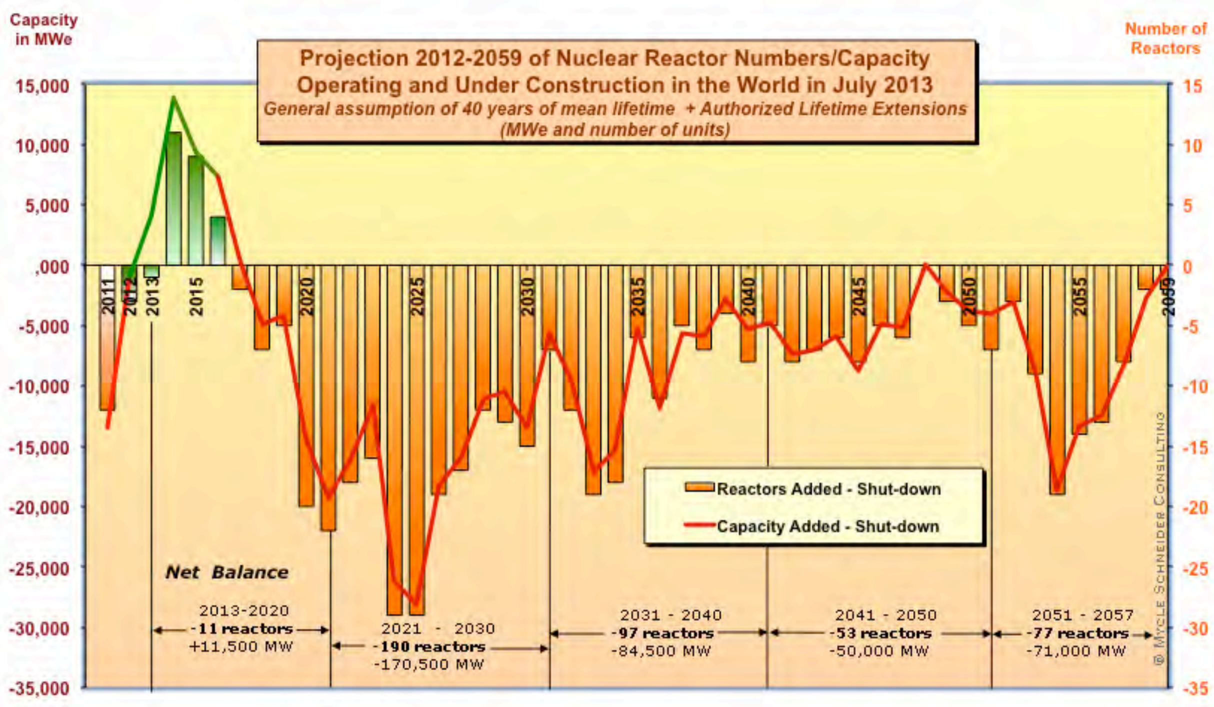
The achievement of the 2020 target appears increasingly unlikely given the existing difficult financial situation of the world's main reactor builders and utilities, the general economic crisis and generally hostile public opinion—aside from any other specific post-Fukushima effects. A notable difference to previous assessments consists in the assumption that constraints on the manufacturing of key reactor components is playing a minor role as reactor orders have not been following capacity extensions, in particular of key component manufacturer Japan Steel Works (JSW).

As a result, the number of reactors in operation will decline over the coming years unless lifetime extensions beyond 40 years becomes widespread. The scenario of such generalized lifetime extensions is however even less likely after Fukushima, as many questions regarding safety upgrades, maintenance costs, and other issues would need to be much more carefully addressed.

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 has reduced Chinese ambitions. While there has been considerable acceleration of construction starts in the past—with 19 new building sites initiated in 2009 and 2010—not a single new construction site was initiated between December 2010 and November 2012, and none was reported in the first half of 2013. In addition, the average construction time for the 18 operating units in China was 5.8 years. At present, 28 units with about 28 GW are under construction and scheduled to be connected before 2018, which will bring the total to 42 GW. The prospects for significantly exceeding the original 2008 target of 40 GW for 2020 is unlikely. There are also indications that new reactors will be allowed only in coastal, not inland, sites, restricting the number of suitable sites available.

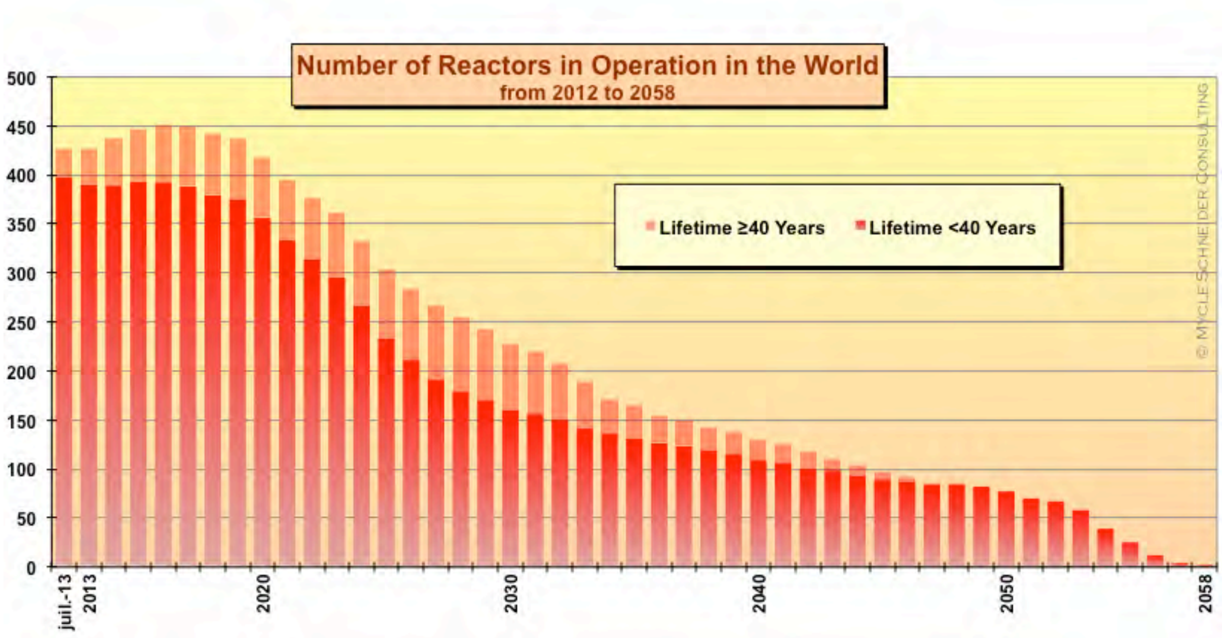
We have also modeled a scenario in which all currently licensed lifetime extensions and license renewals (mainly in the United States) are maintained and all construction sites are completed. For all other units we have maintained a 40-year lifetime projection, unless a firm earlier or later shutdown date has been announced. The net number of operating reactors would still decrease by 11 units even if installed capacity would grow by 11.5 GW in 2020. The overall pattern of the decline would hardly be altered, it would merely be delayed by some years. (See Figures 10 and 11).

Figure 10. The PLEX Projection



Sources: IAEA-PRIS, US-NRC, WNA, MSC 2013

Figure 11. Forty-Year Lifetime Projection versus PLEX Projection *(in numbers of reactors)*



Sources: IAEA-PRIS, US-NRC, MSC 2013

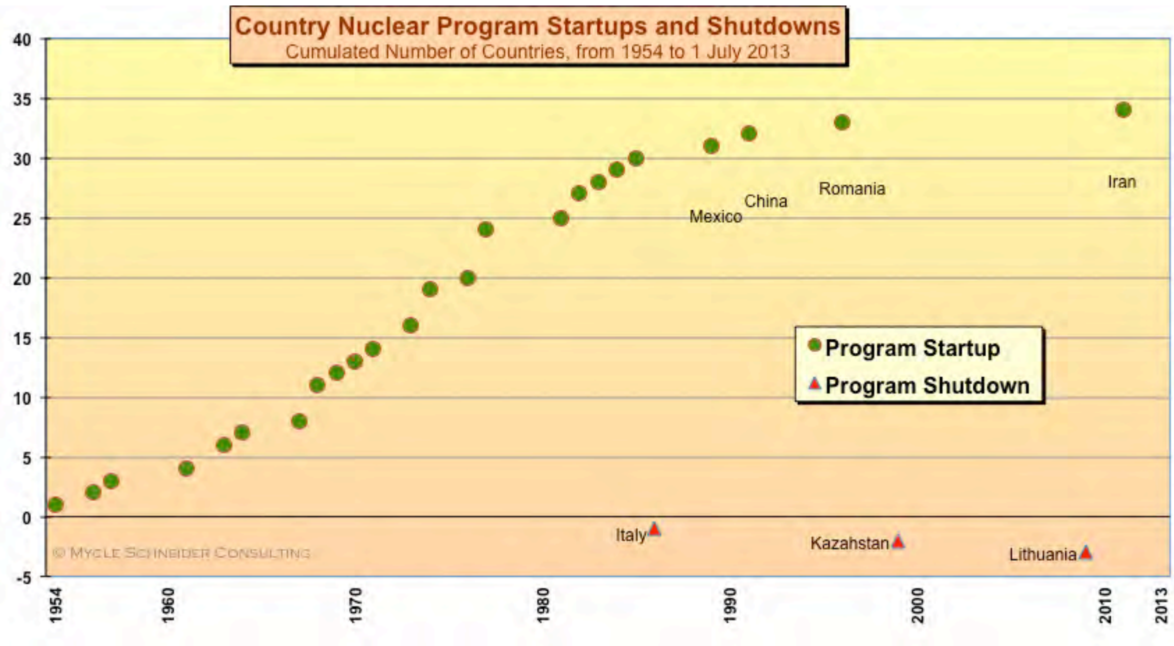
Potential Newcomer Countries

In its International Status and Prospects for Nuclear Power 2012[50] the IAEA estimates that there are a total of 29 countries that are described as developing nuclear power programs for the first time. This includes three countries that have ordered nuclear power plants, 14 countries that are considering starting a nuclear power program and in which there is a "strong indication of intentions to proceed", six countries show "active preparation for a possible nuclear power program" and a further six that are actively preparing for a possible nuclear power program with no final decision. The total number of countries listed as developing nuclear power programs has fallen since the IAEA last published its assessment in 2010, when there were 33.

According to the IAEA, the three countries that have ordered nuclear power plants are the United Arab Emirates (UAE), Turkey and Belarus. The Agency also states that there are nine countries that have suggested a start-up date for first power before 2030. The IAEA does not list those countries, but it is likely to include the three in which orders have been placed, plus Bangladesh, Jordan, Lithuania, Poland, Saudi Arabia and Vietnam. This 2012 analysis from the IAEA is a retreat from its suggestions earlier in the same year when it stated it expected Vietnam, Bangladesh, United Arab Emirates, Turkey and Belarus to start building their first nuclear power plants in 2012 and that Jordan and Saudi Arabia could follow in 2013.[51] This prediction seems to be divergent with actual events, with only the UAE starting construction, one unit each in 2012 and 2013. IAEA Director General Yukiya Amano reported to his Board of Governors in March 2013: "The UAE is the first new country in 27 years to have started building a nuclear power plant."[52]

Figure 12 illustrates the history of national nuclear programs with the startup of the first and shutdown of the last reactor per country.

Figure 12. Start-ups and Closures of National Nuclear Power Programs, 1950–2013



Sources: IAEA-PRIS 2013, MSC, 2013

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[50] IAEA "International Status and Prospects for Nuclear Power 2012", International Atomic Energy Agency, Report by the Director General, 15 August 2012.

[51] Enformable.com, "IAEA – Vietnam and 4 other countries to incorporate nuclear energy after Fukushima", Lucas W Hixson, 24 February 2012, http://enformable.com/2012/02/iaea-vietnam-and-4-other-countries-to-incorporate-nuclear-energy-after-fukushima/; accessed 5 May 2012.

[52] Yukiya Amano, "Introductory Statement to Board of Governors", 4 March 2013, see http://www.iaea.org/newscenter/statements/2013/amsp2013n03.html, accessed 10 June 2013.

Below is an assessment by country of the status of the projects that the IAEA has referred to, which indicates that most are much further from the launch of their program than the IAEA frequently suggests.

Bangladesh currently has an installed electricity capacity of 6 GW, with plans to introduce an additional 20 GW by 2020, reportedly to service the 60 percent of the population lacking access to electricity.[53] Bangladesh has been considering embarking on nuclear power for 50 years[54] and the latest attempt is expected to come from 2 GW of nuclear provided by Russian reactors. In 2011 Science Minister Yeafesh Osman was quoted as saying "we have signed the deal… to ease the power crisis". He said that construction of the plants would start by 2013 and would take five years to complete.[55] In January 2013 Deputy Finance Minister of Russia Sergey Storchak and Economic Relations Division (ERD) Secretary of Bangladesh Md Abul Kalam Azad signed an agreement on the Extension of State Export Credit for financing the preparatory stage work at Rooppur.[56] However, the deal is only for $500 million[57] and will only cover the site preparatory work.[58] According to Rosatom this will begin in January 2014[59] and is being complemented with $150 million of domestic financing. Completion of this phase is expected by June 2017.[60] *Nuclear Intelligence Weekly* suggests that groundwork will only start in January 2015 and startup by 2018.[61]

As with many other countries, access to water has been identified as a potential stumbling block of the Rooppur (or Ruppur) plant, with plans to site it on the banks of the river Padmar. During the first half of the year, much of the river's water resource is already withdrawn by India through the Farakka Barrage, leaving insufficient cooling water for the plant and other activities in Bangladesh.[62]

In mid-2006, the government of **Belarus,** which, 20 years before, was heavily contaminated by the Chernobyl accident, approved a plan for construction of a nuclear power plant in the Mogilev region in the east of the country. An agreement with Russia on cooperation for the construction of a nuclear power plant in Belarus was signed on 15 March 2011. Expressions of interest were sought from international companies, and, not surprisingly given the existing economic and political ties, a bid from Russia's Atomstroyexport was taken forward. Under a financing agreement, Russia would provide a $9 billion loan. Prior to 3/11, the two countries reportedly aimed at the signature of an agreement on plant construction in spring 2011, with construction starting in September of the same year.[63] In November 2011 it was agreed that Russia would lend up to $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 Vnesheconombank (VEB) and Belarusian commercial bank Belvnesheconombank signed an agreement to implement the Russian export credit facility.[64] In July 2012 a contract was signed for the construction of two VVER 1200 reactors (analogous to the Western PWR), with an estimated cost of $10 billion, including a $3 billion

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[53] Economist, "The most bucks for the biggest bang", 6 February 2013.

[54] WNN, "Russian loan for Rooppur construction", 16 January 2013.

[55] BBC, "Bangladesh agrees nuclear power deal with Russia", 2 November 2011, http://www.bbc.co.uk/news/world-asia-15552687, accessed 5 May 2012.

[56] Energy Bangla "Bangladesh, Russia sign nuclear power pact", 17 January 2013.

[57] 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.

[58] The Star, "Russia to lend $1.5B to Bangladesh to build nuclear power station, buy arms", 15 January 2013.

[59] Rosatom , "Photo exhibition 'The Russian Nuclear Power' started in Bangladesh", 2 April 2013.

[60] The Financial Express, "Building Rooppur nuke plant likely to start this year", 2 April 2013.

[61] Nuclear Intelligence Weekly, 15 March 2013.

[62] A. Rahman, "Is Bangladesh Sleepwalking to Nuclear Power", New Age Online, 7 February 2013

[63] Voice of Russia, "Belarus Nuclear Deal to be Signed on March 15," 16 February 2011.

[64] WNA, "Nuclear Power in Belarus", April 2013.

in infrastructure costs to accommodate the undeveloped remoteness of Ostrovets in northern Belarus.[65] In December 2012, Russian Vnesheconombank authorized allocating a $500 million credit line for the Belarusian Finance Ministry to make advance payments for preparation work[66]. This phase was scheduled to be completed by mid-2013 with concreting work to start in September 2013. The first unit is scheduled to be operational in 2017.[67]

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. Both would be of the VVER "NPP-2006" type with a capacity of 1170 MW each.[68] However, it is now expected that the reactors will not be completed until 2018 and 2020.[69] Opposition to the project is increasing. On the 26th anniversary of the Chernobyl catastrophe in 2012, about one-thousand people demonstrated in the Belarussian capital Minsk against the nuclear project,[70] with a similar sized protest held in April 2013[71].

The Lithuanian Government has repeatedly criticised the safety of the project and has particular concerns as the proposed site at Astravyets as it is only 50 km from its capital Vilnius. The Espoo Convention Implementation Committee has instructed Belarus to continue environmental impact assessment procedures based on the Espoo Convention in order to provide answers to all the questions asked by Lithuania and take into consideration all comments. However, Vitalijus Auglys, director of the Pollution Prevention Department in Lithuania's Natural Resources Ministry, stated: "We haven't received the latest information from them. We can't even start consultations with them, because we must hold public discussions."[72]

Lithuania had two large RMBK (Chernobyl-type) reactors at Ignalina which were shut down in 2004 and 2009 as part of the agreement to join the European Union. Before the 2009 shutdown, Lithuania's remaining unit generated 76.2 percent of the country's electricity, the largest percentage share worldwide. As a result of the closure, Lithuania has significantly increased electricity imports from Belarus, Latvia and Russia. The decision to boost electricity imports is purely based on economic considerations. By the end of 2011, the country had an installed capacity of about 2.8 GW compared to a peak load of 1.9 GW.[73]

In February 2007, the governments of the three Baltic States and Poland agreed to build a new nuclear power plant at Ignalina—the Visaginas project. Lithuania passed a parliamentary bill in July 2007 calling for construction and completion by 2015. The Lithuanian government announced that it would conduct direct negotiations with potential investors and that it hoped to begin operation of the new plant in 2020.[74] This led to exclusive negotiations with Korean utility KEPCO, which turned down

[65] Nuclear Intelligence Weekly, "Belarus, Aided by Russia and Broke, Europe's Last Dictatorship Proceeds With NPP, 28 September 2012

[66] Belarusian Telegraph Agency, "Excavation of Belarusian nuclear station second power unit foundation pit begins", 1 February 2013

[67] Itar-Tass, "Belarus NPP cost should not exceed funds for Kaliningrad NPP construction – Semashko", 17 February 2012, see http://www.itar-tass.com/en/c154/346054.html, accessed 1 June 2012.

[68] 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.

[69] Belarusian Telegraph Agency, "Excavation of Belarusian nuclear station second power unit foundation pit begins", 1 February 2013

[70] Nuclear Intelligence Weekly, 17 April 2012.

[71] Belarus Digest, "The Chernobyl Way 2013", 29 April 2013

[72] Lithuania Tribune, "Belarus wants dialogue on nuclear power plant, but no consultations planned", 22 April 2013

[73] Vladas Paskevicius, "Electricity Sector Development in Lithuania", Lithuanian Electricity Association, December 2011.

[74] WNA, "Nuclear Power in Lithuania," October 2012, www.world-nuclear.org/info/inf109.html, accessed 10 June 2013.

cooperation in early December 2010, two weeks after submitting a bid. In December 2011 Poland withdrew from the project[75].

The Lithuanian government, along with its partners in Estonia and Latvia, picked 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.[76] In May 2012, the percentage breakdown of the initially $6.5 billion project were announced with a 20 percent ownership for Hitachi, and 38 percent for Lithuania, while Estonia would take 22 percent and Latvia 20 percent.[77]

However, in October 2012 a consultative national referendum on the future of nuclear power was held in Lithuania and 63 percent voted against new nuclear construction, with sufficient turnout to validate the result.[78] 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”.[79]

Renewable energy suppliers are making use of the current situation to promote their expansion. The Lithuanian wind energy association has stated: “The newly elected government will have to make a new energy strategy, where onshore and offshore wind power possibly could take the place of nuclear power”, both with a doubling of domestic production, to 500 MW and imports linked to wind development in Sweden and Poland.[80]

Remarkably a Lithuanian government commissioned report concluded that under both low and high gas price scenarios it would be cheaper to buy electricity from the regional market than to proceed with the construction of a nuclear reactor in the country. Consultants at the Lithuanian Energy Institute concluded that current costs of electricity, including imports, would be 4–10 Lithuanian cents (1.5–3.8 US cents) per kilowatt-hour less than power from a new reactor. Under these conditions it would save Lithuania $152.8 million per year *not* to build the reactor.[81]

Poland planned the development of a series of nuclear power stations in the 1980s and started construction of two VVER 1000/320 reactors in Żarnowiec on the Baltic coast, but both construction and further plans were halted following the Chernobyl accident. In 2008, however, Poland announced that it was going to re-enter the nuclear arena. In November 2010, the government adopted the Ministry of Economy’s Nuclear Energy Program, which was submitted to a Strategic Environmental Assessment. Poland aims to build 6 GW of nuclear capacity with the first reactor starting up by 2020. In response over 60,000 submissions were received from neighboring Germany; the results are due in the summer of 2013.

Officials have revised the planning in the meantime targeting 2022–23 for the startup of the first reactor. The State utility PGE set up two daughter companies to implement the project, which is supposed to result in two nuclear power stations with 3 GW capacity each. PGE announced the choice of three potential sites in December 2011: Gąski (Mielno), Lubiatowo (Choczewo) and Żarnowiec. Financing of the ambitious project remains unclear and public opinion is highly uncertain. While Poland was the only country showing a majority in favor of nuclear new-build in a 24-country opinion survey in June 2011[82], a local referendum in February 2012 in Mielno showed a surprising 94 percent opposed to the plan. The Polish government reacted by starting a $6 million public information

[75] Nuclear Power Daily, “Poland Freezes Role in Lithuania Atomic Project,”, 9 December 2011

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

[77] Nuclear Intelligence Weekly, “Lithuania”, 11 May 2012.

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

[79] Nuclear Intelligence Weekly, “Lithuania, Prospective PM Wants to Scrape Visaginas”, 9 November 2012.

[80] Bloomberg, “Lithuania May Partly Replace Nuclear Power With Wind, Lobby Says”, 20 November 2012.

[81] Nucleonics Week, “Visaginas generation cost would be above market prices: consultants”, 2 May 2013.

[82] IPSOS, “Global Citizen Reaction to the Fukushima Nuclear Plant Disaster”, June 2011.

campaign, labeled “Meet the Atom”. “We want to make sure that the first Polish nuclear power plant is established with the approval of Polish society”, Hanna Trojanowska, vice minister and government commissioner for nuclear energy, stated in late March 2012.[83] The director of external relations for the state utility PGE, which promotes the project, stated that “obviously we will not proceed against the will of local people”.[84] A September 2012 update of the 24-country opinion survey identifies Poland as one in only three countries where public support for nuclear power decreased, from 61 to 53 percent.[85]

The project does not seem to be going forward very quickly, and in January 2013 the Polish utility PGE selected Australia’s Worley Parsons to conduct a five-year, $81.5 million study on the siting and development of a nuclear power plant, with a capacity of up to 3 GW.[86] The Polish government is reviewing the project and aims to streamline project management in order to reduce costs. It was foreseen that the first units will come into operation around 2023, with the last ones before 2030. A tender for construction and financing was to be opened in the end of 2013. But this schedule is likely to slip as the Prime Minister, Donald Tusk, stated in June 2013 that new nuclear may not be needed if shale gas is developed: "I'm not ruling out nuclear in our energy mix, but later than planned (...) This is primarily due to the expected growth of natural gas as an energy source, including domestic shale gas."[87]

In August 2009 the Kingdom of **Saudi Arabia** announced that it was considering launching a nuclear power program, and in April 2010 a royal decree stated: "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 hydrocarbon resources.”[88] The King Abdullah City for Atomic and Renewable Energy (KA-CARE) has been set up in Riyadh to advance this agenda and to be the competent agency for treaties on nuclear energy signed by the Kingdom. It is also responsible for supervising works related to nuclear energy and radioactive waste projects. In June 2010 it appointed the Finland- and Switzerland-based consultancy firm Pöyry to help define a "high-level strategy in the area of nuclear and renewable energy applications" with desalination. In June 2011 the coordinator of scientific collaboration at KA-CARE said that it plans to construct 16 nuclear power reactors over the next 20 years at a cost of more than 300 billion riyals ($80 billion). The first two reactors would be planned to be online in ten years and then two more per year until 2030.[89]

However, according to a World Energy Council survey, “Saudi Arabia reported that using nuclear is still under consideration and that the WNA figures given above [16 reactors, 20 GW] are speculative.”[90] The assessment confirms reports that the KA-CARE nuclear proposal has still not been approved by the country’s top economic board, headed by King Abdullah.[91] In March 2013, it was reported that a KA-CARE official has said that a tender is now unlikely for another 7–8 years.[92]

Saudi Arabia has very large electricity expansion projects. It plans to double installed capacity to 100 GW by 2021, mainly through fossil fuels, but with a 10 percent renewable target by 2020. There

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83 Nucleonics Week, “As Polish nuclear plans progress, government seeks public support”, 5 April 2012.

84 Idem.

85 IPSOS 2012, “Global support for energy sources September 2012 – Change since Fukushima”, 12 October 2012.

86 Nuclear Intelligence Weekly, Briefs-Poland, 8 February 2013.

87 Business New Europe, “Poland backpedals on nuclear strategy”, 19 June 2013.

88 World Politics Review, “Saudi Arabia’s Nuclear Ambitions Part of Broader Strategy”, 16 June 2011, http://www.worldpoliticsreview.com/articles/9186/saudi-arabias-nuclear-ambitions-part-of-broader-strategy, accessed 6 May 2012.

89 WNA, “Emerging Nuclear Energy Countries”, February 2012, see http://www.world-nuclear.org/info/inf102.html, accessed 7 May 2012.

90 WEC, “World Energy Perspective: Nuclear Energy One Year After Fukushima”, 9 March 2012.

91 Nuclear Intelligence Weekly, “Saudi Arabia – Nuclear Plans Remain Stalled”, 13 February 2012.

92 Nuclear Intelligence Weekly, “US-Saudi NCA Talks Have Yet to Tackle ENR”, 1 March 2013

is a $100 billion state spending commitment over the next ten years on renewables and nuclear combined.[93] Recent announcements tend to emphasize renewables; for example, 24 GW of renewable capacity (producing one-third of projected electricity use) is reportedly targeted by 2020 and 54 GW by 2032. A renewable-and-nuclear policy statement is expected later in 2013.[94]

However, these choices are not only about energy and economics. Senior Saudi Arabian diplomats have reportedly stated that "if Iran develops a nuclear weapon, that will be unacceptable to us and we will have to follow suit", and officials in Riyadh have said that the country would reluctantly push ahead with their own civilian nuclear program.[95] Independent experts have suggested that the drive for civil nuclear power in the region is seen by some as a "security hedge", and that "if Iran was not on the path to a nuclear weapon capability you would probably not see this [civil nuclear] rush".[96] Concerns over nuclear non-proliferation have led the Canadian Government, in a briefing note, to conclude that the Kingdom "does not meet Canada's requirements for nuclear co-operation".[97]

U.S. firms are also currently excluded from any projects due to the lack of a nuclear co-operation agreement. The likelihood of an agreement being signed has been reduced recently with a speech by Hashim Yamani, head of the KA-CARE that the Kingdom was reluctant to willingly forgo enrichment and reprocessing[98].

Turkey has a decades long history of attempting to build a nuclear power program, starting in the early 1970s. In 2006, the government presented a revised nuclear initiative and announced plans for up to 4.5 GW of capacity at Akkuyu and at the Black Sea site of Sinop. The plans met with large-scale local protests. The following year, Turkey approved a bill introducing new laws on the construction and operation of nuclear power plants, which led in March 2008 to a revised tender process for the Akkuyu plant. Only one bid was received jointly from Atomstroyexport and Inter RAO (both from Russia) and Park Teknik (Turkey) for an AES-2006 power plant (another name for the VVER-1200) with four 1200 MW reactors. In May 2010, the Russian and Turkish heads of state signed an intergovernmental agreement for Rosatom to build, own, and operate the Akkuyu plant with four 1200 MW AES-2006 units—a project reported to be worth $20 billion.[99] The main opposition party, the Republican People's Party, resorted to the courts to have the agreement overturned as it says that the tender was not open as required.[100] In December 2011, the project company filed applications for construction permits and a power generation license, as well as for an environmental impact assessment, with a view to starting construction in 2013.[101] However, the power generation licence and environmental approval are only expected by the end of 2013 and the construction licence by mid 2014, enabling full construction to start in 2015.[102] The most recent cost estimate is $25 billion, with the project being built on a 'build, own and operate' (BOO) basis by the Russian consortium, with the electricity being sold at a fixed price. Russia has indicated it would provide 100 percent of financing and reportedly has already spent $700 million on the project. Accordingly, the negotiations about the electricity price are difficult and have been ongoing for years. One source indicates that the 2010

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[93] Ernst&Young, "Renewable energy country attractiveness indices", February 2012.

[94] Saudi Gazette, "Saudi Arabia seeks to become 'green' energy efficient by 2032", 5 July 2013, see http://www.saudigazette.com.sa/index.cfm?method=home.regcon&contentid=20130705172382, accessed 7 July 2013.

[95] Guardian, "Riyadh will build nuclear weapons if Iran gets them, Saudi prince warns", Jason Burke, 29 June 2011.

[96] The Times, "Six Arab States join rush to go nuclear", Richard Beeston, 4 November 2006.

[97] Ottawa Citizen, "Canada concerned about Saudi Arabia's nuclear intentions", 28 January 2013

[98] Nuclear Intelligence Weekly, "US-Saudi NCA Talks Have Yet to Tackle ENR", 1 March 2013

[99] WNN, "Russia's Plans for Akkuyu", 13 May 2010.

[100] Todays Zaman, "Turkey's main opposition to appeal nuclear power plant bill", 22 July 2010

[101] WNN, "Site Work to Start for Turkish Plants," 25 February 2011.

[102] WNA, "Nuclear Power in Turkey", 9 April 2013.

intergovernmental agreement committed to paying Turkey $123.5/MWh for the first 15 years.[103] The licensing process is by its very nature complex, especially as this is the first time a commerical nuclear reactor would be licenced in the country and that there are no VVER 1200 designs in operation. Therefore the licensing process will be heavily reliant on the reactor vendor.[104]

In March 2010, Turkey also signed an agreement with Korea Electric Power Corporation (KEPCO) to prepare a bid for the Sinop plant. However, the parties failed to reach an agreement because of "differences in issues including electricity sales price."[105] Negotiations switched to Toshiba, with the support of the Japanese government, and in December 2010 the parties signed an agreement to prepare a bid for development. A French consortium of AREVA and GDF Suez has also indicated an intention to bid for the project, as has French state utility EDF and the Chinese Guangdong Nuclear Power Company (CGN). In November 2011 the prime minister requested the South Korean president to renew the KEPCO bid[106]. Yet another candidate entered the process when, on 24 April 2012, Turkish state utility EUAS signed a memorandum of understanding with the Canadian firm CANDU-AECL (now owned by SNC-Lavalin) that covers a feasibility study for a 4-unit nuclear plant at Sinop. However, as the trade journal *Nuclear Intelligence Weekly* points out, "the deciding factor in Ankara will almost certainly not be the technology as much as the financing that comes with it".[107]

In May 2013, a $22 billion intergovernmental agreement was signed between Japan and Turkey for the construction of the Sinop plant. Within the Japanese lead consortium will be Mitsubishi, the Itochu Corportation, and GDF-Suez. The consortium chose a, as yet never built PWR Generation III+ design—the ATMEA—form the French nuclear group AREVA. The bulk of the project will be financed by Nippon Export and Investment Insurance (NEXI), Japan's export credit agency, and French credit insurer Coface.[108]

In October 2010, **Vietnam** signed an intergovernmental agreement with Russia's Atomstroyexport to build the Ninh Thuan 1 nuclear power plant, using 1200 MW reactors. Construction was slated to begin in 2014, and the turnkey project will be owned and operated by the state utility Electricity of Vietnam (EVN), with operations beginning in 2020.[109] However, in April 2013, the Song Da Corporation stated that it expected to start construction in the next 2–3 years.[110] 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 used fuel for the life of the plant. An agreement for up to $9 billion finance was signed in November 2011 with the Russian government's state export credit bureau, and a second $0.5 billion agreement covered the establishment of a nuclear science and technology center.[111]

Vietnam has also signed an intergovernmental agreement with Japan for the construction of a second nuclear power plant in Ninh Thuan province, with its two reactors 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

[103] NIW, "Turkey – Financing Continues to Hold Back Nuclear Plans", 7 September 2012.

[104] Bookings Institute, "Human Resource Development in New Nuclear Energy States: Case Studies from the Middle East, John Banks, Kevin Massy, Charles Ebinger (Ed.), November 2012.

[105] Bloomberg, Tsuyoshi Inajima, "Turkey Holds Nuclear Talks With Japan After South Korean Discussions Fail," Bloomberg.com, 23 December 2010.

[106] WNA, "Nuclear Power in Turkey", May 2013.

[107] Nuclear Intelligence Weekly, "Candu Down in Jordan, Up in Turkey", 4 May 2012.

[108] Reuters, "UPDATE 1-Turkey, Japan sign $22 bln nuclear power plant deal", 3 May 2013.

[109] Global Energy Magazine, "Japan and Russia to Build Ninhthuan Nuclear Power Plants for Vietnam," 3 November 2010.

[110] Investvine, "Vietnam prepares for nuclear power", posted by Arno Maierbrugger on 13 April 2013

[111] WNA, "Nuclear Power in Vietnam", May 2013, http://world-nuclear.org/info/vietnam_inf131.html, accessed 10 June 2013.

issued a master plan specifying Ninh Thuan 1 & 2 nuclear power plants with a total of eight 1000 MWe-class reactors, one coming on line each year 2020–27, then two more larger ones to 2029 at a central location. However, the State owned Electricity of Vietnam Corporation, which is to be the sole investor in the four reactors, is still preparing the feasibilty studies.[112] 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.[113] Both of these development suggest that a 2020 startup date for the first reactor is unrealistic.

The **United Arab Emirates** (UAE) has the most advanced new nuclear development plans in the Middle East. In April 2008, the UAE published a nuclear energy policy that stated that nuclear power was a proven, environmentally promising and commercially competitive option that "could make a significant base-load contribution to the UAE's economy and future energy security."[114] The policy proposed installing up to 20 GW of nuclear energy capacity, including 5 GW by 2020, which would then represent about 22 percent of total planned installed power generating capacity. This would require the operation of four reactors, two between Abu Dhabi city and Ruwais, one at Al Fujayrah, and possibly one at As Sila.

A joint-venture approach, similar to that developed for the water and conventional power utilities, was proposed in which the government would retain a 60 percent share and a private company a 40 percent share. A call for bids in 2009 resulted in nine expressions of interest and the shortlisting of three companies: AREVA (France) with GDF-SUEZ, EDF, and Total, proposing EPRs; GE-Hitachi (U.S.-Japan), proposing ABWRs; and a South Korean consortium, proposing APR1400 PWRs. In December 2009, the Korean consortium was awarded the $20 billion contract for the construction and first fuel loads of four reactors, reportedly because the consortium could demonstrate the highest capacity factors, lowest construction costs, and shortest construction times. The trade press considers that "it remains to be seen whether South Korea's bid was realistic, or whether it was seriously under-priced". The outcome might be fatal: "If things go wrong, Korea's entry to the nuclear export market could be short-lived.“[115] Indeed, updated cost estimates are reportedly already skyrocketing between $36 billion and "closer to $40 billion".[116]

The regulatory review undertaken in the UAE has relied on the original 2008 assessement by the Korean Institute of Nuclear Safety (KINS), as "since the basic reactor design had already been reviewed by another nuclear regulator, FANR (Federal Authority for Nuclear Regulation) said that it used the KINS Safety Evaluation Report to gloss over some parts of the Preliminary Safety Analysis report, provided that the documentation was complete".[117]

In July 2010, a site-preparation license and a limited construction license were granted for four reactors at a single site at Barakah, 53 kilometers along the coast from Ruwais.[118] The application is based substantially on the safety analysis prepared for South Korea's Shin–Kori units 3 and 4, the "reference plant" for the UAE's new-build program. A tentative schedule published in late December 2010, and not revised since, projects that Barakah-1 will start commercial operation in 2017 with unit 2 operating from 2018. Construction of Barakah-1 officially started on 19 July 2012 and of Barakah-2 on 28 May 2013. In March 2013, the Emirates Nuclear Energy Corporation (ENEC) submitted its application for the construction of units 3 and 4, to the national regulator.[119]

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[112] Nucleonics Week, "Vietnam might require investors to set up fund for closure costs", 11 January 2013.

[113] WNN, "New nuclear development council for Vietnam", 9 May 2013.

[114] ArabianOilandGas.com "Abdullah Al Mutawa Explains How the UAE is Preparing to Meet Future Power Demands,", 10 June 2008.

[115] Energy Economist, "Prospects for Nuclear Power in 2012", Platts, February 2012.

[116] Nuclear Intelligence Weekly, "United Arab Emirates: No Plans for Second NPP", 20 April 2012.

[117] Nuclear Engineering International, "Building Barakah", 28 September 2012

[118] ArabianBusinesss.com, "ENEC Welcomes Regulator's License Approval," 11 July 2010.

[119] WNN, "Application in for the next two Barakah units", 4 March 2013

Construction Times

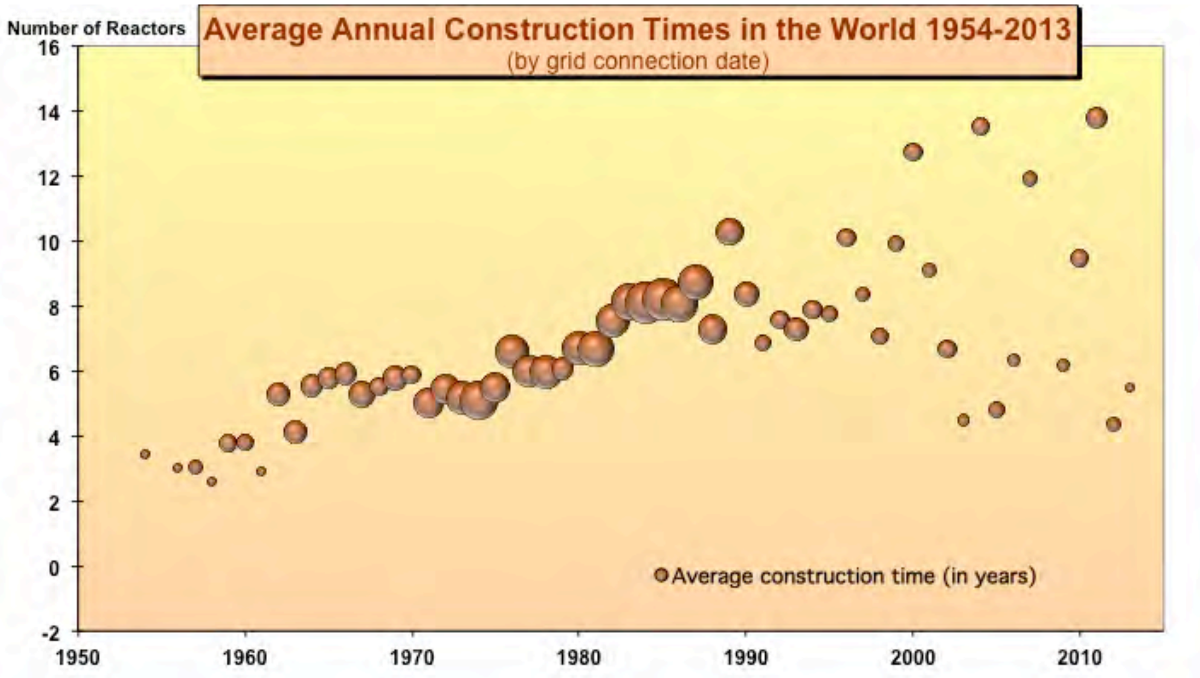
Construction Times of Past and Currently *Operating* Reactors

There has been a clear global trend towards increasing construction times since the beginning of the nuclear age. National building programs were faster in the early years of nuclear power. As Figure 13 illustrates, in the 1970s and 1980s construction times were quite homogenous, while in the past two decades they have been varied. The only unit that started up in the first half of 2013, a Chinese reactor, took 5.5 years to build and two South Korean units and a Chinese reactor that were connected to the grid in 2012 averaged a 4.5-year construction time. Worldwide, however, it took an average of 13.8 years to build the seven units started up in 2011 and 9.5 years for the five reactors that began operating in 2010.

The reasons for gradually increasing construction times are not well understood. It is clear that continuously increasing safety requirements and, in some countries, lengthy legal cases due to public opposition have played a role. While growing system complexity as a consequence of the previous conditions is also likely to have affected construction times and costs.

Most, but not all of the nuclear countries have experienced this symptom. The latest generation of operating units provides an illustration of this. Over a 10-year period between 2003 and July 2013 a total of 34 reactors started up. Average construction time was 9.4 years with a large range from 3.8 to 26.8 years. (See Annex 2 for details). There are significant differences between the nine countries that started up reactors during that period.

Figure 13: Average Annual Construction Times in the World 1954–2013



Sources: MSC based on IAEA-PRIS 2013

Note: The bubble size is equivalent to the number of units started up in the given year.

All 34 reactors that started up over the past decade are located in Asia (China, India, Japan, Pakistan, South Korea), Eastern Europe (Romania, Russia, Ukraine) or the Middle East (Iran). Not a single unit was started up in the Western world during that period.[120] With 11 units China, started up the largest fleet, followed by India (6), and South Korea (5).

Construction times over the past decade were most impressive in Japan and South Korea with 4.4 years on average for the nine units built in both countries together, compared to performance in other countries. China reached an average of just under six years, ranging from 4.4 to 11.2 years.

Iran holds the negative record. Its only commercial nuclear power reactor took over 36 years to finally operate, while Romania built for over 24 years to finish its second unit and Russia an average of just under 24 years to complete three reactors.

The increase in construction times is considered the primary driver of rising costs.

Construction Times and Costs of Reactors Currently *Under Construction*

As indicated in the General Overview section, at least 23 of the units listed by the IAEA as "under construction" have encountered costly multi-year construction delays. All of the 42 remaining units were started within the last five years or have yet to reach their projected start-up date, making it difficult to assess whether they are on schedule. Average construction time of the 62 listed projects started up before 2013 currently stands at eight years, ranging from Tianwan-3, launched on 27 December 2012, to the Watts Bar-2 site in the U.S. with 40 years.

The Economics of Nuclear Power – An Update

Introduction

At the center of the claims for the new generation of nuclear power plants, so-called Generation III, that was expected to drive a "Nuclear Renaissance" were ambitious forecasts for their economics. Ten years ago, construction cost estimates of around $1,000/kW allowed the nuclear industry to claim that power from these new designs would be competitive with the cheapest source of power, natural gas, then being sold at low prices compared to current prices. The two key markets these claims seemed to have opened up were the U.S. and the U.K., both potentially substantial markets but also highly influential because of their historically pioneering role in nuclear power development and the strong credibility of their safety regulatory bodies. The present chapter looks at whether the U.K. proposals for nuclear new-build would be legal under current European Union legislation, and whether, if it were, other Member States could adopt the 'British Model' to launch their own nuclear programs.

The chapter also assesses developments in China, by far the largest market for nuclear power plants in the past decade and a potential proving ground for Generation III+ designs[121]; as well as progress at the two sites in Western Europe, Olkiluoto (Finland) and Flamanville (France), where there has been instructive construction experience with one of the two key Gen III+ designs, the French AREVA European Pressurized water Reactor (EPR).[122]

A decade on, it is clear that claims for these new reactors were hopelessly inaccurate and by 2012/13, the typical cost estimate for Gen III+ designs is of the order $7,000/kW (levelized 2012/13 USD). Analyzing which kinds of organizations published which costs at what dates reveals that the low early estimates were by vendors or their surrogates.[123] Moreover, as analyst Jim Harding first noted, these

[120] The last units to start up in the Western world were Brazil's Angra-2 after 24 years of construction and Civaux-2 in France in 1999 after 8.5 years of construction.

[121] The criteria for the different design generations are not precise but generation III+ designs are generally expected to rely more on 'passive' rather than 'engineered' safety features and were therefore expected to be simpler and cheaper than its predecessors

[122] For the US market, the EPR is known as the Evolutionary Power Reactor.

[123] Amory, B. Lovins, Rocky Mountain Institute, "Reinventing Fire: Bold Business Solutions for the New Energy Era", White River Junction, VT: Chelsea Green, see www.reinventingfire.com.

were 'variable' prices, meaning that the buyer took all the risk of cost overruns. But in the late 2000s, as commercial discussions developed for many proposed U.S. reactors, financial institutions and independent analysts found that the actual bids suddenly became many times higher if, as they nearly always were, the prices were 'fixed' (the vendor takes all the price risk) or 'firm' (the vendor takes all the price risk beyond predefined metrics of inflation in the cost of the main factor inputs like steel, concrete, and labor). That is, when the vendors actually had to take much or all of the price risk themselves, so they had an incentive to bid honest prices rather than seductive but ephemeral dreams, the quoted nuclear construction cost soared by several- to manifold, to levels that are far, often several or many times, higher than the observed market prices of available carbon-free alternatives (notably efficient use, combined-heat-and-power, onshore wind power, and, in some cases, even modern photovoltaics).

Thus at the order of cost revealed in the marketplace in recent years, new nuclear power plants are amongst the most expensive generation options available and, despite a substantial rise in gas prices in most regions, far more expensive than gas and renewable options such as onshore wind. Whilst the cost curve for renewables is generally downwards, nuclear costs, as throughout the 60 year history of nuclear power are still on an upward trend, especially as lessons from Fukushima are identified and incorporated into reactor designs.

Deriving a full estimate of the cost of a kWh of electricity from a nuclear power plant is an immensely complex process requiring a large number of assumptions. Many of these are based on little or no practical experience of the processes involved, such as disposal of intermediate and high-level wastes and the decommissioning of retired nuclear power plants. However, from a corporate point of view and using conventional project appraisal techniques, there are just three variables that will largely determine the cost of nuclear power: the cost of construction, the cost of capital and the reliability. These three variables determine the fixed cost element of a kWh of nuclear electricity, which is normally more than 70 percent of the total cost of a kWh of nuclear electricity.

It is important to note that the process of 'discounting' future costs and benefits, explained below, under which the further into the future costs and benefits occur, the less weight they carry in project appraisals means that any costs and benefits incurred decades in the future have much less impact on the overall economics. This is particularly important for waste disposal and decommissioning but it also means that the economics of nuclear power is, all things being equal, relatively insensitive to assumed plant lifetime but is particularly sensitive to reliability in the early years of operation.

The Characteristics of Nuclear Economics

"What is clear is that it is completely impossible to produce definitive estimates for new nuclear costs at this time."

Steve Kidd
Director of Strategy & Research
World Nuclear Association
22 August 2008[124]

Fixed Costs

Reliability

Reliability is measured by the plant's load factor (capacity factor in U.S. parlance). This is calculated as the kWh produced by the plant in a given period as a percentage of the kWh that would have been produced had the plant operated uninterrupted at its maximum power rating. Typically, the nuclear industry has forecast the nuclear power plants would achieve load factors of 85 percent or more. In practice relatively few plants have achieved this level of reliability over a significant period of time and in 1980, the worldwide average load factor was 60 percent with some plants achieving good levels

[124] Steve Kidd, "Escalating costs of new build: what does it mean", 22 August 2008, see http://www.neimagazine.com/opinion/opinionescalating-costs-of-new-build-what-does-it-mean/, accessed 7 July 2013.

of reliability but others performing very poorly. Reliability is less uncertain than it was and the worldwide average is now about 70 percent with some plants tending to do considerably better than the average. A high level of reliability of nuclear plants is not guaranteed, especially for new untested designs, but the risk of poor performance might be less than in the past.

Construction Costs

As noted above, construction costs are highly uncertain with little prospect in the next few years that estimating accurate construction costs will become any easier. For the purposes of analysis and comparison, costs should exclude the financing cost during the construction process but include the cost of the first fuel charge. In other words, overnight costs should be clearly distinguished from total costs. Comparisons also require conversion into a common currency (usually the US$) and common base date. This can cause problems because currency exchange rates are unstable and can fluctuate by 10 percent or more, even in a short period, so care must be taken to ensure exchange rates are representative of long-term exchange rates and that costs are adjusted to a common time basis. These adjustments are inevitably not exact, and mean that modest differences in costs (perhaps ±10 percent) may result simply from the inaccuracies inherent in translating to a common currency and time-basis.

Cost of Capital

In the past, the cost of capital was not subject to much debate in forecasts of nuclear power costs. This was because electricity was then a monopoly business under which the owner of the power plants could pass on to consumers whatever costs were incurred. This meant that while nuclear power was clearly a very risky investment because of its poor record of plant being built to time and cost and operating reliably, this risk was generally entirely borne by customers. For financiers, nuclear power was a low risk loan because electricity is a vital purchase and consumers nearly always paid their bills. This meant the cost of finance—rightly or wrongly—was also assumed to be low in developed countries. In developing countries with unstable economies and currencies, finance often has been problematic.

As soon as the assumption of cost pass-through no longer held, either because regulators no longer allowed whatever costs were incurred to be passed through (as in the U.S. in the late 1970s) or because monopoly had been replaced by a competitive electricity market, finance became problematic. In a competitive market, if a company's power is too expensive, it will be forced out of business. It seems highly likely that if there is no assurance that regulators will allow cost pass through or the nuclear plant will have to survive in a genuinely competitive market, finance will not be available (or prohibitively expensive). All the nuclear plants on which construction has started in the past decade are in monopoly systems, usually state-owned, or in markets where the plant owner has such a dominant position that competition is too weak to have any impact on the owner's ability to set prices or the plant is largely protected by a long-term power purchase agreement (PPA).

In general, large investments are typically financed by a mix of debt (borrowing from financiers) and equity (typically from the company's own resources or effectively foregone profits). The relative proportions of debt and equity vary but typically equity is significantly more expensive than debt. If a project is financed by 60 percent debt at a real interest rate of 5 percent and 40 percent equity at a real interest rate of 10 percent, the Weighted Average Cost of Capital (WACC) is 7 percent.[125]

Whilst it can be helpful to compare construction costs using the "overnight cost" convention (what the plant would cost to build if that could be done overnight), over the years of actual construction the project must also finance its capital. Longer construction thus incurs more interest (and/or dividend) costs, which compound. Moreover, if real (inflation-adjusted) construction costs escalate over time, as they have tended to do virtually worldwide, longer construction means more cost escalation, also compounding. The combined effect of these two phenomena in U.S. nuclear projects proposed since the mid-2000s has been that expected total construction cost, including financing and real escalation during construction, approaches double the overnight cost.

[125] 5*0.6 + 10*0.4 = 7

Cost of Decommissioning and Waste Disposal

Other costs such as waste disposal and decommissioning are expected to be huge, on the order of billions of dollars per reactor, and are highly uncertain because of the relative lack of experience of these processes, (especially if many reactors must be decommissioned at once, straining limited technical resources). But under conventional project appraisal techniques, these costs are 'discounted' to give a 'net present value' (NPV) far below their undiscounted cost. For example, it is often assumed, as in the U.K., that the expensive, problematic and unproven part of the decommissioning process, cutting up and disposing of the reactor vessel, takes place perhaps 150 years after the start of operation. Under conventional accounting procedures, the owner of the plant effectively puts aside a sum of money now and it is assumed this money will earn interest until it is required to pay for decommissioning. If we assume a real (net of inflation) interest rate of 3 percent, over 150 years[126], a sum of money will grow by a factor of more than 80. So if we assume that the construction of a new reactor would be $10 billion and the undiscounted decommissioning cost would be half that figure, the discounted cost of decommissioning (NPV) would be just $59m. Even if we assume a delay of 75 years (perhaps 15 years after plant closure) and take the more cautious assumption, of a real interest rate of 2 percent earned over 75 years[127], the discounted decommissioning cost (NPV) would be about $1 billion. In practice, the funds are accumulated through what is effectively a surcharge on the price of electricity, although in some countries they may be not *set aside* at all but spent for other purposes.

For this method of provisioning to give a high level of confidence that sufficient funds are available to carry out decommissioning when a future generation (whose decision it will be on timing, not the current generation) decides to carry out the task, the following conditions will have to be fulfilled:

- The funds are actually *set aside* and are not lost, for example due to investment in funds that fail;
- The processes required are technically feasible, including disposal of the waste;
- The cost estimates for each step are accurate;
- The forecast rate of interest is actually achieved;
- The forecast timing of decommissioning is correct; and
- The plant operates for as long as expected.

Current best-practice, certainly not implemented in most countries, is that decommissioning funds and funds to pay for waste disposal, are invested in funds that are 'segregated' from the company that owns the plant so if the company fails, the provisions are not lost and the company cannot use the provisions as a cheap source of capital to fund its own, perhaps risky investments. Funds are also placed in very low risk investments—inevitably, this means the interest rate will be correspondingly low—to minimize the risk of failure of the investments made. This best practice partly addresses the first risk but addressing the other risks, where possible at all, would require additional safeguards, for example, expensive financial instruments that would be guaranteed to make up any shortfall in funds. It is not clear whether such instruments would be available and credible, nor what their cost would be.

The U.S. Nuclear Power Program

The U.S. government was the first to respond to the promises made of a 'Nuclear Renaissance' through President George W. Bush's Nuclear 2010 Program launched in 2002. At that time, the most recent order for a nuclear power plant not subsequently cancelled was placed in 1973. The Bush government believed that new nuclear power plants were competitive with any other form of generation (including gas) and all that was needed to re-start ordering was to provide subsidies to allow the construction of a handful of demonstration plants (perhaps three projects) that would show that the issues that had led to the collapse of ordering in the U.S. had been solved by Generation III+ designs. The expectation at the time of the launch of the program was that the first plants would come on line by 2010.

[126] Based on an operating life of 60 years and a delay to complete decommissioning of 90 years.
[127] Based on an operating life of 40 years and a delay to complete decommissioning of 35 years.

Loan Guarantees and Other Subsidies[128]

The U.S. Energy Policy Act of 2005 (EPACT 2005) provided a legal basis for the program and envisaged three types of support.[129] First, a limited number of new nuclear power plants could receive \$18/MWh production tax creditfor eight years for up to \$125m per 1000MW (or about 80 percent of what the plant could earn if it ran 100 percent of the time).[130] The second benefit was a provision for federal loan guarantees covering up to 80 percent of project costs. The third benefit provided up to \$500m in risk insurance for the first two units and \$250m (€187.5m) for units 3–6. This insurance was to be paid if delays not the fault of the licensee slow the licensing of the plant.[131]

The key subsidy was the Federal loan guarantees which allowed the developers to borrow at interest rates comparable to the Treasury rates. In 2009, four of the projects were shortlisted for loan guarantees. Two of these, the Summer (South Carolina) and Vogtle (Georgia) projects, were for twin AP1000s and were in states where electricity remains a regulated monopoly, while the other two, Calvert Cliffs (a single EPR) and South Texas (a pair of ABWRs) are in states with competitive wholesale electricity markets. Not by coincidence, the two projects in competitive markets are highly unlikely to go ahead even with loan guarantees. Federal loan guarantees require the payment of a fee that reflects the riskiness of the project.

The fee for the Calvert Cliffs plant was reported to be 11.6 percent of the amount of loan guarantees offered, \$7.6 billion and the size of this fee was reported to be a key element in the decision not to pursue this project.[132] There was also an issue over the ownership of the plant. U.S. law prohibits foreign control of nuclear power plants, but after the main U.S. partner, Constellation, withdrew from the project, this left EDF as the sole owner. As a result, the NRC refused permission for the project to go ahead.[133] In April 2011, NRG, the main developer for the South Texas project stopped funding and work effectively ceased on the project.[134] This left Toshiba American Nuclear Energy Corporation (TANE) as the effective controller of the project. Whilst TANE's nominal stake is only 10 percent in Nuclear Innovation North America (NINA), the NRC ruled that "its overwhelming financial contributions give it significantly more power than is reflected by this ownership stake."[135]

[128] Doug Koplow dedicated an entire report to the specific issue of nuclear subsidies. He concluded that in the U.S. proposed subsidies to many of the new-build projects exceed actual power generation prices. See Doug Koplow, "Nuclear Power: Still Not Viable without Subsidies", Union of Concerned Scientists (UCS), February 2011, available at http://www.ucsusa.org/nuclear_power/nuclear_power_and_global_warming/nuclear-power-subsidies-report.html.

[129] This subsidy, in pretax levelized value, is worth \$25/MWh at a 15 percent annual hurdle rate, 40 percent marginal tax rate, and 40-year operating life (or \$11/MWh using a 3 percent real discount rate). That's less than the value—\$28 and \$18/MWh respectively—of new wind power's tax credit, which (unlike the permanent nuclear one) currently expires for projects not begun by the end of 2013. However, legacy operating subsidies of \$3–8/MWh more than make up the difference, giving the next 6 GW of U.S. nuclear new-build a higher-than-wind-power operating subsidy in addition to ~100% construction subsidies; Amory B. Lovins, personal communication, 7 July 2013.

[130] This production tax credit, which approximates the credit available for wind power, is available to the first 6GW of new units over the next eight years and is to be divided among the eligible plants. So if 12GW worth of new plants meets the criteria each one would get the credit only for 500 MW. It is equivalent to paying about \$140/ton for avoided carbon assuming that the plant displaces half coal and half gas, though of course the plant would go on avoiding carbon for many years after the credit expired.

[131] All three measures require implementing regulations, and the loan guarantees require an appropriation. So the actual scope and benefit of the subsidy is unclear.

[132] Nucleonics Week, "Constellation move casts doubt about nuclear merchant plants' future", 14 October 2010.

[133] Washington Post, "New nuclear reactor rejected; Rule against foreign ownership trips up UniStar's bid", 12 March 2013.

[134] Nucleonics Week, "Merchant economics hurt new projects, operating units: analysts", 13 September 2012.

[135] http://www.worldnuclearreport.org/US-Ownership-Rules-Hurdle-for.html, accessed 9 May 2013.

Generic Design Reviews[136]

Four designs[137] started a process of generic design review intended to resolve all significant design issues other than site-specific ones. A fifth design, the ABWR[138], had already received generic design approval in 1997 but this approval expired in 2012 and is being renewed. A large number of potential projects quickly emerged with about 23 substantial proposals with a total of 36 reactors projected. The optimism quickly waned as estimated costs escalated at an alarming rate, the required Federal budget for loan guarantees skyrocketed, generic design reviews took much longer to complete than expected and natural-gas prices fell. Many of the projects made little significant progress.

Of the five designs, the ESBWR and the APWR have no realistic prospects for orders. Only the AP1000 has received full generic design approval.[139] In April 2013, no completion date for the ABWR reviews was specified, the EPR review was not expected to be complete before 2015,[140] and the APWR review was scheduled for completion in 2015.[141]The ESBWR review was said to be near completion but a new issue arose and there is now no scheduled date for completion.[142]

Vogtle and Summer

The Vogtle site is where two reactors were completed in the 1980s which suffered some of the largest cost escalations of any project. Those two reactors were originally budgeted to cost $660m but ended up costing $9 billion.[143] The current Vogtle project, to add two modern reactors, was given a conditional offer of $8.3 billion in loan guarantees in 2010. The size of the fee was not published but was reported to be between 0.5 and 1.5 percent based on the strong backing of the parent company of the developer, Southern Company, and on the expectation that the Georgia Public Service Commission (PSC) would allow full cost recovery.[144] The Georgia PSC allowed Southern Company to begin to recover the costs of the plant from consumers in 2011.

By early July 2013, there was still no agreement on the final terms of the loan guarantees and the offer's deadline was extended for the third time, to the end of September 2013. On 21 June 2013, ratings agency Zacks downgraded Southern Company's credit rating.[145] Construction (pouring of first structural concrete) at the first unit at Vogtle started on 12 March 2013[146], by which time the cost and schedule were already beginning to overrun.[147] When the project was approved, its estimated cost had risen to $14 billion. However, in the year up to the start of construction, problems with site preparation and initial construction work had led to the owners of the plant to sue two major contractors for $900 million.[148] The plant is reported to be already about a year behind its schedule of completing the first unit in 2017. Georgia Power, the largest partner in the project (but still a minority owner, having laid off most of the cost and risk on relatively small partners), requested a $381 million increase in the certified capital cost of its share of the project to approximately $4.8 billion from $4.4 billion, according to Moody's. It also indicated that financing costs would rise to about $2.1 billion from

136 http://www.nrc.gov/reactors/new-reactors/design-cert.html, accessed 1 May 2013.

137 These were the Westinghouse AP1000, the GE-Hitachi ESBWR, the AREVA EPR, the Mitsubishi AP1400.

138 The ABWR is offered both by Toshiba and GE-Hitachi in competition.

139 http://www.nrc.gov/reactors/new-reactors/design-cert/ap1000.html, accessed 13 May 2013.

140 http://www.nrc.gov/reactors/new-reactors/design-cert/epr/review-schedule.html, accessed 13 May 2013.

141 http://www.world-nuclear-news.org/RS-APWR_design_certification_rescheduled-1306124.html, accessed 13 May 2013.

142 http://www.nrc.gov/reactors/new-reactors/design-cert/esbwr/review-schedule.html, accessed 13 May 2013.

143 Associated Press, "'Significant' issues building new Ga. nuke plant", 10 June 2011.

144 Nucleonics Week, "Varying financing terms seen for utility, merchant projects", 11 March 2010.

145 PR Newswire, "Another Vogtle Reactor Deadline Passes: Taxpayer Advocates Warn Government Keeps Pushing Bad Deal That Wall Street Won't Touch", 2 July 2013.

146 http://www.worldnuclearreport.org/Construction-Start-at-Vogtle.html, accessed 13 May 2013.

147 The Atlanta Journal-Constitution, "Vogtle rises, but nuke revival lags", 17 February 2013.

148 Nucleonics Week, "US modular nuclear construction going slower than expected: monitor", 3 January 2013.

$1.7 billion because of a delay in the scheduled completion date.[149] Credit rating agencies are critically examining the credit rating of one of the smaller of the four partners in the project.[150] The largest partner in the project with 46 percent is Georgia Power, part of the huge Southern Company and seen as being large enough not to be put at risk by cost overruns. However, the second largest partner with 30 percent is the much smaller Oglethorpe Power Corp. The cost overruns led Fitch to put its credit rating on "negative outlook", i.e. at risk of being downgraded.

The Summer project has even stronger backing from the state regulatory body in South Carolina, and although the owners sought loan guarantees of about $8 billion, which they may decline if they consider the fee too high. In March 2013, an appeal to the South Carolina Supreme Court was launched by, amongst others, the Sierra Club, against the decision by the South Carolina Public Service Commission to allow recovery of $300m from consumers for expenses related to construction of Summer.[151] Construction of the first unit started in March 2013 with a targeted completion date of 2017 and 2018 for the second unit.[152]

The Vogtle and Summer projects both depend on unusual state laws that require customers to pay for the plant as it's built, whatever it costs, and whether it ever runs or not. The owners apparently think this manages their own risk. However, similar arrangements turned out in the 1970s–80s nuclear boom to increase the owners' risk for two reasons: price elasticity has longer to work during construction—increasing the likelihood of lower-than-expected demand and hence revenue once the plant is finished—and continual price increases and cost-overrun headlines annoy customers and hence regulators, who have many ways to penalize the utility no matter what the law says about the project.

Further prospects

The low spot price of natural gas in the U.S. and the booming renewable energy industry (see Chapter Nuclear Power vs. Renewables) have limited prospects for new nuclear (and coal-fired) plants and even threaten the viability of existing plants. Beyond Summer and Vogtle, there seems little prospect in the next few years of any other projects going ahead. The former CEO of Constellation, Michael Wallace, told *Nucleonics Week*[153]:

> It is now not possible for merchant generating companies to move forward with new nuclear projects. Only those projects in highly-supportive states like Georgia and South Carolina, where nuclear plant expansions at Southern Nuclear's Vogtle and South Carolina Electric & Gas' Summer are located, appear likely to go ahead. The economic pressures are threatening even operating units. It is quite likely—more than that, highly probable—that there will be existing plants prematurely shut down for economic reasons.

The closure of the Kewaunee[154] (PWR, 584 MW started up in 1973) and Crystal River[155] (PWR, 838 MW, started up in 1977) plants was announced in 2012/13 despite both plants' having received NRC license extensions from 40 years to 60 years.

UBS saw these closures as harbingers of further closures for 'merchant plants' (those exposed to competitive electricity markets) as the non-fuel operating costs of nuclear plants more than counterbalanced low fuel costs. UBS stated[156]:

> Following Dominion's recent announcement to retire its Kewaunee nuclear plant in Wisconsin in October, we believe the plant may be the figurative canary in the coal mine. Despite substantially lower fuel costs than coal plants, fixed costs are approximately 4–5x times higher than coal plants of

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[149] The Bond Buyer, "Moody's: Vogtle Nuclear Plant Cost Hikes, Delays are Negative", 4 March 2013.

[150] Associated Press, "Credit agencies eyeing Plant Vogtle cost overrun", 10 April 2013.

[151] SNL Generation Markets Week "SC court to review SCE&G's recovery of additional Summer nuke project costs", 26 March 2013.

[152] http://www.worldnuclearreport.org/Summer-South-Carolina-First.html, accessed 13 May 2013.

[153] Nucleonics Week, "New nuclear expectations modest, conference told", 21 June 2012.

[154] http://www.worldnuclearreport.org/Kewaunee-Plant-in-Wisconsin-Closed.html accessed 10 May 2013.

[155] http://www.worldnuclearreport.org/Crystal-River-Reactor-Shut-Down.html, accessed 10 May 2013.

[156] UBS Investment Research, "Re-evaluating merchant nuclear" 2 January 2013.

comparable size and may be higher for single-unit plants. Additionally, maintenance capex of ~$50/kW-yr, coupled with rising nuclear fuel capex, further impede their economic viability and mask underlying FCF generation when comparing EBITDA and ascribing EV/EBITDA multiples. Units at particular risk include Exelon's Clinton unit in Central Illinois, and its Ginna plant (CENG) in upstate NY, as well as ETR's Fitzpatrick and Yankee plants. We see risk to primarily deregulated assets in New York and Midwest, which suffer from low capacity payments due to over-capacity and structural regulatory interference, in conjunction with low power prices.

The U.K. Nuclear Program

The U.K.'s commitment to renew nuclear ordering came in 2006, a year later than that of the U.S. By then, the promise of $1,000/kW had been proven to be far too optimistic by the fixed-price bid that had won the tender for the Olkiluoto plant at more than $2,000/kW in 2003. The basis for the U.S. program was that the new designs would be economically competitive with the cheapest fossil-fueled options. All that was needed was a handful of subsidized demonstration plants after which ordering without subsidies would supposedly be self-sustaining. The British case was that new nuclear would not be as cheap as the cheapest fossil-fueled options but with a carbon price on the European Union Emissions Trading System (EU ETS) of €36 in 2020 (in 2008 values) new nuclear would be competitive. On this basis, the government claimed that with a few enabling decisions, such as allocation of sites and generic approval of the designs, utilities would choose nuclear power over other options.

To back this claim, the government made a firm commitment that no public subsidies would be given. This claim was never realistic, and as is discussed below, what is proposed now, despite the U.K. government's claim that no subsidies are being offered, represents a massive subsidy to new nuclear power plants. Nevertheless, like the U.S. program before it, the claim that subsidies would not be needed was a hugely influential endorsement of the new-generation designs.

The Plans: 2006–10

In November 2005, the Government of Tony Blair instituted a review of energy policy widely reported as being aimed at restarting a nuclear program only two years after the completion of an earlier review that found no economic case for new nuclear power stations[157]. A key element of the proposed nuclear program was the promise that there would be no subsidies. In 2006, well before the review was complete, the Secretary of State for Trade and Industry (the ministry then responsible for energy) was questioned by a Select Committee on the issue of subsidies:[158]

> Q: 'Do you think the Government would be prepared to consider guarantees: for example, a cap on the waste costs of new nuclear, or sharing initial planning costs, or even guaranteeing the price of the energy produced from nuclear?
>
> A: 'I would be very surprised if we issued that kind of guarantee. The one thing I am clear about is that when we look at nuclear, we have to look at cost, safety and waste. Those are the three big issues that were around in 2003 and they are the big issues now. I expect new plant to be built and run by the private sector. There is a market here…. First of all, and I know this is not the precise question you are asking, there is no expectation of taxpayers' money being thrown into this. It is down to the private sector.'

The government was also adamant that there would be competition between vendors and developers. It therefore instigated a program in 2007 of Generic Design Assessment (GDA) under which the U.K. safety regulator, then the Nuclear Installations Inspectorate, subsequently renamed the Office of

[157] The Energy Policy Review of 2003 found: "While nuclear power is currently an important source of carbon free electricity, the current economics of nuclear power make it an unattractive option for new generating capacity and there are also important issues for nuclear waste to be resolved.", BERR (2003) "Our energy future - creating a low carbon economy", BERR, London p 61 http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file10719.pdf, p.61, accessed 1 May 2013

[158] http://www.publications.parliament.uk/pa/cm200506/cmselect/cmenvaud/584/5112304.htm, accessed 1 May 2013

Nuclear Regulation (ONR), would carry out a comprehensive review of a number of designs so that a potential customer would know the only regulatory issues remaining for that design would be limited site-specific ones. Four designs entered the GDA: the AREVA EPR, the Toshiba/Westinghouse AP1000, the Hitachi-GE ESBWR, and the AECL ACR1000. This process was scheduled to be completed in July 2011.

In 2009, EDF took over the company that owned most of the U.K.'s nuclear power plants, British Energy, giving it access to the main expected sites for new nuclear power plants. To ensure competition between developers, the government auctioned land at sites of existing nuclear power plants to other potential developers. It was expected such sites would be suitable for new nuclear power plants and would see much less opposition than new sites. Three consortia were set up to develop new nuclear plants:

- NNB GenCo, a joint venture between EDF (80 percent) and the U.K. energy supplier, Centrica (20 percent);
- Horizon, a 50/50 joint venture between the two German utilities, E.ON and RWE, which already had a strong position in the U.K. market; and
- Nugen, a joint venture comprising the owner of Scottish Power, the Spanish Iberdrola (37.5 percent), the French GDF Suez (37.5 percent), and Scottish & Southern Energy, S&SE (25 percent).

NNB GenCo planned to build four EPRs, two each at Hinkley Point and Sizewell, the first then expected on-line by 2017. Horizon also planned to build four reactors, design not specified, two each at Oldbury and Wylfa; while Nugen acquired a site at Sellafield but did not specify the number and design of reactor to be built. A White Paper on nuclear power was published in January 2008. It concluded:[159]

> The Government believes it is in the public interest that new nuclear power stations should have a role to play in this country's future energy mix alongside other low-carbon sources; that it would be in the public interest to allow energy companies the option of investing in new nuclear power stations; and that the Government should take active steps to open up the way to the construction of new nuclear power stations. It will be for energy companies to fund, develop and build new nuclear power stations in the U.K., including meeting the full costs of decommissioning and their full share of waste management costs.

The cost calculations behind this conclusion showed that nuclear power was not as cheap as gas-fired plants but with a carbon price of €36/ton, it was competitive.[160] The Government's cost-benefit analysis used a central assumption on an overnight construction cost of £1,250/kW (less than $2,000/kW). A lower-cost case of £850/kW (about $1,300/kW) and two higher-cost scenarios of £1,400/kW (about $2,100/kW) and £1,625/kW (about $2,400/kW) were examined. Even then, the highest-cost estimate was grossly out of line with estimates emerging from the U.S. program and from tenders for new nuclear capacity in Canada and South Africa, which were then around $5,000/kW.[161]

Electricity Market Reforms

Until 2010, the government maintained the façade that new nuclear power stations would compete in the wholesale electricity market set up 20 years earlier on equal terms with other forms of generation, with just the Carbon market price derived from the EU ETS as support. In February 2010, the Labour energy minister, Ed Miliband,[162] and the energy economic regulator, Ofgem,[163] both stated that the

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[159] Department for Business, Enterprise & Regulatory Reform (2008), "Meeting the Energy Challenge: A White Paper on Nuclear Power", The Stationery Office, Norwich.
http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file43006.pdf, p.10, accessed 1 May 2013.

[160] Idem, p.59.

[161] Steve Thomas, "The economics of nuclear power: an update", Heinrich Boell Stiftung, 2010, see http://www.boell.de/downloads/ecology/Thomas_economics.pdf, p.48 accessed 1 May 2013

[162] The Times, "Labour prepares to tear up 12 years of energy policy", 1 February 2010.

existing electricity market arrangements had to be reformed if security of supply were to be maintained and the U.K.'s targets on reductions of greenhouse gas emissions were to be met. In May 2010, Gordon Brown's Labour government was replaced by a coalition government comprising the Conservatives and Liberal Democrats (previously opposed to nuclear power) but there was no less governmental enthusiasm for nuclear power, and the process of Electricity Market Reform (EMR) foreshadowed in the February statements, noted above, was instigated in July 2010.[164]

In a statement to Parliament in October 2010[165] by Chris Huhne, the Government maintained the rhetoric of no subsidies for new nuclear: "I should like to take the opportunity to reconfirm the Government's policy that there will be no public subsidy for new nuclear power." However, in the next sentence the government acknowledged that subsidies could be offered: "To be clear, this means that there will be no levy, direct payment or market support for electricity supplied or capacity provided by a private sector new nuclear operator, unless similar support is also made available more widely to other types of generation." The current minister in charge of the Department of Energy and Climate Change (DECC), Ed Davey (also a Liberal Democrat), has affirmed that this statement remains Government policy.[166]

A White Paper on EMR in July 2011 was eventually followed by a draft Energy Bill in November 2012. The two proposals of most relevant to nuclear power were:[167]

1. A Carbon Price Floor to reduce investor uncertainty, putting a fair price on carbon and providing a stronger incentive to invest in low-carbon generation now;
2. The introduction of new long-term contracts (Feed-in Tariff with Contracts for Difference) to provide stable financial incentives to invest in all forms of low-carbon electricity generation.

The Carbon Floor Price (CFP) was introduced in 2013 and will rise to €36/ton (in 2010 prices) by 2020, the level at which the 2008 White Paper claimed it would be competitive with gas-fired generation.

Technologies

Less than a year after GDA was started, the Canadian ACR1000 design was withdrawn from the process.[168] Hitachi-GE's application for the ESBWR was suspended in September 2008.[169] The GDA process was due to be completed in July 2011, but some time before then, the U.K. regulatory body, the Office of Nuclear Regulation (ONR) acknowledged that it would not be able to issue a timely Design Acceptance Certificate (DAC). It proposed that it could issue an Interim DAC (IDAC) with a list of issues to be resolved subsequently. The Fukushima disaster delayed things for six months and in December 2011, the ONR issued IDACs for the two remaining designs, EPR and AP1000.[170] The AP1000 vendor, the Westinghouse division of Toshiba, stated that as they had no prospective customer for the AP1000, they would not be attempting to resolve the remaining issues, and no further work on the AP1000 has been carried out by ONR since then.[171]

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[163] http://www.ofgem.gov.uk/Media/PressRel/Documents1/Ofgem%20-%20Discovery%20phase%20II%20Draft%20v15.pdf, accessed 1 May 2013.

[164] http://www.decc.gov.uk/en/content/cms/consultations/emr/emr.aspx, accessed 1 May 2013.

[165] http://www.decc.gov.uk/en/content/cms/news/en_statement/en_statement.aspx, accessed 1 May 2013.

[166] http://www.libdemvoice.org/there-will-be-no-public-subsidy-for-nuclear-28150.html, accessed 1 May 2013.

[167] http://www.decc.gov.uk/en/content/cms/legislation/white_papers/emr_wp_2011/emr_wp_2011.aspx, accessed 1 May 2013.

[168] Nuclear News, "AECL drops out of new build process", May 2008.

[169] European Daily Electricity Markets "Two designs left in UK's nuke screening process, as GE-Hitachi suspends involvement", September 2008.

[170] http://www.hse.gov.uk/newreactors/regulators-issue-interim-dac-soda-gda-key-milestone.htm, accessed 1 May 2013.

[171] http://www.prnewswire.com/news-releases/westinghouse-welcomes-interim-approval-for-ap1000-reactor-from-uk-regulators-135586383.html, accessed 1 May 2013.

In effect, given that the only remaining developer in the near term is EDF, which is highly unlikely to choose any technology other than one supplied by AREVA—both companies being majority owned by the French state—this means that the objective to have competing technologies has failed and the only option is the EPR (discussed below). ONR claimed the remaining 31 issues could be resolved within a year of issuing the IDAC. In December 2012, ONR issued a DAC for the EPR.[172] It is therefore clear that in the short term there can be no competition between technologies except in the unlikely event that a new developer emerges hoping to build the AP1000.

Developers

NNB GenCo owns the prime sites, having been granted in November 2012 a site license for Hinkley Point.[173] EDF's commitment to nuclear power is strong and it has the full backing of the French Government and NB GenCorp must be seen, for these purposes, as driven by EDF. Centrica withdrew from the joint venture in January 2013 and despite speculation that a Chinese partner would be brought in to replace it, EDF remains the sole owner.

In March 2012, E.ON and RWE announced they were seeking to sell their stakes in Horizon. Several buyers were mooted but in November 2012, Horizon was sold to the reactor vendor Hitachi-GE.[174] The sale figure was reported to be £700m[175] but it is likely this figure is contingent on a number of factors. Hitachi-GE's technology is the Advance Boiling Water Reactor (ABWR). The U.K. safety authorities have little experience of assessing boiling water reactors and so it seems highly unlikely getting a DAC would take less than the 5–6 years it took the EPR, so it seems unlikely that an order for an ABWR could be placed before about 2020.

The Nugen joint venture was always the least committed of the three consortia. S&SE announced its withdrawal from the consortium in September 2011[176], leaving the other two members to increase their stake to 50 percent. In autumn 2012, it was widely rumored that Iberdrola was also considering withdrawal from Nugen.[177] Keith Anderson, the U.K. head of Iberdrola, said that with the possibility of blackouts looming as soon as 2015, there was no point rushing to build nuclear reactors because they take about ten years to go online.[178] The assumption must therefore be that Nugen is not likely to proceed with new-build in the near future.

The Negotiations

With Nugen and Horizon not in a position to proceed, the Government has opened bilateral talks with EDF on the terms of a long-term Contract for Difference (CFD) for the first station, Hinkley Point. The CFD and Feed-in Tariff (FIT) framework to be set up under EMR provided a framework under which negotiations were able to start between the Government and NNB GenCo. The FIT arrangements provided certainty that all the output of any nuclear plant would be sold at a predetermined price, while the CFD provided predictability on the income per unit sold. Under a CFD, the selling price is partly fixed but with "escalators" to cover general inflation and allow price increases outside the control of the plant owner to be passed on to consumers. The "difference" element is simply a device for reimbursing any difference between the market price and the sale price. So if the market price is less than the contract price, the plant owner will receive the market price from the market, and any difference between the contract price and the market price will be paid to or from the plant owner, ultimately by customers.

[172] http://www.hse.gov.uk/newreactors/reports/step-four/close-out/epr70475n.pdf, accessed 1 May 2013.

[173] http://www.hse.gov.uk/nuclear/hinkley-point-c/index.htm, accessed 1 May 2013.

[174] http://www.horizonnuclearpower.com/files/downloads/Horizon%20Completion%20Release%20%28National%29.pdf, accessed 1 May 2013.

[175] Independent, "Hitachi signs '100-year commitment' to boost UK's nuclear expansion plans", 30 October 2012.

[176] http://www.nugeneration.com/download/GDF_SUEZ_IBERDROLA%20release.pdf., accessed 1 May 2013.

[177] Utility Week, "Iberdrola cooling on UK nuclear?", 5 October 2012.

[178] The Times, "The answer to future power supply is blowing in the wind, says Iberdrola" February 15, 2013

Negotiations will focus on two elements. The more obvious one, the "strike price", is the basic price paid per MWh. This has to be high enough to cover the full expected costs of building and operating the nuclear plant and much of the publicity has included speculation on what the price will be with reports in 2013 suggesting a price of £100/MWh.[179] However, of at least as much concern to NNB GenCo and its financiers are the escalators. It might be expected that the strike price would be indexed to general inflation so the real value of the income from the plant was protected, but this does not cover the economic risk. If construction costs escalate, or reliability is poorer than assumed, or operations & maintenance costs are higher than forecast, the costs will be higher than expected and if these costs cannot be recovered from consumers, the viability of NNB GenCo would be in doubt. Note that it is not clear how far EDF would back NNB GenCo if it did get into financial difficulties. If it were allowed to fail as happened when British Energy went bankrupt in 2002, British taxpayers could again be called upon to provide subsidies to allow the plants to continue to operate. Whether the detailed conditions of the CFDs will be made public is doubtful even though it would be a contract signed by a public body underwritten by taxpayers and electricity consumers. It is likely that the Government and NNB GenCo would argue important details were commercially sensitive and should not be made public. There has also been no decision on the duration of the CFD although media reports in late May 2013 suggest 35 years.[180] Reports also suggest that EDF is holding out for terms that will ensure it obtains a 10 percent real rate of return.

Negotiations will hinge on whether a contract can be agreed that passes enough of the economic risk of a nuclear power plant on to consumers to satisfy financiers that their loans were secure enough to issue, but not so much that the Government, especially the Treasury, will be unwilling to agree to the terms because they placed too much risk on taxpayers. In June 2013, the U.K. Government announced it would offer loan guarantees, reported to be worth about £10 billion of the £14 billion that the Hinkley Point reactors are forecast to cost.[181] Despite this, the Secretary of State for Energy acknowledged on 2 July 2013 that agreement was "a few months away".[182]

Further Prospects

At time of writing, it is unclear whether an agreement can be reached. However, as in the U.S., the costs are so high and the problems of obtaining terms that will allow finance to be obtained at affordable interest rates that the prospect of a stream of orders following to fulfill the Government's objective of getting orders for 16 GW of new capacity placed appear to be minimal. Also note that even an agreement on a CFD is no guarantee to secure financing for the actual implementation of a new-build project. And whatever the financing, there is no guarantee that the project can be built to cost, nor that even if it is, customers will want to buy its output, since the prices reportedly being discussed are roughly twice the market price of U.K. electricity and far above those of abundant competitors, such as onshore wind power.

European Union Policy

State Aid

While prospects in the U.K. are limited, even if only one or two reactors are ordered in the U.K., the implications for the rest of the EU would be significant. If an agreement can be struck between the U.K. Government and EDF, it seems inevitable that a major investigation by the EU Competition Commission will have to take place to determine whether the U.K. contracts represent illegal state aid. This is likely to further delay start of construction by two or three more years. Nevertheless, about

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[179] See Independent, 29 October 2012; Financial Times, 24 July 2012 and Daily Telegraph, 13 August 2012.

[180] Wall Street Journal, "EDF, U.K. Near Agreement on Most of Nuclear Reactor Deal", 26 May 2013.

[181] See https://www.gov.uk/government/speeches/speech-by-chief-secretary-to-the-treasury-danny-alexander-investing-in-britains-future and Guardian, "Nuclear power gets £10bn financial guarantee boost", 27 June 2013.

[182] Bloomberg, "EDF Nuclear Deal in U.K. May Take 'A Few Months'', 2 July, 2013

eleven other Member States are reported to be interested in using the U.K. model of CFDs as a basis for ordering in their home markets. This includes Poland, Czech Republic and France.

There would seem to be little doubt the CFD regime for nuclear power does represent state aid – it does clearly benefit nuclear power and it is granted by the State. The crux of the case would be whether it "favors certain undertakings or the production of certain goods (selectivity)"; and "is liable to distort competition and affect trade between Member States". Fouquet & Thomas[183] argue it clearly does violate these conditions and would, or at least should, be judged to be unfair state aid and therefore illegal under EU law.

Changes to State Aid Guidelines

In parallel with this effort, there is also pressure to change the EU guidelines on state aid for nuclear power so that it can be subsidized in the way that renewables and energy efficiency are subsidized in some countries. These efforts are part of a review by the Commission of "block exemption regulation" under which the Commission can exempt certain categories of aid from the notification requirement applicable to all State aid measures of Article 108(3) of the Treaty on the Functioning of the European Union (TFEU). Those categories refer, among others, to environmental protection. Thus the General Block Exemption Regulation does not, for example, provide for a general exemption in the field of energy, or an exemption to ensure security of supply.

State aid can be cleared by the Commission in some specific cases under the guidelines for environmental protection (2008) and under the Internal Electricity Market directive (2009). In the first case energy efficiency and renewables are exempted whereas in the second case, the state can subsidize infant technologies or projects remedying problems of security of supply. It is hard to see how an industry with more than half a century of commercial experience can be categorized as "infant". Equally, given the very long lead-time for nuclear projects of a decade or more if things go to plan and up to two decades or more if they go wrong, as has frequently been the case, it is hard to see how nuclear power could be portrayed as being appropriate to meet shorter-term concerns on security of supply.

Draft revised guidelines for state aid for energy were due to be published for consultation in late July 2013 at time of writing with an expectation that final guidelines would be agreed in early 2014.

Likely Outcomes in the Rest of Europe

It is clear the nuclear industry will lobby hard for favorable treatment under European legislation because without this, its prospects in Europe are minimal. However, the impact of the Fukushima disaster has been to change the political balance in the EU and it looks highly unlikely that a majority of Member States could be engineered for proposals that favored nuclear power. Regardless, as with the U.S. and the U.K., the economic fundamentals of nuclear power seem so poor that even if the "British Model" were cleared for application elsewhere, the resulting number of additional orders would be minimal.

The Chinese Program

Whilst the U.S. and the U.K. were expected to bring credibility to the 'nuclear renaissance' because of their long history and expertise in the sector, China has increasingly been seen as the market with sufficient volume to provide scale economies and learning; to identify and deal with 'teething problems' with the new design; and to provide an efficient, cheap and high-quality supply chain for the major components.

[183] Steve Thomas & Dörte Fouquet, "The new UK nuclear power programme – a FIT for nuclear and a blueprint for illegal state aid?", 2013, Greens/EFA Group – European Parliament, Brussels, Belgium.

Old Designs

China started to order nuclear power plants in large numbers from 2008 onwards, and today 28 of 66 units under construction worldwide are in China. The Chinese program has been based mainly on a 1000 MW design called M310 licensed from AREVA, which in turn had licensed it from Westinghouse based on a design ordered before 1970. The reactors were supplied mainly by Chinese Guangdong Nuclear Power Company (CGNPC) using its CPR1000 design, with a couple of orders going to its competitor Chinese National Nuclear Company (CNNC) based on the same French design as CGNPC, designated CNP1000. Even in 2008, it was clear that the M310 derived designs were too old to be a basis for the future and plans were underway to move to Gen III+ designs. A third Chinese vendor, State Nuclear Power Technology Corp (SNPTC), was also active but did not win any orders in this phase. An additional issue was that the designs were still under license to AREVA who are not willing for China to export such reactors.

Gen III+ Designs

China ordered six Gen III+ reactors in 2007–08, four from Westinghouse using the AP1000 design (in collaboration with SNPTC) and two from AREVA using the EPR design (in collaboration with CGNPC/EDF). This was a major plus for the Western vendors because it was expected to provide a shop-window for the new designs and, because it was China, the reactors would be built to time and apparently to cost. The expectation was that the AP1000 rather than the EPR would take over as the main design for reactors built in China supplied under license by local companies. However, as estimated costs of these designs escalated in China as well as the West, there was an increasing perception that these designs were too expensive for China. There are also reports of construction delays of about a year and cost overruns with the AP1000s. And around the time when Kang Rixin, the head of CNNC, was arrested on corruption charges in 2009 (he was sentenced to life imprisonment a year later), press reports suggested he may have accepted bribes from a foreign reactor vendor.[184]

When the Fukushima disaster occurred, there were already signs that the ordering rate of up to ten reactors per year was putting unsustainable strains on the Chinese nuclear supply chain, and in the three months up to the Fukushima disaster, no reactor construction starts took place. After the Fukushima disaster, a halt to new reactor starts was called and not lifted until November 2012. Then construction started on two more reactors of the old 1000-MW design, and a month later on two demonstration plants using the pebble bed modular reactor design.[185] However, by the end of April 2013, no further construction starts had taken place in China and it seems clear that China has not returned to the days of ten reactor orders per year.

For the future, the prospects for large numbers of orders of AP1000s and EPRs in China appear to be receding, and the three Chinese vendors are all reported to be developing their own Gen III+ designs. CGN is working with AREVA to develop a 1000-MW design, designated ACPR1000; SNPTC is working with Westinghouse to develop a scaled up AP1000, designated CAP1400; and CNNC is developing its own design which would be entirely independent of foreign vendors, ACP1000.

How close these designs are to deployment is difficult to tell, and whether they would satisfy an experienced Western regulator like the U.S. NRC is hard to know. Equally, it is too early to tell whether these designs would prove significantly cheaper to build than AP1000 and EPR.

Development of the ACP1000 appears to be ahead of the other two designs. In April 2013, it was reported that the design had passed an "authoritative industry evaluation" and was on par with Gen III designs elsewhere.[186] This is clearly not equivalent to the generic design assessment process carried

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[184] RFI, "L'ex-patron du nucléaire chinois condamné à la perpetuité", 19 November 2010, see http://www.rfi.fr/asie-pacifique/20101119-ex-patron-nucleaire-chinois-condamne-perpetuite, accessed 8 July 2013.

[185] http://www.worldnuclearreport.org/Reactor-Building-Starts-Again-in.html Accessed May 13, 2013

[186] Xinhua General News Service, "China's self-developed nuclear reactor passes industry evaluation", 19 April 2013.

out by the U.S. and U.K. safety authorities, because the detailed design, which would be needed for a generic review, was only then going to commence. It was also reported that an export sale had been achieved, but the country involved was not named so this report must be treated with skepticism.[187] A vice president of CNNC claimed: "We have submitted an application to the International Atomic Energy Association [Agency] for a review of the ACP1000, which will help us get the permits to export to Europe and North America." This suggests a naivety about the Western regulatory processes, as the IAEA has no jurisdiction over national safety issues and a positive verdict by the IAEA would have little impact on national safety authorities' verdicts.[188]

Nevertheless, reports did suggest the design would be ready for start of construction by the end of 2013, and with 85 percent indigenous content, would be 10 percent cheaper than foreign Gen III+ designs.

Relevance of Chinese Experience

With much of the recent experience of nuclear construction taking place in China particularly with Gen III+ designs, it is important to determine how much can be learnt from this experience. The majority of plants built recently use an old design closely based on the one used for the 34 900-MW reactors completed in France during 1977–1987. Most of these were built largely to time, though the construction period did keep lengthening, and experience in China also appears to be good in that respect. In terms of costs, the picture in France was more complex.[189] However, no useful and reliable cost data from China have been published.

For the Gen III+ designs, there are two EPRs under construction at Taishan and four AP1000s, two at Sanmen and two at Haiyang. The EPRs started construction in October 2009 and April 2010. There is no strong evidence of any delays at Taishan.[190] It is clear that the Instrumentation & Control system installed would not satisfy the U.K. safety regulator, which until November 2012 had not approved the design submitted to it (see below for a discussion of Instrumentation & Control). It is also not clear what would have happened if the quality control issues that have bedeviled the Olkiluoto and Flamanville projects (see below) had first occurred in China.

The Haiyang reactors started construction in September 2009 and June 2010 while the Sanmen reactors were started in April and December 2009. While Westinghouse claimed in early 2012 that the original schedule of completion of the first unit at Sanmen before end 2013 can still be met[191], there are industry reports that all of the Haiyang and Sanmen units are to start up "in 2014 or 2015"[192].

Overall, whilst the apparently smoother progress with these Gen III+ designs in China certainly serves their reputation, until Chinese experience is more clearly and independently documented and the regulatory process is more open, it would be dangerous to read too much into this experience. Basic cost factors also differ markedly: a common remark in the industry is that Chinese reactor-builders employ twice as many people at a tenth the salary of their Western counterparts.[193]

Olkiluoto and Flamanville

These two projects, Olkiluoto-3 in Finland and Flamanville-3 in France, were meant to be the showcase for Gen III+ projects. France generally had a good reputation for completing plants to time, while Finnish reactors were also completed largely to time and have a formidable reputation for reliability. Given the importance of these projects to the credibility of the EPR and the need to show

[187] China Daily European Edition, "Nuke reactor gets foreign contract", 20 April 2013.

[188] China Daily European Edition, "Nuke reactor gets foreign contract", 20 April 2013.

[189] Arnulf Grübler, "The costs of the French nuclear scale-up: A case of negative learning by doing", Energy Policy 38, 2010, 5174–5188.

[190] Nucleonics Week, "Heavy component installation finished at Taishan-1", 24 January 2013.

[191] Nucleonics Week, "AP1000 in China to start up as scheduled: Westinghouse", 2 February 2012.

[192] Nuclear Energy Institute, "Nuclear Energy Overview", 26 April-2 May 2013.

[193] Amory B. Lovins, personal communication, 7 July 2013.

that the problems of cost and time control that earlier generation reactors had suffered, there was a strong expectation that enough resources would be devoted to these projects to ensure their construction went smoothly. In fact, closer examination of the French record would have led to some concerns. Experience with the EPR's predecessor design and the design it was developed from, the N4, was extremely bad. The four reactors of this design built took on average 14 years from construction start to commercial operation and their costs were also very high.[194] The N4 was the first indigenous French design while the previous models were built under Westinghouse license. And equally seriously, the French constructor's latest construction start was in 1991—long enough before to have lost a whole generation of experienced managers for such complex projects. This as much as other factors—such as the dozens of main languages spoken by the highly international workforce, and cultural and procedural mismatches between the French designer/builders and the Finnish safety regulator—proved to be the project's undoing despite Finland's well-earned reputation for engineering prowess and general competence.

Olkiluoto-3

As has been amply documented, these projects have gone wrong on a scale exceptional even for nuclear projects. The latest estimates for Olkiluoto suggest that the reactor, which was expected at construction start to take four years to build and cost €3 billion, will take at least 11 years (completion in 2016) and cost at least €8.5 billion. With three years of construction still left, there can be little confidence that there will not be further cost and time overruns (see Table 2).

A large number of issues, in particular quality-control problems, have contributed to the delays (see previous editions of the World Nuclear Industry Status Report), so there is no simple fix. For future buyers of the EPR, there can be no confidence that relatively simple changes to project management can remove the risk that projects will go badly wrong.

Flamanville-3

By the time construction at Flamanville-3 began, a rationale was emerging that the problems at Olkiluoto were due to Finland's lack of experience with nuclear construction, and to AREVA's lack of project management experience[195] and the shortage of relevant skills. In France, with EDF's vast experience of nuclear construction and its wealth of relevant skills, the problems would not recur. However, as with Olkiluoto, problems emerged immediately with errors in the pouring of the first structural concrete.[196] As with Olkiluoto-3, no single, particular issue was behind the delays and therefore no easy lessons emerge for future customers for the EPR to learn. It seems clear the Flamanville project is going wrong just as badly as the Olkiluoto project and perhaps worse (see Table 2).

[194] Arnulf Grübler, "The costs of the French nuclear scale-up: A case of negative learning by doing " Energy Policy 38, 2010, 5174–5188.
[195] OL3 is actually the first time that AREVA has overall project responsibility. In the case of all previous French nuclear construction projects, inside and outside the country, EDF was the architect.
[196] Nucleonics Week "Concrete pouring at Flamanville-3 stopped after new problems found", May 29, 2008

Table 2: Evolution of EPR Cost Estimates 2003-2012

Origin of Estimate	Construction Costs (€/kW)[197]	Production Costs (€/MWh)
DGEMP 2003[198]	1,043 (1,274 €$_{2012}$)	28.4[199] €uro$_{2001}$
EDF 2005[200]	?	(33-)41[201] €uro$_{2004}$
EDF 2005[202]	?	(35-)43[203] €uro$_{2004}$
EDF 2006[204]	2,063 (2,331 €$_{2012}$)	46 €uro$_{2005}$
AREVA 2007[205]	1,300–1,800 (1,498–2,074 €$_{2012}$)	29.9[206] €uro$_{2004}$
DGEC 2007[207]	?	44.9 €uro$_{2007}$
EDF 2008[208]	2,500 (2,677 €$_{2012}$)	54-60[209] €uro$_{2008}$
Cour des Comptes 2012[210]	3,700 (3,874 €$_{2012}$)	70-90 €uro$_{2010}$
EDF 2012[211] [U.K. EPR]	5,400 €$_{2012}$	110-166[212] €uro$_{2012}$
EDF 2012[213] [Finland EPR]	5,300€$_{2012}$	?
EDF 2012[214] [France EPR]	5,300€$_{2012}$	?

Sources: As indicated, assembled by MSC

Instrumentation & Control

A particular issue that has caused regulatory concern has been the level of redundancy in the Instrumentation & Control (I&C) system. As far back as 2004, there were small delays in AREVA's supplying the Finnish regulator with details of the design of the I&C, which was to be entirely digital.[215] There continued to be apparently small issues arising on the I&C and in 2006, it became

[197] Figures in brackets are adjusted for inflation.
[198] DGEMP, "Coûts de référence de la production d'électricité", Ministère de l'Industrie, 2003.
[199] Equivalent to 29.9€$_{2004}$/MWh, according to EDF.
[200] Serge Massart, Goulven Graillat, "La place d'EPR dans la stratégie d'EDF", EDF, in Revue Contrôle, May 2005.
[201] 41€ pour la tête de série, 33€ pour une série de 10 réacteurs.
[202] EDF, "Projet Flamanville 3 – Construction d'une central électronucléaire 'tête de série EPR' sur le site de Flamanville", Dossier Débat Public, CPDP, July 2005.
[203] 43€ pour la tête de série, 35€ pour une série de 10 réacteurs.
[204] EDF, "Investor Day", London, 4 December 2008.
[205] Anne Lauvergeon, "Le nucléaire, un des atouts maîtres dans la nouvelle donne énergétique mondiale", Réalités Industrielles, February 2007.
[206] Equivalent to 28.4€$_{2001}$/MWh.
[207] According to Cour des Comptes, "Les coûts de la filière électronucléaire", January 2012.
[208] EDF, "Investor Day", London, 4 December 2008.
[209] Low estimate Flamanville-3 case; high estimate potential additional costs inherent to the site.
[210] Cour des Comptes, "Les coûts de la filière électronucléaire", January 2012.
[211] The Times, "Soaring costs threaten to blow nuclear plans apart", 7 May 2012.
[212] Citigroup; "New Nuclear in the UK – It isn't getting any easier", 8 May 2012.
[213] Kauppalehti.fi, "Olkiluoto kolmonen maksaa 8,5 miljardia", 13 December 2012, see http://www.kauppalehti.fi/etusivu/olkiluoto+kolmonen+maksaa+8,5+miljardia/201212321921, accessed 8 July 2013.
[214] Le Figaro, "EDF: la facture de l'EPR s'envole de 2 milliards", 4 December 2012, see http://www.lefigaro.fr/societes/2012/12/03/20005-20121203ARTFIG00635-la-facture-de-l-epr-s-envole.php, accessed 8 July 2013.
[215] Nucleonics Week, "I&C data lagging slightly for STUK safety analysis of new EPR", January 29, 2004

clear the Finnish and French regulators were imposing different requirements with the Finnish regulator requiring a hard-wired back-up to the digital system.[216]

Concerns continued and culminated in a letter in April 2009 from the U.K. regulatory authority to EDF and AREVA expressing its concern about the adequacy of the redundancy in the I&C system.[217] The Finnish regulator voiced similar concerns in July and in November 2009, the French, Finnish and U.K. regulators wrote jointly to AREVA expressing their worries.[218] The French authorities were still not expecting to require a hard-wired back-up but the U.S. authorities, who had launched their generic review a couple of years before, were also asking questions. In 2010, AREVA modified its U.S. EPR design to include a hard-wired back-up in response to issues raised by the U.S. NRC.[219]

In December 2011, when the U.K. safety regulator, Office of Nuclear Regulation (ONR) issued an "Interim Design Acceptance Certificate" (IDAC) for the EPR, six of the 31 issues still to be resolved concerned the I&C system. The ONR forecast that these issues could be resolved in a year. However, progress with I&C seemed slow. The ONR introduced a "traffic light" system to indicate the status of these issues in their quarterly progress reports. In the report for the period to end June 2012, four out of six of the issues were given a "red light" signifying that "closure of the GDA Issue is in serious doubt with major risks apparent", while the other two were given an amber light—"closure of the GDA Issue appears feasible but significant risks exist requiring prompt attention."[220] By the end of the next quarter, one of the issues had been completely resolved, three were given green lights—"Closure of the GDA Issue appears highly likely", one was given an amber light, and one still had a red light.[221] However, in December 2012, the ONR announced all issues had been resolved.[222] It is not clear how an issue that had been causing serious concern for more than three years and which in June 2012 appeared nowhere near resolution could be resolved so quickly. This is especially puzzling given that there appears no agreement in sight on how the Finnish regulators can be satisfied.[223]

In April 2012, the French regulator announced that it was satisfied with the solution offered by AREVA and lifted the hold it had placed on the design of the system placed in October 2009.[224] While the French solution was reported to require an element of hard-wired back-up, it was not as extensive as the U.K. and Finnish regulators are requiring. China is reported to be adopting whatever system is approved for Flamanville, although it is not clear whether this was finalized in time for installation at Taishan.[225]

Conclusions on Nuclear Economics

Making significant improvements to the economics of nuclear power plants was central to the promises of the 'Nuclear Renaissance'. Simplification of the designs was meant to reduce both the cost and the risk of problems in the construction phase. By making construction more predictable, this was expected to make nuclear projects less economically risky and therefore easier and cheaper to finance. These promises are in tatters with cost estimates now roughly seven times the level predicted a decade ago and the two projects underway in the West using Franco-German EPR technology massively over budget and time. Early experience with the two projects recently stated in the U.S. using AP1000 technology gives little confidence that these problems are restricted to the EPR.

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216 Inside NRC, "DGSNR says license for EPR at Flamanville-3 'months' away", May 15, 2006

217 http://www.hse.gov.uk/newreactors/ri-ukepr-0002.pdf, accessed April 30, 2013

218 Nucleonics Week, "Regulators from France, UK, Finland share concerns about EPR's I&C", November 5, 2009

219 Nucleonics Week, "AREVA agrees to modify US-EPR after NRC raises I&C concerns", July 1, 2010

220 http://www.hse.gov.uk/newreactors/reports/gda-q2-12.pdf accessed April 30, 2013

221 http://www.hse.gov.uk/newreactors/reports/gda-q3-12.pdf accessed April 30, 2013

222 http://news.hse.gov.uk/onr/2012/12/uk-regulators-confirm-acceptance-of-new-nuclear-reactor-design/ accessed April 30, 2013

223 Nucleonics Week, "Olkiluoto-3 EPR likely not to operate before 2016: TVO", 14 February 2013.

224 Nucleonics Week, "ASN lifts hold on Flamanville-3 I&C architecture", 19 April 2012

225 Nucleonics Week, "Olkiluoto-3 EPR likely not to operate before 2016: TVO", 14 February 2013.

Largely as a result, what were probably the three key markets to crack—the U.S., the U.K. and China—now look very restricted whilst other major and previously influential potential markets like Germany and Italy are closed to nuclear or, like India, remain—perhaps—a potential market for tomorrow. Both the U.S. and the U.K. now appear likely to build fewer than a handful of new reactors, while China has slowed down the pace and appears likely to opt for its own rather than Western designs.

With the credibility of Gen III+ designs in serious doubt and little significant progress made on their expected successor designs, so-called Generation IV, the nuclear industry is seeking funding for new design concepts, such as Small Modular Reactors (SMRs). Experience suggests that after significant amounts of public money have been spent on these, they will probably turn out to have no significant advantages over existing designs. One analyst, having long asked in vain for SMR advocates to provide a production-cost and economic analysis demonstrating their claimed advantages, summarizes their key issue thus: "As a matter of physics, reactors don't scale down well; that's why they're big. If you try to overcome this handicap by capturing economies of mass production, you quickly run up against a fatal competitor called Small Modular Renewables (and efficiency techniques). Those do scale down very well; they currently outcompete new reactors by severalfold; and they're already decades ahead of SMRs in exploiting their mass-production economies (they're attracting a quarter-trillion dollars of private investment per year), and will be another decade ahead by the time an SMR could be demonstrated. So SMRs might have been worth considering a half-century ago, but today they're far too late. End of story."[226]

The U.K. Government is considering guaranteeing a profit range for nuclear investors in the form of a "Contract for Difference" (CFD). However, making up for the difference between the current baseload power on the market and the estimated cost range of 110–166 €uro per MWh (the "strike price") would be difficult to sell for the Government. A Citigroup analysis[227] wonders:

> Transfer Construction Risk?: if construction costs are rising, then the only way to contain the rise in the strike price is to reduce the risk faced by the developer and thereby lower their cost of capital. In practice this means transferring the construction risk to the taxpayer / consumer. On the face of it the CFD arrangement is not designed to tackle construction risk allocation so some other mechanism will be needed alongside the CFD. If the government shoulders all of the construction risk then a cost of capital below 10 percent is feasible; but the government would be taking on a huge risk over which it has little control.
>
> Conclusion: if construction costs are indeed anything like £7 billion per reactor, then an already very challenging programme may be reaching the point of impossibility in our view.

Citigroup's analysis resonates interestingly with the May 2012 statement by Energy Secretary Ed Davey when introducing the draft energy bill that would pave the way for a CfD scheme:

> Unless nuclear can be price competitive, as the industry says it can be, unless it can be price competitive, these nuclear projects won't proceed.[228]

The bill, in contrast, apparently seeks to ensure nuclear new-build regardless of its economic merit.

Financial Markets and Nuclear Power

Electricity utilities in many parts of the world are facing significant economic and financial problems. These problems are, in most OECD countries, as a result of low demand increases, often with accompanying lower market prices, uncertainties over carbon markets and pricing, greater demand and supply interventions from government to address concerns over climate change and energy security,

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[226] Amory B. Lovins, personal communication, 6 July 2013; see also "'New' nuclear reactors, same old story," 2009, www.rmi.org/Knowledge-Center/Library/2009-07_NuclearSameOldStory

[227] Citigroup; "New Nuclear in the UK – It isn't getting any easier", 8 May 2012.

[228] BBC, "Energy bill avoids carbon pledge", 22 May 2012, see http://www.bbc.co.uk/news/science-environment-18146940, accessed 22 May 2012.

volatile global energy prices and higher costs of capital. These conditions have led many analysts to predict a gloomy future for utilities.

Nomura says of the current situation in Europe that "there is no let-up in the dire outlook for utilities"[229]. The situation in Europe is particular acute for utilities in Europe, due to the significant increase in the use of renewable energy, at a time of flat demand, which is squeezing out the traditional utilities and investors. Worse, having almost no running cost, renewables in competitive power markets drive down the market-clearing wholesale price—which just hit new lows in Germany—and thus force fossil-fueled and even some nuclear plants to operate fewer hours, sell their output for a lower price, and thus earn lower, zero, or negative profits. According to Moody's:

> Large increases in renewable energy have had a profound negative impact on power prices and the competitiveness of thermal generation in Europe. What were once considered stable companies have seen their business models severely disrupted. Given that further increases in renewables are expected, these negative pressures will continue to erode the credit quality of thermal based utilities in the near to medium term.[230]

While in North America it is primarily the rise in production from shale gas in the last few years that has had a significant impact on the U.S. utility sector and in particular on the traditional central thermal power plants, primarily coal and nuclear. Moody's stated in February 2013 that there was still no sign of recovery for the unregulated utilities due to low gas prices' depressing electricity prices. Furthermore, they state "the low natural gas prices make operating coal and nuclear power less competitive because their fixed costs are relatively high".[231] However, gas is not the only formidable competitor: wind power, recently selling 25-year fixed-price power for around $22/MWh in the U.S. Midwestern 'Windbelt' net of its $18–28/MWh Production Tax Credit, combined-heat-and-power, and efficient use of electricity are all helping to drop power prices.

The impact of these conditions was seen in early 2013 with the retirement of the Kewaunee nuclear power plant, which was described by UBS as potentially "the figurative canary in the coal mine". UBS further stated that[232]:

> We believe what started as a focus on coal plant retirements has been expanding into growing risk of retirement of all fuel types, particularly nuclear and oil-fired units.

However, in North America it is not just the rise in shale gas and wind power that is making current capacity less profitable or unprofitable to operate; renewables are fundamentally threatening utilities' business model with 'radical bypass', much as mobile telephones bypassed wire-line telephone companies and stranded their assets.[233] For example, in more than 20 of the United States, entrepreneurs offer to install solar power on your roof with no down payment and beat your utility bill; this is expected to spread to most other states within the next few years. The Edison Electric Institute published a report on the disruptive challenge of new technologies, particularly small scale renewables and storage, on the electricity utility sector and concluded that "recent technological and economic changes are expected to challenge and transform the electric utility industry" and that "while the various disruptive challenges facing the electric utility industry may have different implications, they all create adverse impacts on revenues, as well as on investor returns[234]". In the United States revenues from retail sales in 2012 were at the same level as in 2007.

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229 Nomura, "Utilities sector Outlook – 2013", December 2012

230 Moody's, "European Utilities: Wind and Solar Power Will Continue to Erode Thermal Generators' Credit Quality", 5 November 2012

231 Moody's, "Moody's: Still no sign of recovery for unregulated utilities; regulated remain stable", 6 February 2013.

232 UBS, " Re-evaluating Merchant Nuclear", UBS 2nd January 2013.

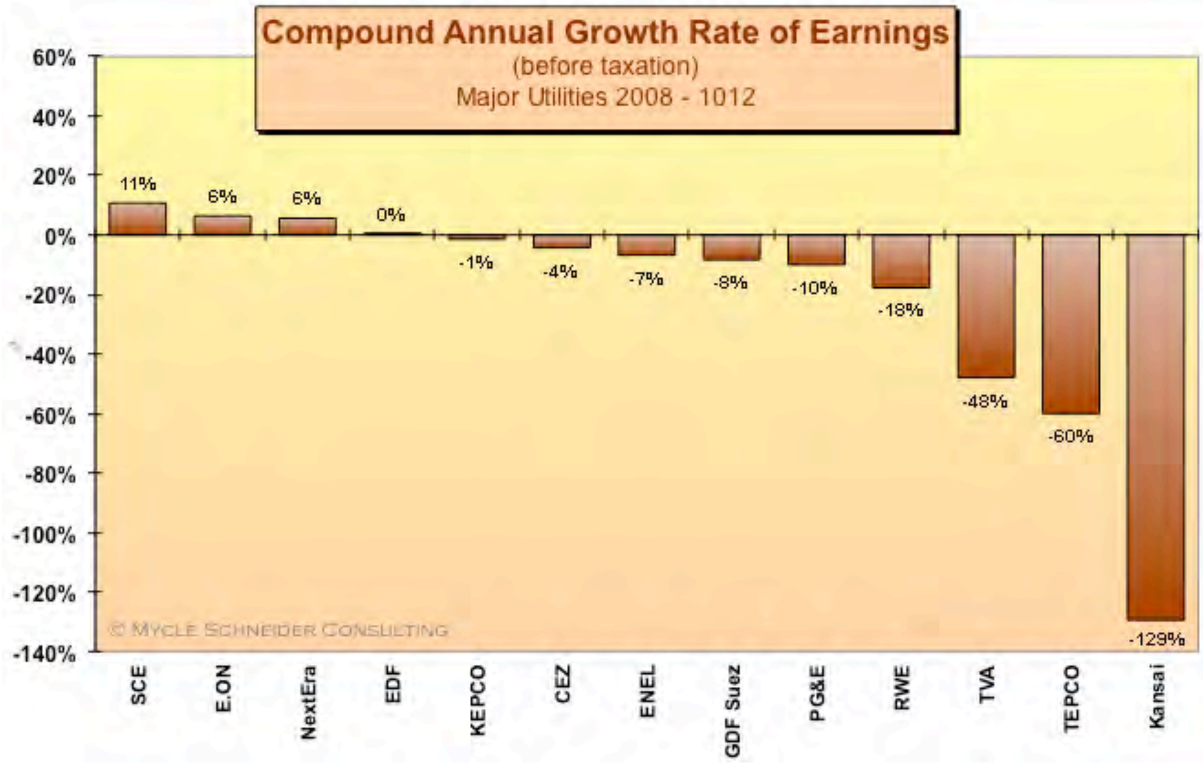
233 Amory B. Lovins, 9-page feature (article, interview, and retrospective), Public Utilities Fortnightly, March 2013.

234 EEI, "Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business", Edison Electric Institute, January 2013.

As can be seen in Figure 14, the majority of the major utilities across the various continents have suffered loss of income in the past few years. Of the 13 companies measured, only four have shown a growth in earnings, two of them in the U.S., SCE (Southern California Electric) and NextrEra (formerly Florida Power and Light Company), while there have been slight increases or stagnation in Europe from Germany's E.ON and France's EDF. The earnings of the U.S. utilities have benefited from relatively low fossil fuel prices. In 2012 coal prices for the power sector fell by 2.1 percent, while the price of gas did increase, they are still significantly lower than a decade ago. While the retail price for electricity across all types of consumers (residential, commercial, industrial and transport) increased on average, between 2012 and 2013, by 12 percent.[235]

Not surprisingly there have been major falls in income in Japan, in this case Kansai Electric Power Company and TEPCO, the owner of the Fukushima nuclear power plant, which along with all but two Kansai reactors has been closed for nearly a year. KEPCO, of South Korea, while showing positive earnings in 2009 and 2010, has seen losses since 2011.

Figure 14: Annual Growth Rates of Earnings of Major Nuclear Companies 2008-2012



Source: Financial Times 2013

The utility sector is finding it increasingly difficult to attract investment. A global survey by PWC found that many utilities are facing a reduction in capital raising options, with 78 percent of those surveyed reporting that the financial crisis and economic downturn have had a medium to very high impact on shortage of capital for infrastructure projects, and 63 percent saying it has had a high or very high impact. Somewhat surprisingly, PWC found that shortage of capital for infrastructure projects is felt even more acutely among companies in Asia, the Middle East and Africa than in North America and Europe[236].

The perception of a higher financial risk associated with nuclear power is important as it can lead to a higher interest rate at which utilities can borrow, and therefore significantly raises the final cost of

[235] US EIA, "Electricity Data", US Energy Information Administration, accessed June 2013, http://www.eia.gov/electricity/data.cfm#avgcost, accessed 11 June 2013.

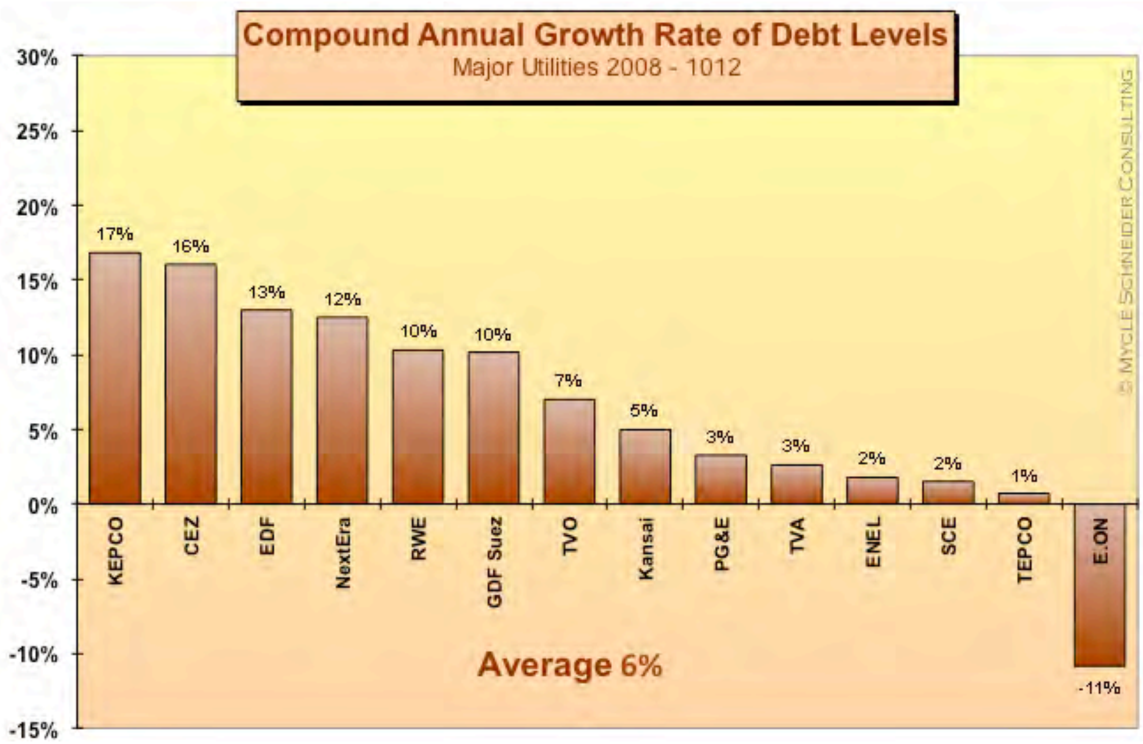
[236] PWC, "The shape of power to come, investment, affordability and security in an energy-hungry world", the 12th Pricewaterhouse Coopers Annual Global Power and Utilities Survey, 2012

construction. This is why investment institutions, such as Citibank, have stated: "Due to the uncertainties on timing and cost, we believe nuclear projects should have a higher ERP [Equity risk premium] than the overall market"[237] and more recently have stated on the situation in the U.K. that "if the latest cost figures are true, new nuclear power plants in the U.K. are not commercially viable… the only way they could be built is if the construction risk was transferred to the taxpayer".[238]

As a result nuclear power is perceived as a higher risk investment than other conventional electricity-generating sources, particularly gas. Even amongst the major utilities, gas ranks the most likely new projects, with 55 percent making major or very major investments versus 37 percent onshore wind, 24 percent offshore wind, and only 21 percent for new coal and nuclear generation.[239]

Most utilities do not have the financial capabilities to finance new nuclear build solely with their own balance sheets: to do so could place the entire company at risk. Therefore the companies need to borrow. However, with nuclear projects having high capital costs, long construction times and a bad construction track record, the financial risks and therefore the borrowing costs are high. This is one reason why nuclear projects often involve financing through export credit agencies and why some governments, such as the U.S., make available loan guarantees to lower the cost of borrowing.[240]

Figure 15: Compound Annual Growth Rate of Debt levels of Major Utilities 2008–2012



Source: Financial Times 2013

Since 2008, only one of the companies analyzed in Figure 15, E.ON, has decreased its debt levels, while all 11 other companies have seen an increase in debt. Over the past year E.ON has made a concerted effort to reduce its engagement in new investment across Europe. This has included the sales of its share of Horizon, a company established with RWE to build a nuclear power station in the U.K., and in October 2012 the announcement it was selling its 34 percent stake in the Fennovoimma

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[237] CitiBank, "New Nuclear – The Economics Say No", November 2009

[238] Reuters, "UK nuclear build requires taxpayer rescue –Citi", 8 May 2012

[239] PWC, "The shape of power to come - Investment, affordability and security in an energy-hungry world", the 12th Pricewaterhouse Coopers Annual Global Power and Utilities Survey, 2012

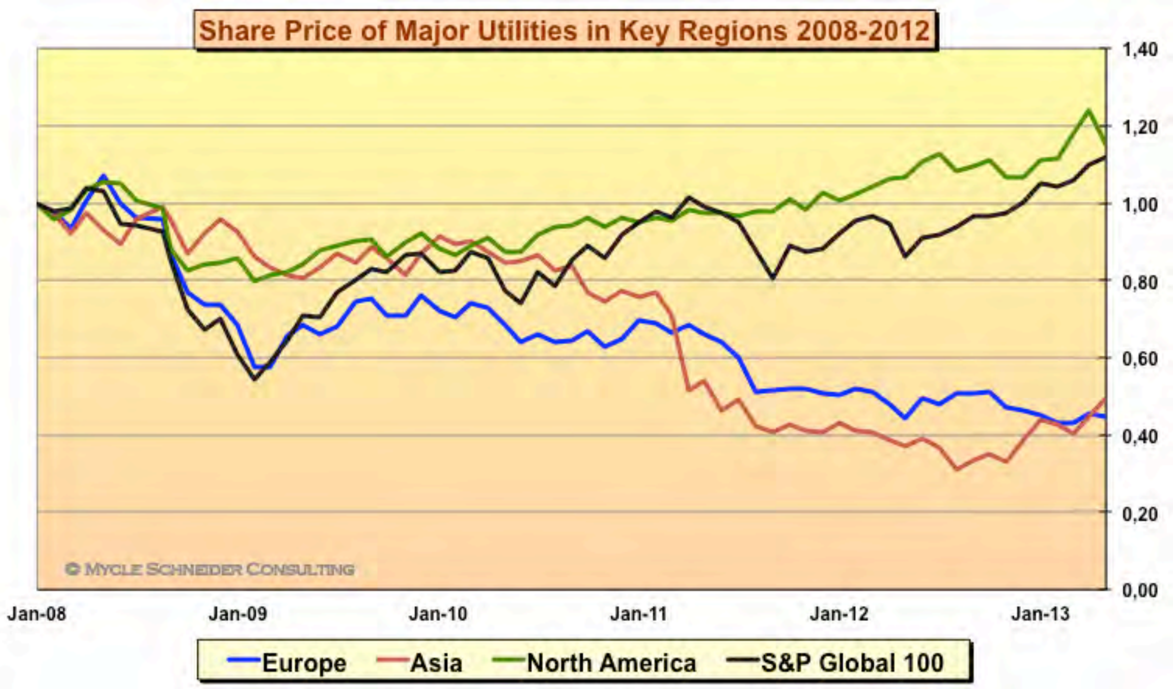
[240] UCS, "Nuclear Loan Guarantees – Another Taxpayer Bailout Ahead?" Union of Concerned Scientists, March 2009

nuclear projects where the plans were to begin construction of a 1,600 to 1,800 MW reactor at Pyhaejoki in northern Finland in late 2016[241].

The higher debt level of the utilities will make it particular difficult for these important firms to invest in large, risky and long-term projects, which will affect investment in nuclear power.

Figure 16 shows the relative share price performance of twelve utilities across Europe, Asia and North America, and compares them to the S&P Global 100 index, which measures the performance of 100 global companies that derive a substantial portion of their operating income from multiple countries.

Figure 16: Share or Bond Prices of Major Utilities in Key Regions 2008–June 2013 compared to S&P Global 100



Source: Yahoo Finance, Accessed June 2013

Nuclear companies are not the only energy sector whose share prices have fallen. Changes in government policies have also had a significant impact on the prices of renewable energy companies. Uncertainties over the relative prices of fossil fuels, particularly relating to reductions in demand resulting from the economic downturn, have led to reductions in the values of many other major energy companies. However, as the next chapter illustrates, the renewable energy sector is rather subject to a shift between companies, and continues overall to retain very substantial growth figures.

Since 2011, the share or bond prices of North American companies have diverged from those in Europe and Asia despite increasing indebtedness amongst all four companies shown, and a decline in revenues from both PG&E and TVA[242]. The share prices of North American companies, Southern California Edison, NextEra Energy, TVA and PG&E have either tracked or outperformed the S&P Global 100 Index. However, Exelon, operating 20 per cent of the U.S. nuclear fleet, has seen the performance of its stock prices track more closely to the European and Asian utilities.

AREVA, Hitachi-GE, Toshiba Power Systems, and Mitsubishi Heavy Industry are the major nuclear vendors; of these only AREVA is an almost purely nuclear stand-alone nuclear constructor. Hitachi-GE is a joint venture between the two firms, while Toshiba Power Systems is a subsidiary of Toshiba,

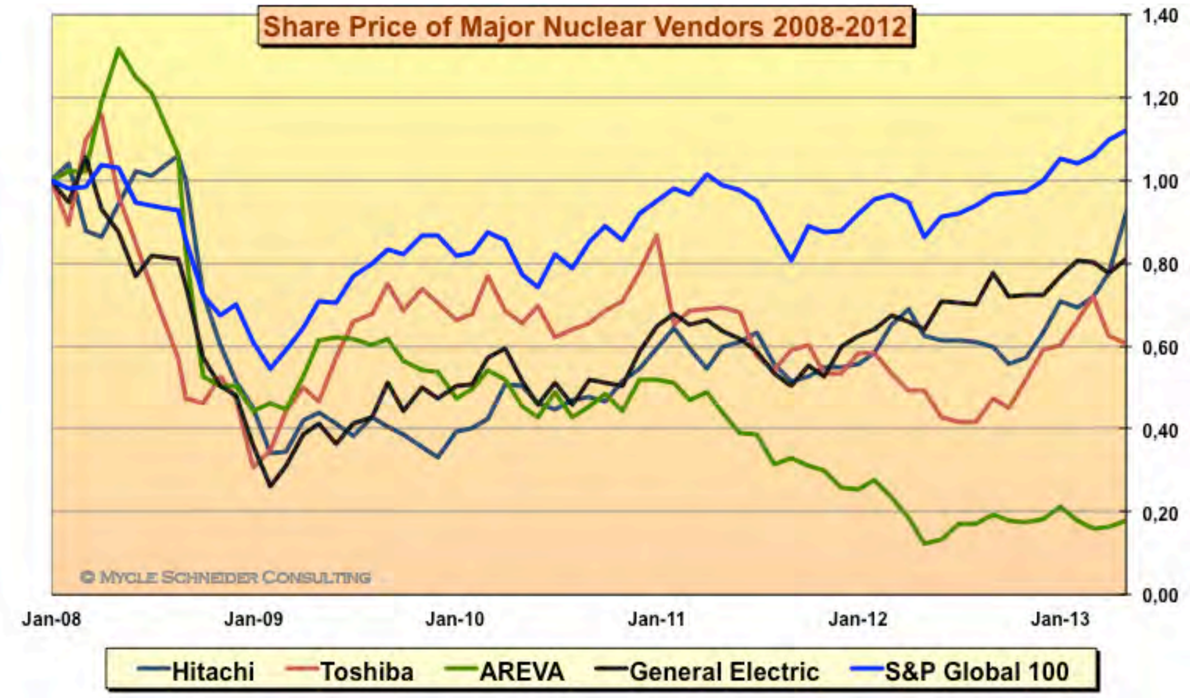
[241] Bloomberg, "EON Withdraws From Finnish Nuclear Project on Price Slide", 24 October 2012

[242] Although TVA isn't a public traded company, its bonds are traded on the New York stock exchange, see http://www.snl.com/IRWebLinkX/GenPage.aspx?IID=4063363&GKP=205782

and Mitsubishi Heavy Industries is a subsidiary of Mitsubishi, a group of autonomous companies. Figure 17 shows the share price of these highly diversified companies or their parent companies and compares them to the global average. What is important to note is the extent to which all of these electrical and heavy electrical firms have performed below the global average. However, AREVA, a purely nuclear company, has had a significantly worse performance over the past five years, with its share price just 20 percent of that of 2008.

The fall in share value for AREVA is reflected in the company's credit rating (defined in Annex 3), which, according to S&P, was cut in December 2011 to BBB-, as they believed that "credit metrics and free cash flow to remain very weak in 2012, with a substantial recovery only in 2014, two years later than we previously assumed".[243] With net losses in the second half of 2012, at €179 million[244], the group will have to see a significant upturn in its fortunes to see a upgrading of its credit rating.

Figure 17: Share Price of major nuclear vendors, 2008-13, Compared to the S&P Global 100



Source: Yahoo Finance, Accessed June 2013

Rating agencies, of which there are three major institutions, Moody's, Standard and Poor's (S&P) and Fitch, assess the financial strength of companies and governmental entities and their ability to meet the interest and principal payments on their bonds and other debts. (See Annex 3 for rating definitions). The ratings given can affect the interest rates at which a company is able to borrow and therefore is an important factor for utilities' ability to fund nuclear and other projects through external investment. A Moody's analyst was quoted in the energy trade press in March 2012 as stating:

> The risks are writ larger when you think of a nuclear project [than for other forms of generation], because construction and planning is that much more tortuous, construction risk is higher and from an operational point of they have a high fixed cost base.[245]

Another utility analyst stated:

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[243] Bloomberg, "AREVA Credit Rating Cut to BBB- by S&P on Weak Cash Flow", 20 December 2011

[244] Bloomberg, "AREVA – information page", http://www.bloomberg.com/quote/AREVA:FP, accessed June 2013.

[245] ICIS Heren, "New nuclear electricity costs hit utility ratings - Moody's", 27 March 2012, http://www.icis.com/heren/articles/2012/03/27/9545356/power/edem/new-nuclear-electricity-costs-hit-utility-ratings---moodys.html, accessed 11 June 2013.

> If [a utility] is already on the edge of a ratings band, a nuclear project could be the thing that pushes them over the edge—it's just another negative factor.[246]

Of the utilities surveyed, only one, Korea Electric Power Co. (KEPCO), has received a ratings upgrade from S&P.[247] In the rational for this upgrade, S&P state that the "potential extraordinary support" from the Government of the Republic of Korea in the event of financial stress would be "extremely high". This upgrade the highlights the important role that Government support plays in many nuclear operators ability to secure finance. In essence, KEPCO, like EDF and TVA, is being rated more on its government's than on its own stand-along creditworthiness.

As can be seen in Table 3, other than KEPCO, all utilities examined that have nuclear interests across the world continue to be static or downgraded by S&P. In some cases this relates to specific events, such as Fukushima or it may be a reflection of the general problems facing the electricity sector. July 2012 saw the downgrading of Germany's two largest utilities, RWE and E.ON, driven by declines in wholesale power markets, and the divestment from nuclear energy following the acceleration of the nuclear phase out in Germany. S&P also note that the increasing share of renewable energy has pushed many of the company's traditional thermal plants down the merit order: : they run fewer hours and take lower prices in Europe's competitive power markets.[248]

Table 3: Long Term Credit Ratings of Utilities with Nuclear Investments

Company	**Date of last action**	**2013** June	**2012** June	**2011** June	**2011** April	**2010**	**2009**	**2008**
European Union								
CEZ	Oct 2006	A-	A-	A-	A-	A-	A-	A-
EDF	Jan 2012	A+	A+	AA-	AA-	A+	A+	AA-
E.ON	July 2012	A-	A	A	A	A	A	A
ENEL	Mar 2012	BBB+	BBB+	A-	A-	A-	A-	A-
GDF-Suez	July 2008	A	A	A	A	A	A	A
RWE	July 2012	BBB+	A-	A-	A-	A	A	A
TVO	June 2012	BBB	BBB					
Asia, South Africa, USA								
Kansai[249]	May 2012	AA-	AA-	AA-	AA	AA	AA	AA
KEPCO	Sept 2012	A+	A	A	A	A	A	A
TEPCO	May 2012	B+	B+	B+	BBB+	AA	AA	AA
ESKOM	Sept 2012	BBB	BBB+	BBB+	BBB+	A-	A-	A-
SCE	Feb 2005	BBB+	BBB+	BBB+	BBB+	BBB+	BBB+	BBB+
PG&E	Dec 2011	BBB	BBB	BBB	BBB+	BBB+	BBB+	BBB+
FLP	Mar 2010	A-	A-	A-	A-	A	A	A
TVA	Aug 2011	AA+	AA+	AA+	AAA	AAA	AAA	AAA

Sources: S&P, Financial Times, Reuters, Company websites and Annual Reports 2013[250]

In addition to the general trends, there have been a number of notable recent judgments by the rating agencies on nuclear power. For example, in the U.K., the announcement that Centrica would not

[246] ICIS Heren, "Nuclear electricity investment could risk utility credit ratings – analysts", 20 March 2012, http://www.icis.com/heren/articles/2012/03/20/9543406/power/edem/nuclear-electricity-investment-could-risk-utility-credit-ratings--analysts.html, accessed 11 June 2013.

0[247] Standard and Poor's, "Korea Electric Power Corp", http://www.standardandpoors.com/prot/ratings/entity-ratings/en/eu/?entityID=269949&sectorCode=UTIL, accessed 3 July 2013.

[248] Reuters, "S&P cuts German Utility E.ON to 'A-/A-2';outlook stable", 27 July 2012.

[249] Moody's rating cited because Kansai is not rated by S&P.

[250] Based on research by John Corbett, London, commissioned by MSC.

exercise its option to take a 20 percent interest in the construction of new nuclear plants in conjunction with its partner EDF Energy, led Moody's to state:

> This decision is credit positive because it removes the high investment and construction risks that would have resulted from the project. The costs, according to the company, were uncertain and the construction timetable had lengthened by a number of years since Centrica's original investment in 2009.[251]

Likewise in April 2012, RWE and E.ON announced that they would no longer proceed with their plans to build nuclear power in the U.K.. The reaction of Moody's investor service was again credit positive:

> The companies' decision to pull out of their U.K. nuclear joint venture, known as Horizon Nuclear Power, is credit positive for both German utilities, which can instead focus on investment in less risky projects[252].

In its rating rationale for the **Czech utility** CEZ in May 2013, Moody's stated that important factors in its credit downgrade is the fall in electricity prices and the decline of nuclear energy as the marginal producer. Moody's noted that electricity prices have fallen in Central and Eastern Europe due to low-cost renewables and weak demand for electricity in the region, which has pushed higher-cost plants down the merit order, including "fixed cost" lignite, nuclear and hydro power plants. As a result, many nuclear power plants are not price-competitive with renewables, placing considerable financial pressure on their operators. Further, Moody's comments that the strategy to develop new nuclear units could put further downward pressure on the group's credit rating, due to the financial burden of the Capex requirements.[253] In relation to CEZ's credit profile, S&P notes that "...although nuclear electricity generation is favorable as a low carbon-emission generation source, we believe that it introduces significant construction, operating, and market-exposure risks, especially in volatile liberalized energy markets."

The ongoing construction problems at the **Finnish** Olkiluoto-3 reactor have significantly affected the views of the rating agencies on the utility Teollisuuden Voima Oyj (TVO).

Table 4 shows the extent to which in the past few years the cost over-runs have harmed the rating of the utility, taking its Fitch rating from A- to BBB.

Standard & Poor's rated TVO BBB in 2012 and argued that risk was linked to operating as well as to new-build reactors: "TVO's dependence on its current two nuclear plants in Finland exposes the company to asset concentration risk, primarily disruption of operations" and "we expect that TVO's financial risk profile will continue to be negatively affected in the near to medium term by the large investment in the new nuclear plant" (Olkiluoto-3). Standard & Poor's does not exclude further down-rating, arguing that ratings could be negatively affected if TVO's liquidity position weakened, for example if the company's net cash outflows were higher than expected primarily related to the construction of Olkiluoto-3. [254]

Construction delays and cost over-runs have also affected the credit rating of EdF in **France**. In December 2012, following further announcements of the cost increases for the Flamanville-3 project (to €8.5 billion) and a ruling by the Conseil d'Etat on the tariff for distribution of electricity, Moody's investment services changed from stable to negative the outlook on the Aa3 senior unsecured ratings of EdF[255].

[251] Moody's, "Centrica's Withdrawal from New Nuclear Plants Is Credit Positive" 7 February 2013.

[252] I-nuclear, "Moody's says German withdrawal 'credit positive'; decision gives EDF bargaining power", 2 April 2012, http://www.i-nuclear.com/2012/04/02/moodys-says-german-withdrawal-credit-positive-decision-gives-edf-bargaining-power/, accessed 11 June 2013.

[253] Moody's, "Credit Opinion: CEZ", 14 May 2013.

[254] Standard & Poor's, "Ratings Direct, Teollisuuden Voima Oyj", 28 June 2012

[255] Moody's, "Moody's changes outlook on EDF's Aa3 rating to negative from stable", 5 December 2012

Table 4: Fitch Rating for Teollisuuden Voima Oyj (TVO) during 2009–2013

Date	Rating	Fitch Comments
June 2009	A-	As at May 2009, the new Olkiluoto-3 (OL3) plant is likely to be commissioned by 2012, a delay of 38 months. However, given the fixed-price, turn-key nature of the contract with the AREVA-Siemens Consortium, Fitch Ratings expects TVO's exposure to the delay to be relatively modest, with only a small impact on annualized production costs.
June 2010	A-	(OL3) to 2013 (from June 2012) to have a limited effect on TVO's costs—with only a small impact on annualized production costs. Fitch anticipates production costs to remain competitive after the commissioning of OL3 and subsequently to fall as capital costs decrease. Fitch notes that while the OL3 project carries construction and project risks, these are largely mitigated by the fixed-price, turn-key nature of the contract.
June 2011	A-	The new Olkiluoto 3 (OL3) plant will be commissioned by end-2012, a 52-month delay. TVO's exposure to the delay is likely to be modest, with only a small impact on annualized production costs, as the contract with the AREVA-Siemens consortium is a fixed-price, turn-key contract.
June 2012	BBB+	The Long-Term IDR and senior unsecured ratings were downgraded in June 2012 due to the impact on Teollisuuden Voima Oyj (TVO)'s credit profile of the continued delay in commissioning the third 1,600 megawatt (MW) nuclear plant Olkiluoto 3 (OL3). The delay to August 2014 is of 64 months. Annual production costs will increase as a result, and while still competitive against forward Nord Pool prices, the gap between the two has narrowed and indicates some erosion of cost advantage.
May 2013	BBB	The downgrade reflects the continued delay in expected commissioning of the third 1,600 MW nuclear plant Olkiluoto 3 (OL3) and our weakened mid-term outlook for the forward Nord pool wholesale electricity prices. This will erode the value creation for TVO's shareholders, a key consideration for our assessment of TVO's credit profile. The delay of OL3 to 2016 is about seven years against the original schedule. The substantially longer than planned construction phase of OL3 is negative for TVO's cash flows as the company continues to service debt related to OL3, while OL3's full cost coverage by TVO's shareholders may be initiated only when the new plant is commissioned.

Source: Fitchrating[256]

In **Korea**, Moody's announced in May 2013 that the scandal relating to the stoppage of operation at four reactors as a result of the revelation that substandard parts had been used with forged test results was credit negative for KEPCO. The reactors are not expected to restart for another 4–6 months, until the parts had been replaced, increasing costly natural-gas imports. This is the latest announcement of inadequate parts' being used in the reactor fleet.[257]

In most regions of the world the financial situation of utilities is precarious due to changing supply technologies, increasing policy interventions, and new consumption patterns. This is reflected in the generally lower ratings of major utilities, the rising debt levels, falling income, and in most regions—although currently not North America—falling stock prices. In this uncertain environment, significant new investment in the power sector is needed, $16.8 trillion according to the IEA[258], in order to replace retiring capacity or meet future predicted increases in demand.

At one time nuclear would have been seen as an important part of this mix, but increasingly it is being rejected by the financial community as it is by its very nature an expensive investment, due to high construction costs and long lead times. Its history of cost over-runs and delays has also given it a reputation as a highly risky investment. As a result, in the majority of countries, nuclear power can proceed only if many of these risks are taken away from the utilities and its financial backers and put onto customers or taxpayers—see U.K. or U.S. sections for more details.

[256] TVO Credit Ratings http://www.tvo.fi/Credit percent20ratings, accessed 11 June 2013.

[257] Moody's, "Moody's: Stoppages at nuclear plants; credit negative for KEPCO", 29 May 2013

[258] IEA, "World Energy Outlook 2012", International Energy Agency

Fukushima – A Status Report

On 11 March 2011, a long and strong earthquake followed by a series of once-in-1,000-years-grade tsunami waves devastated the east coast of *Tohoku*, the northeastern region of *Honshu*, Japan's main island. The earthquake and tsunami hit 14 reactors in 4 nuclear power stations on the Pacific coast, namely from north to south, Onagawa with 3 BWR units operated by Tohoku Electric Power Co., Fukushima Daiichi with 6 BWRs and Fukushima Daini with 4 BWRs[259], both operated by Tokyo Electric Power Co. (TEPCO), and Tokai Daini (1 BWR) operated by Japan Atomic Power Co. (JAPCO). Units 1 to 4 of the six Fukushima Daiichi units were devastated, resulting in massive release of radioactivity into the environment. The other 10 reactors escaped meltdown and radioactive release by a series of lucky circumstances, but they were nevertheless damaged considerably. It was also mere fortune that the Rokkasho reprocessing plant on the Pacific coast of Aomori, 300 km north of Onagawa, escaped major damage; it did lose all external power supplies, but emergency generators worked to keep liquid high-level waste from boiling and thus from releasing large additional quantities of radiation.

Concerns over the health of firemen, site workers, and some general public inside and outside of the exclusion zone and other scheduled zones are grave, as well as the economic consequences for 200,000 refugees, utilities, government and local authorities, but remain outside the scope of this chapter.[260]

Characteristics of the Fukushima Disaster

On-site Challenges: Earthquakes, Station Blackout, Flooding, Explosions

TEPCO's two nuclear stations in Fukushima had a total of about 9 GW of electricity output (Daiichi 4.7 GW and Daini 4.4 GW). Daiichi and Daini are 12 km apart, both located on the Pacific coast of Fukushima Prefecture more than 200 km away from the offshore epicenter of the 3.11 quake.[261]

The devastated four reactor units of Fukushima Daiichi are all GE Mark-I BWRs. Unit-1 is of 460 MW power output and has 400 fuel assemblies, while Unit-2, -3 and -4 are each of 784 MW with 548 fuel assemblies. All the units began operation in the 1970s. Unit-3 has 32 MOX fuel assemblies loaded in 2010, of a total of 548, as first step of a one-third-core MOX program (but no irradiated MOX fuel currently in the spent fuel pool), while others had normal uranium fuel. At the time of the main shock of the mega-quake, three reactors (Units 1–3) were operating, while the other three (Units 4–6) were shut-down for maintenance, repair and refueling. Unit-4 was in the middle of core shroud replacement work; all the fuel assemblies had been moved to the spent fuel pool.

Seismometer signals tripped the Unit 1–3 reactors on 11 March 2011 at 14:47 JST. All of the five powerlines that had been transmitting electricity to and from Fukushima Daiichi were destroyed by the earthquake, which left the station without external power supply. Emergency diesel generators, two

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259 *Daiichi* means "The First" and *Daini* "The Second"; thus the stations may also be referred to as Fukushima-I and Fukushima-II, respectively.

260 The May 2012 WHO report (see http://whqlibdoc.who.int/publications/2012/9789241503662_eng.pdf, accessed 18 June 2013) gives a rather optimistic forecast of the health risks, whereas the May 2013 report by the Special Rapporteurs to the UN Human Rights Council (www.ohchr.org/Documents/HRBodies/HRCouncil/RegularSession/Session23/A-HRC-23-41-Add3_en.pdf, accessed 18 June 2013) recommends more precautions.

261 Another nuclear plant operated by TEPCO, Kashiwazaki-Kariwa, in Niigata Prefecture on the other side of Honshu Island, has 7 BWRs with the combined output of about 8 GW, the world's largest concentration of power reactors. Kashiwazaki-Kariwa had been hit by a level 6.8 earthquake in July 2007. Only 4 of the 7 units of Kashiwazaki-Kariwa were since restarted, but the March 2011 earthquake led again to the shutdown of all reactors. As of June 2013, no TEPCO nuclear stations are running.

each for all of the reactor-turbine units, automatically started. Less than an hour later, the units were overrun by water by a tsunami wave exceeding 13 meters and all the diesel generators were flooded.[262]

All of the diesel generators, circuit boards, and DC[263] batteries stored in the basement of the turbine building went underwater. The doors of the turbine buildings were at 10 m above sea level, but the tsunami rose higher. The total loss of electric power, or station blackout (SBO), resulted in successive reactor core meltdowns and melt-through events. Large amounts of hydrogen gas were generated inside the pressure vessel as hot steam reacted with the zirconium alloy of the fuel cladding. This hydrogen exploded later, but how the gas moved out, and exactly where it deflagrated, remains unexplained.

Table 5 shows the latest plant parameter figures of the four Fukushima Daiichi reactors in question. Continuous cooling is also imperative at Units 1 to 4 spent fuel pools. The irradiated fuel rods in these four in-house pools would otherwise overheat. Failure of the cooling and excessive build-up of decay heat could cause a zirconium fire, and then uncontrolled release of radioactivity into the atmosphere. The Unit-4 spent fuel pool is generally considered most vulnerable because of damage to the building, which is no longer structurally sound, and the number of fuel rods stored and their relative high temperature.

Table 5: Spring 2013 plant parameters of Fukushima Daiichi Units 1–4[264]

Fukushima Daiichi Units	Radiation inside the reactor building (mSv/h)	Temperature at bottom of pressure vessel (°C)	Quantity of radioactive water (tons)	Temperature of spent fuel pool (°C)
Unit 1	23 - 11,100	≈26	13,900	≈24
Unit 2	5 - 72,900	≈39	22,800	≈22
Unit 3	10 - 4,780	≈37	20,900	≈20
Unit 4	0.1 - 0.6	n/a	15,900	≈28

Radioactive emissions into the atmosphere from the three units (1, 2 and 3) continues at a rate of 10 MBq/h of cesium (= 240 MBq/day)[265]. This does not include the radionuclides that flow into the waste water and the unknown direct flow into the groundwater and Pacific Ocean.

Off-site Challenges: Evacuation, Decontamination

The vast scale of the economic loss, real-estate devaluation, primary-industries damage, environmental hazards, and the enormous personal and community sufferings caused by the Fukushima accident is hard to grasp in its totality. As of April 2013, more than 150,000 people are still forced to remain evacuated from their communities in the restricted zones.[266] Tens of thousands of other people,

[262] The exact height of the 3/11 wave at the Fukushima Daiichi site is unknown. It scaled out the TEPCO's offshore wave gauges, whose limit was ±7.5m. Since the flood reached the Unit-5 turbine building, which was 13 m above the sea level and the highest among the 6 units, the wave height is estimated as more than 13 meters. In 2008, TEPCO had calculated a maximal possible height of a tsunami wave at Fukushima Daiichi at 15.7 m, based on the Governmental study group's prospect (July 2002) of a M-8 class earthquake-and-tsunami on the eastern Pacific coast of Japan (see NAIIC 2012: p.54, Section 1.2.1.2-e).
[263] Direct current.
[264] Temperatures (pressure vessel bottom and spent fuel pools) are as of 7 May 2013; other figures are from the press release of 16 April 2013. See www.tepco.co.jp/en/nu/fukushima-np/index-e.html.
[265] TEPCO press release, 26 April 2013. It is one-sixth of the earlier estimate made by the Government (60 MBq/h, technical document in Japanese, released by the Cabinet Secretariat, 16 December 2011; see http://www.cas.go.jp/jp/genpatsujiko/pdf/111216e.pdf). TEPCO's figure is based on dust sampling on-site and monitors only Cs-134 and -137. The Government 2011 figure includes inert gas estimates. There has been a considerable variance, with occasional spikes, of Cs-134 and -137 fallout monitored in Fukushima City (60–70 km offsite) in the past six months (regular announcement on the Fukushima Prefecture official website).
[266] *Fukushima Minpo* (newspaper), 27 March and 18 April 2013.

especially concerned mothers with small children, had to seek voluntary refuge away from their home towns outside contaminated zones. Many of them still live in exile with poor official support. Roughly 130,000 compensation claims have been made by individuals, corporations, trade unions, and local governments against TEPCO[267], of which 6,000 are handled by the statutory mediator, the Center for Dispute Resolution for Compensating Nuclear Accident (the so-called Nuclear ADR).[268]

The Japanese Government designated 101 municipalities (city/town/village) in eight Prefectures as a Scheduled Contamination Survey Zone, where an additional radiation dose of 1 to 20 millisievert per year (mSv/y) is predicted. Areas where the additional dose is over 20 mSv/y are designated as a Special Decontamination Zone. In the Survey Zone, local governments are responsible, with national government subsidies, to conduct decontamination and/or remediation work to decrease radiation dose rates. In the Special Decontamination Zone, a 235-km^2 area in 11 municipalities of Fukushima Prefecture, the central government is in charge of radiation remediation projects.

So far only 5 percent of the Survey Zone and 4 percent of the Special Decontamination Zone have been worked on.[269] In the 40 Fukushima municipalities designated as Survey Zone (1–20 mSv/y), only 12 percent of the houses, 17 percent of the roads, 60 percent of public buildings (including schools and playgrounds)[270], 75 percent of rice fields, and 53 percent of other farmlands have gone through remediation work.[271] It is often the case that after premises are decontaminated they become recontaminated due to the wind and/or water flows from the surrounding environment. There are three main reasons why the remediation projects are badly behind schedule: technical difficulties, lack of waste disposal arrangements, and shortage of manpower. The Government will have to review the whole framework of the remediation projects, particularly in the Special Decontamination Zone. If the remediation effect is little more than the rate of natural decay, which is actually the case in a number of work areas[272], then it is no use spending a huge budget at the expense of refugees' support.

Health concerns are increasing. We decided to exclude this issue from this short overview considering its importance, poor survey quality and complexity. The discussion of health concerns stemming from the Fukushima disaster vastly exceeds the scope of this report.

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[267] Japan Federation of Bar Associations, 8 June 2013.

[268] ADR stands for Alternative Dispute Resolution. In case this officially supported out-of-court mediation fails, claimants can go to court, but that can be a further burden for them in time, cost, and energy.

[269] *Mainichi Shinbun*, 4 March 2013; NHK News, 17 May 2013.

[270] As to schools and childcare facilities, 98% of the premises have been worked on and the dose rates have been substantially lowered (see *Jiji*, 7 June 2013, based on Ministry of Environment press release).

[271] Fukushima Prefecture administration press release, as reported in the local newspaper, *Fukushima Minpo*, 4 June 2013.

[272] According to the monitoring results in the model areas of the official decontamination projects, an average of 25% reduction of gamma dose rate is reported after 15 months (December 2011–March 2013) of trials (Ministry of Environment press release, 7 June 2013). The figure means it is mainly due to the natural decay of Cs-134 plus weathering, rather than due to the human intervention. By comparison, the reduction rate was around 60% in the period up to December 2011, which was mainly due to human efforts plus weathering. In other words, although the early, urgent work of decontamination, such as shaving playground surface soils, had some effect, further reduction turned out to be hard to achieve and rather unrealistic. To cite a typical case from Fukushima City, the eastern hillside residential area of Watari, where the city-contracted (and sub-contracted) operators slowly conduct remediation work, people still live in ambient exposure rates of 1 to 4 microsievert per hour (µSv/h) with a number of micro-hotspots of up to 150 µSv/h here and there, as monitored by Greenpeace Japan, Friends of the Earth-Japan, local resident groups, and one of the authors and colleagues, during the period from May 2011 to May 2013.

Current Status of Fukushima Daiichi 1–4

After six different professional investigations (see hereunder), the real story of why and how the destruction of each reactor unit came about is still in the mist. This section reviews the current conditions and the specific problems of each reactor units.

Unit-1

Meltdown in the Unit-1 reactor proceeded much sooner than the other units. The fuel mostly melted through (thus the temperature at the pressure vessel bottom is now lower than other units; see Table 1) and dropped down onto the secondary container floor. The molten fuel is probably eroding the thick concrete base at the bottom of the container, although the depth of the erosion is hard to estimate. The quick meltdown and melt-through seem to have been accelerated by the operators' failure to keep the isolation condenser running properly, and by a loss of coolant accident (LOCA) caused by the earthquake shocks. [273]

The radiation environment at Unit-1 is not so severe as at Unit-2, but the dose rate inside the Unit-1 container is more than twice as high as that of Unit-3 (see Table 5).

The Unit-1 building is currently covered with polyester sheets to minimize radioactive releases into the atmosphere. However, TEPCO plans to remove the cover early next year so that the debris scattered around on the top floor (Level-5) of the building can be removed and a crane to retrieve irradiated fuel from the spent fuel pool can be installed above the building.[274] The company says a new, larger sheet will be installed to cover both the building and the crane in 2017. In the meantime, radioactive releases will inevitably increase.

Unit-2

Unlike the other three units, the building of Unit-2 was not severely damaged by explosions, but most investigators agree that the radioactive release from this reactor was the worst (the largest in Bq). This was because the blow-out panel in the wall of the Unit-2 collapsed from the force of the Unit-1 explosion, leaving a large opening in the Unit-2 building. The good news was that explosive hydrogen escaped from the hole; the bad news was that radioactive gas found an easy way out as well.

The Reactor Core Isolation Cooling (RCIC), which had activated just after the main shock on 11 March 2011, ceased to function on 14 March and meltdown started in the Unit-2 reactor. Secondary containment pressure went as high as 750 kPa, but venting failed. On 15 March, the pressure was rapidly lost after the operators/workers heard an explosive sound somewhere around the torus (suppression chamber in the bottom part of the container).

The location of the explosion, its cause and nature—hydrogen or nitrogen explosion and where the gas came from—and the degrees of the damage in the torus and/or pipings are all unknown, and will remain so for some time given the high radiation environment (maximum of 72.9 Sv/h as monitored in March 2013) in and near the container vessel impeding even a cursory human inspection. What is known is that there is a large leak (supposedly a substantial rupture) somewhere and the cooling water poured into the reactor vessel is constantly escaping.

The reactor temperature (39ºC at the bottom of the pressure vessel) is relatively and constantly higher than at the other reactor units, indicating that the cooling is less effective in this reactor. It probably reflects the condition of meltdown. The hot molten fuel may have gone deeper into the concrete floor of the container vessel, and pouring in water has a limited cooling effect. If that's the case, it means that retrieving the fuel would be more difficult and would take longer. TEPCO's decommissioning roadmap shows that the company is planning on more time in the case of Unit-2 (2017–2023 for spent

[273] Mitsuhiko Tanaka, 2013, *Kagaku* 83(4): 363.
[274] TEPCO press release, 9 May 2013.

fuel pool evacuation and 2020–2024 to begin with fuel debris recovery from the reactor containment) than in the case of Unit-1 (2017 and 2020–22, respectively, for the same operations).[275]

Unit-3

Venting was carried out twice in Unit-3, but it could not prevent the explosion, which took place outside the containment seven hours after the second venting. As to the Unit-3 explosion, independent nuclear expert Arnie Gundersen claims a possibility of small nuclear detonation due to moderated prompt criticality in the spent fuel pool, probably due to distortion of fuel assembly racks in the pool caused by the impact of the hydrogen explosion that occurred close to the spent fuel pool.[276] So far, most other professional engineers remain doubtful or reject this scenario outright. However, findings of fragments of fuel material outside the Unit-3 building and the recent retrieval of extremely contaminated debris (540 mSv/h recorded at the surface) in the Level 5 (spent fuel pool floor) of the Unit-3 building[277] reflect the fact that the Unit-3 explosion was much more intense than that of Unit-1. The detonation theory will be ultimately challenged and resolved when the fuel assembly racks and the fuel rods are physically inspected years from now.

The temperature at the bottom of the Unit-3 reactor pressure vessel was around 36ºC in December 2012. It went down to 25ºC in late March 2013, but again it is around 37ºC in early June 2013. The fluctuation is much larger than at Unit-1 (low twenties) and Unit-2 (upper thirties). TEPCO plans to start retrieving fuel debris from the Unit-3 containment in 2021, one year later than Units-1 and -2, while the fuel retrieval from the Unit-3 spent fuel pool is planned for 2015, two years sooner than from pools at Units-1 and -2.[278] As the explosion of Unit-3 was rather large, the conditions of debris inside and outside the Unit-3 building are worse than in other units. This makes decommissioning work particularly hazardous in Unit-3.

Unit-4

At the time of the earthquake and tsunamiUnit-4 was not operational and was undergoing a periodic inspection. All fuel had been taken out of the reactor vessel and moved to the spent fuel pool, where older spent fuel assemblies were also stored. At approximately 6:10 am, 15 March 2011, the Unit-4 building exploded, blowing the upper-floor walls and the ceilings away, leaving the spent fuel pool filled with 1,535 assemblies (1,331 irradiated ones and 204 fresh ones)[279] in the open air without containment, though debris fell into the pond. The cause and mechanism of this explosion are still unclear. Unlike the earlier explosions at Unit-1 and -3, no video-recording is available; even the exact time of the explosion remains uncertain. A likely explanation is that hydrogen came from Unit-3 via the piping; there is also a probability that Unit-4 spent fuel pool temperature went high enough to cause radiolysis of the water, producing hydrogen gas.

What if the spent fuel pool gets cracked and loses its cooling water? What if the already severely-damaged (and, as it seems, slightly leaning) reactor building collapses and the spent fuel pool crashes down, perhaps triggering a spent fuel fire? This could lead to a worst case scenario that was drawn up in March 2011 by Prof. Kondo, Chairman of the Japan Atomic Energy Commission (JAEC), would still apply. Evacuation of over 10 million residents in the wider Tokyo megalopolis within a 250-km radius of Fukushima Daiichi, depending on wind direction, may be required.[280] Radioactivity of the

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[275] TEPCO press release, 10 June 2013.

[276] Arnie Gundersen's remark at the Session 1, the International Symposium on the Truth of the Fukushima Nuclear Accident and the Myth of Nuclear Safety, held at the University of Tokyo, 29 August 2012, as recorded in the Proceedings [in Japanese] (published by Iwanami, November 2012): 16-17.

[277] TEPCO press release, 4 May 2013.

[278] TEPCO press release, 10 June 2013.

[279] Two of the 204 unirradiated assemblies were retrieved in a test operation of July 2012, so the remaining number of the fuel assemblies is 1,533.

[280] Shunsuke Kondo, 25 March 2011, 15 slides as reported to the government. Archived at www.asahi-net.or.jp/~pn8r-fjsk/saiakusinario.pdf, accessed 18 June 2013.

Unit-4 spent fuel pool is more or less equivalent to three full reactor-loads; i.e. the quantity of the irradiated fuel rods kept in that single pool roughly equals those in Unit-1, -2 and -3 reactor cores combined. Thus, full release from the Unit-4 spent fuel pool, without any containment or control, could cause by far the most serious radiological disaster to date.

TEPCO claims that the Unit-4 building has been reinforced enough to survive further quakes, but retrieving the heat-generating spent fuel from the pool is nonetheless imperative and as quickly as possible. TEPCO puts a top priority to the construction of a crane-supporting iron framework over the Unit-4 building. Retrieval of the assemblies is scheduled to begin in November 2013 and to be completed by 2014.[281]

Wave or Shake?

So far, six projects of investigation into the Fukushima accident were carried out and five of them published (mostly in Japanese). They are in order of publication: (1) Ohmae project[282], (2) RJIF[283], (3) TEPCO[284], (4) NAIIC commissioned by the Diet (Parliament)[285], (5) the Government[286] and (6) the Atomic Energy Society of Japan (AESJ).[287] The reports differ not only in their perspectives but also in many of the details in their analysis of the accident sequences. This may not be surprising given the reality that most of the crucial devices, and the specific locations in the reactor systems where the destruction and/or dysfunctions occurred, remain uninspected or even inaccessible due to the lethal radioactive environment in and around the reactor containments.

The most important difference among the above reports is about whether the main cause of the Fukushima Daiichi disaster was the earthquake shocks or the tsunami inundation. Only the NAIIC report claims that ruptures in piping or destruction of generator(s) could have caused decisive failures prior to the tsunami arriving. Other investigation reports are rather negative about that possibility and consider the tsunami the cause. The quake/tsunami issue bears a key influence on the matter of the country's safety regulations of nuclear facilities in general, and the controversy in particular of whether to restart other power reactors under the current aseismic codes.

Fukushima Daiichi lost all its external power sources as the transmission towers collapsed in the earthquake. Subsequently, the station lost all its onsite power generators, including those installed for the case of emergency. This happened also at the Daini station, but one external powerline held up at

[281] TEPCO, press release, 10 June 2013.

[282] K. Ohmae, "The Last Conditions of Reboot: Final Report of the Investigation Project of the Fukushima Daiichi Accident" [in Japanese], Shogakkan Publishers, 2012.

[283] Rebuild Japan Initiative Foundation (RJIF), usually called Minkan Jikocho (Minkan means private sector and "jikocho" is short for Accident Investigation Committee) was chaired by Professor K. Kitazawa, former President of the Japan Science and Technology Agency (JST), "The Independent Investigation Commission on the Fukushima Nuclear Accident, Investigation Report" [in Japanese], RJIF, 1 March 2012, see http://rebuildjpn.org/en/fukushima/ for an English summary, accessed 19 June 2013.

[284] TEPCO, "Fukushima Nuclear Accidents Investigation Report", 2012, see www.tepco.co.jp/en/press/corp-com/release/2012/1205638_1870.html, accessed 7 May 2013.

[285] National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC), usually called "Kokkai Jikocho" (kokkai means the Japanese Diet) was chaired by Emeritus Prof. K. Kurokawa of Tokyo University. NAIIC, "The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission", The National Diet of Japan, 5 July 2012 (NAIIC 2012). English edition at http://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/en/report/, accessed 30 April 2013.

[286] Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company (ICANPS), usually called "Seifu Jikocho" (seifu is the national government) was chaired by Emeritus Prof. Y. Hatamura of the University of Tokyo. ICANPS, Final Report on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company, 23 July 2012. English edition at http://www.cas.go.jp/jp/seisaku/icanps/eng/final-report.html, accessed 30 April 2013.

[287] Final report to appear by the end of 2013.

Daini, narrowly enabling the operators to bring the reactors to cold shutdown, unlike at Daiichi after its total station blackout. Apparently the Daiichi site's onsite generators were lost due to the inundation. NAIIC investigators, however, see the possibility that at least some of the generators had been destroyed by the earthquake, and that perhaps the Unit-1 reactor suffered a loss-of-coolant accident due to pipe ruptures before the station blackout.

The nature of the earthquake oscillation experienced by the Daiichi station was rather abnormal in that it continued for 180 seconds, twice as long as the basic design earthquake ground motion (Ss) for the reactor building. The length reflects the magnitude of what happened in the epicenter: the main shock of 3/11 came from the huge fault surface of 450 km longitudinal x 200 km latitudinal. It is highly likely that the repeated load caused fatigue fractures in all corners of the buildings and installations of the power stations—not only at Fukushima Daiichi, but also in other reactors that escaped meltdown. Therefore full investigation of the degrees and extensions of the ruptures, fractures and other modes of destructions at those other plants seems imperative, though the Government and the power companies are not open to this suggestion, perhaps because it could bear on both their suitability for potential restart and on the adequacy of national nuclear seismic standards.

In the "wave or shake" controversy, the exact time of flooding of the emergency diesel generators is of crucial importance. TEPCO says the first wave (4m high) arrived at 15:27 on 3/11, and the much higher second wave (scaling out the wave recorder limit of ±7.5m) arrived at 15:35. Both *Seifu Jikocho* (Government) and *Minkan Jikocho* (private) studies adopted these figures. NAIIC (*Kokkai Jikocho*), however, found that these were actually the times recorded 1.5 km offshore where the wave meter was buoyed, and the big wave must have taken a further 2 to 2.5 minutes to reach the shoreline (i.e. at 15:37 to 15:37:30). It would take some more time for the tsunami to inundate the diesel generators. According to the plant record, the respective time of the diesel generator power failure is the following:

15:35 or 36 — System A, Unit-1

15:37 — System B, Unit-1

15:38 — Systems A and B, Unit-3

Thus apparently the System A of Unit-1 failed before the tsunami. It is most likely that it had stopped due to the aftershocks before the inundation. It is also possible that the System B of Unit-1 and the two systems of Unit-3 failed before the flooding. By this logic and evidence, TEPCO's claim that station blackout would not have taken place without the tsunami cannot be maintained.[288]

NAIIC investigators applied a series of failure-tree analysis (FTA) regarding the impacts of the repeated oscillations and reached a reasonable assumption that the rapid loss of coolant at the Unit-1 reactor, leading to its meltdown, was explicable as caused by a small-scale rupture (or ruptures) somewhere in the reactor's piping system, including the piping to the Reactor Core Isolation Cooling Condenser (IC). Operators who were at the Level 4 of the Unit-1 reactor building on 3/11 testified in their interviews with NAIIC that they had experienced water leakage at Level 4. Onsite inspection is essential to determine whether this water was from ruptured pipe(s) or from the damaged spent fuel pool at Level 5. NAIIC also interviewed a number of Unit-1 operators and plant workers to confirm that the safety relief valve, an essential device to depressurize the reactor in trouble, did not open, because nobody heard a loud noise indicating that the main steam had escaped the valve (thus making the water injection easier and possibly avoiding meltdown). The malfunction of the safety relief valve would support the small-scale rupture hypothesis.

The NAIIC investigation presents a strong argument that the loss of coolant accident at Unit 1, leading to its meltdown quicker than other reactor units, had been caused by the earthquake strikes *before* the tsunami crippled the emergency generators. Onsite investigation, particularly in Level-3 to Level-5 floors of the Unit-1 building, is needed to specify how much and what kind of damage is found in

288 NAIIC 2012, *ibid*:227. (Section 2.2.3.4; English edition, Chapter 2, pp.80-81). See also p.17 of the English summary of NAIIC 2012, http://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/en/report/ (accessed 1 June 2013).

which parts of the building and installations. NAIIC's repeated request for onsite inspection was refused by TEPCO for safety reasons. TEPCO has so far disclosed only a very limited amount of video recordings of the floors in question. On 13 March 2013, Hiroshi Kawauchi[289] entered the Unit-1 reactor building and his video recording is now open for public inspection.[290] The footage shows the Level-4 devastation is much more than previously estimated; it is now fairly probable that, apart from the big explosion at Level-5, there was also a hydrogen explosion at Level-4 destroying the piping systems connecting the reactor vessel and the isolation condenser.[291]

Notice also that the shake intensity at Unit-1 of Fukushima Daiichi was within the assumed range in the reactor design, but it caused fatal damage to the unit. The Fukushima Daini reactor units—shaken by the quake, flooded by the tsunami, and exposed to a station blackout—narrowly escaped the catastrophe. It is important to understand these event sequences and learn their lessons.

On-site Challenges: Water, Waste, Radiation

Difficulties with Radioactive Water Management

Cooling of the reactor vessels continues at Units-1, -2 and -3. Since the reactor cores of all three units are melted down and more or less melted through the vessels, the normal reactor cooling systems are of no use. Operators know where and how the water is injected, but they do not know exactly where it then goes and how leakage occurs. The coolant (freshwater plus neutron-absorbing boron) is pumped and sprayed into the main vessels (i.e. pressure vessel, though the pressure is long lost), then leaks into the secondary containment through the holes and cracks at the bottom of the reactor vessels. After hopefully cooling the melted nuclear fuel somewhere in the primary and secondary vessels (the forms and distributions of the fuel debris being unknown), the water leaks out from unidentified ruptures of the containments and overflows into the basements of the reactor buildings and the connected turbine buildings. This drainage continuously washes out radionuclides from the destroyed reactors. Nonetheless, the water injection must continue to prevent the fuel from overheating.

Operators collect the drained radioactive water from the basements and send it through filter systems to decrease radioactivity and recirculate it back into the reactors. By May 2013, this water circuit was 4 km long, many sections of which were still composed of makeshift vinyl (chloroethylene) tubes installed above-ground in 2011, rather than severe-duty steel pipes. Thus site workers are always busy mending leaks and holes, caused for example by frost.

Mr. Ebisawa, who had served NAIIC as an expert reactor engineer, estimated the amount of radioactivity that had seeped into the water that fills the basement of the reactor buildings (Unit-1, -2 and -3, as of 20 November 2012) as follows:[292]

Cesium-137:	276 PBq[293] (i.e. 40 percent of the reactor core inventory)
Strontium-90:	23 to 33 PBq (i.e. 4.4 to 6.3 percent of the reactor core inventory).

[289] Kawauchi is an ex-Member of Parliament and the former chairman of the House of Representatives Special Committee on Promotion of Science, Technology and Innovation. This committee tried actively to inquire into the Fukushima accident before the official parliamentary commission, NAIIC, was organized.

[290] See http://youtu.be/y0GCj12RSO4 or http://youtu.be/QXcgajz87b0, both accessed on 30 May 2013.

[291] On 31 May 2013, the Nuclear Regulatory Authority (NRA) personnel went inside the Unit-1 building to inspect the physical condition of the IC at Level-4. The dose rate is 20–30 mSv/h, so the inspectors' stay had to be limited to 15 minutes. Their report, with several hundred photographs, is yet to come. (*Mainichi Shimbun* reports, 30 May and 4 June; NHK TV report, 5 June 2013.)

[292] Toru Ebisawa, 2013, Bulletin of the Citizens' Nuclear Information Center, 465: 12. J. Kanda gives an earlier estimate of 160 PBq, as of May 2011, Ocean Policy Research Foundation, Kaiyo Hakusho 2012 [annual report in Japanese], p. 45. Seizando-Shoten Publishing, 2012.

[293] 1 PBq = 1 petabecquerel or 1 million billion becquerels or 10^{15} nuclear distintegrations per second.

These are far larger amounts than those released into the atmosphere in gaseous form: for example, more than 27 times the amount of cesium-137 released into the air in the first three weeks[294], or about 2.5 to 3.3 times, depending on the estimate, the total amount released into the environment from the Chernobyl accident[295].

The extreme radioactivity (several million Bq per cm^3 prior to decontamination) of the outflow is a serious problem by itself, and to make the situation much worse, the volume of the contaminated water is continuously increasing. This is due to the influx of groundwater from the hillside into the reactor buildings through the broken walls. The groundwater influx (Units 1–3 combined) is estimated at a rate of about 400 tons per day—more than the water pumped in to cool the three reactors (about 360 tons per day).[296] TEPCO has been trying to control the influx by drilling extraction holes to the west (uphill) of the reactor units, but their effect seems to be limited. TEPCO is asking the local fishermen's union to approve discharge of the drained water, only to meet a strong opposition from both the union and the general public.[297]

The excess of entering over exiting water results in increasing stocks of excess water, after minimal decontamination, in the storage tanks that are now covering the Fukushima Daiichi station site. The overall volume of radioactive water that cannot be used in the cooling circulation reached 380,000 tons in early May 2013 (290,000 tons in the storage tanks and the rest in the basement of the reactor/turbine buildings). If the current regime continues, TEPCO estimates that the amount will be over 600,000 tons in mid-2015. The company claims to have plans to install more tanks, up to the total capacity of 700,000 tons, which however will be filled up in less than three years; as yet there is no planning beyond that target.

In another makeshift attempt, TEPCO dug seven large (10,000-ton-class) sink ponds adjacent to the tanks, but a series of radioactive leakages was detected in March and April 2013. It was found out that TEPCO had adopted conventional lining techniques usually applied to solid (non-liquid) industrial waste, making leakage likely. Following criticism, TEPCO is now pumping the contaminated water from the leaking ponds up to the new steel tanks. The utility said the transfer would be finished by the end of June 2013. However, leakage from those new tanks was already detected in late May 2013. This is not surprising since those tanks are no more than temporary facilities; they are not properly welded containers but simply steel plates rounded and fastened tightly with bolts. Most of these makeshift tanks will survive only a few years or less, prone to constant leaks and corrosion.

All these operations and repairs yield additional radiation exposure to the site workers. Also, the high radioactivity of the waste water stored in the increasing number of tanks results in a sharp rise of gamma-ray dose rate (from 0.9 up to 7.8 mSv/y) at the power plant boundary.[298] This means that the company's radiation management target of 1 mSv/y at the site boundary will be exceeded.

In a desperate breakthrough hope, TEPCO started a 4-month test operation of a new multi-nuclide removal equipment (called ALPS), which is intended to filter out 62 radionuclides other than tritium. If this works, then the question is what to do with the ALPS-processed water, which may contain only trace amounts of cesium, strontium, uranium, plutonium, etc, but does contain the full amount of tritium coming out of the reactor cores. Apparently TEPCO is considering a controlled release into the sea, which will be fiercely opposed by fishermen, the general public, and overseas neighbors. The Fishery Union of Fukushima Prefecture already expressed its strong concern even to the proposed bypass discharge of the hillside water (i.e. control extraction of groundwater before flowing into the reactor buildings), which contains only trace amounts of the radionuclides.

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294 The release of cesium-137 into the atmosphere during the period from 12 March to 31 March 2011 is estimated at around 10 PBq, see TEPCO press release, 24 May 2012). The total atmospheric release, mostly iodine-131 and inert gases, is estimated at 480 PBq (MITI, February 2012) to 900 PBq (TEPCO, ibid).

295 Estimates range between 85 PBq (UNSCEAR, 1996) and 110 PBq (Ian Fairlie, et al, TORCH Report, 2006).

296 Groundwater influx is also the case at Unit-4, -5 and -6 buildings, but radioactive contamination of water is much less serious in those units.

297 *Mainichi Shimbun*, 31 May 2013; Reuters Japan, 4 June 2013.

298 TEPCO press release, 7 May 2013.

Apart from the overflow from the cooling circulation described above, and apart from the initial large-scale discharge of radioactive water into the sea in March–April 2011, the release of contaminated water to the sea at the power plant port is continuing, although at a decreased rate, and TEPCO has no effective way to restrain it. The average release rate of Cs-137 was estimated to be 93 GBq per day in summer 2011 and 8.1 GBq per day in summer 2012.[299] In June 2013, it was revealed that the groundwater sampled from a monitoring well adjacent to the Unit-2 turbine building is contaminated with strontium and tritium, so the highly radioactive water that filled the unit basement has already made its way to the aquifer, whence it can easily flow into the sea.[300]

One big difference between Chernobyl and Fukushima is the serious sea contamination.[301] High concentrations of Cs-137 and Sr-90 in fish/mollusk/seaweed samples offshore have been reported repeatedly, giving a crushing blow to the fishery, which was the main source of income not only of Fukushima but also of Japan's wider Tohoku (Northeast) region.

The Government has recently come up with a radically new engineering plan to cope with the groundwater problems. The idea of freezing the groundwater, or "artificial tundra", was proposed by the construction giant Kajima Co., and was adopted by a Government committee of experts that reviewed the water management at Fukushima Daiichi.[302] Artificial tundra itself appears as a simple and reasonable concept: a number of 20–30-meter-long pipes will be put vertically into the ground in line, and very-low-temperature antifreeze solution will be circulated in the pipes to freeze the groundwater near the pipes, making an underground ice wall. It is an existing technology used in subway construction and mining to block the influx of groundwater. Such a system, however, would consume huge amounts of electricity to maintain below-zero temperatures for a long period of time. It would have to run for more than 10 years while the reactors need coolant circulation. There is also a risk of reversing the water flow, making the highly radioactive water seep out from the reactor buildings to the aquifer. TEPCO is now considering the proposal, but does not seem as enthusiastic about the idea as the Government does.

Contaminated Debris

The total of the station site debris (except the fuel debris) will reach 176,000 tons by the end of March 2016. The solid waste, such as metals, concrete pieces, plastics, and combined materials will be separated and piled or sealed according to their radioactivity. TEPCO secured a 20,000-ton storage capacity for debris of 0.1–1.0 mSv/h grade, but the actual amount is likely to exceed this capacity in early 2016. At the same time, the 34,000-ton storage capacity for contaminated debris of 1–30 mSv/h grade will be filled up to 33,000 tons. Total available storage capacity for contaminated debris is less than 200,000 tons, which is estimated to be 90 percent saturated by March 2016. TEPCO is yet to work out how much debris will accumulate from the site decommissioning work beyond 2016.[303] Poor waste management planning may prove a serious obstacle on the difficult half-century-long road to decommissioning.

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299 J. Kanda, "Continuing ^{137}Cs release to the sea from the Fukushima Dai-ichi Nuclear Power Plant through 2012", Biogeosciences Discussions, 10: 3577-3595, 2013. See www.biogeosciences-discuss.net/10/3577/2013/bgd-10-3577-2013.html.

300 The contamination was confirmed in late May 2013, but it took TEPCO more than two weeks to publicly release the information, see TBS News, NHK News, Mainichi Shimbun, 19 June 2013. Also see http://enformable.com/2013/06/tepco-confirms-fukushima-daiichi-groundwater-contaminated-with-strontium-and-tritium/, accessed 20 June 2013.

301 J. Kanda, "Continuing radioactive cesium release to the sea from the Fukushima Dai-ichi Nuclear Power Plant" [in Japanese], in Kagaku 83(6):634-638, 2013.

302 *Yomiuri Shimbun*, 30 and 31 May 2013.

303 *Kahoku Shimpo*, 18 May 2013.

Workers Exposure to Radiation

Through March 2013, officially a total of 26,942 workers (3,710 TEPCO employees plus 23,232 contractors and subcontractors) have worked at the Fukushima Daiichi site since the accident started on 11 March 2011. Among those, at least 167 people received radiation doses over 100 mSv (internal and external), including 9 persons over 200 mSv, over the two years from March 2011 to March 2013. The maximum personal dose identified was 678.8 mSv. The average was 12.27 mSv per person. Eighty percent of the workers received doses below 20 mSv.[304]

These figures exclude the contingent troops (firemen, policemen and the Self-Defence Force) that entered or flew over the site in March 2011. The size and accuracy of the radiation dose estimations for these emergency servicemen seem to vary wildly. Under the emergency conditions of March–April 2011, there were a number of cases in which the workers approached high radiation areas without a radiation manager, who usually escorts the workers to supervise their radiological protection and monitor the dose rate of the work area. There were also frequent cases in which the workers did not carry individual dosimeters because of the shortage of the dosimeters in the emergency.[305] Thus the actual total dose could be considerably higher than the official figures given above.

Radiation-exposed workers' legal dose limit is 100 mSv for five years, but 50 mSv in any one year.[306] As a matter of fact, a number of workers who continuously work at Fukushima Daiichi easily receive their the 5-year limit in less than a year, or the annual limit in only a few months. There are workers who intentionally "forget" to put on their dosimeters in the hope of securing longer months of employment. There were even cases where subcontractors put lead shielding around their dosimeters to lower their recorded exposures so they could work longer.[307] This criminal case might just be the tip of the iceberg. Unless certain compensation schemes or alternative non-exposure jobs are provided for those who exceed dose limits earlier than their term of service, numerous subcontractors in need of work will commit clandestine tricks one way or another, doctoring their radiation exposure records. Currently at the Fukushima Daiichi site, a daily average of 3,000 workers are engaged in radiation-exposed operations. TEPCO employees are less than 7 percent of them; the rest are employed by contractors, subcontractors, sub-subcontractors, … down to 9th-level-subcontractors. Recruitment of new workers is becoming more and more difficult, while experienced workers, such as tower crane operators, must leave the site once they have achieved the dose limits.

Summary and Prospects

The reactor units are still in instable conditions and the cooling system depends on the temporary soft hoses that were laid in April-May 2011. Aftershocks are still continuing and the maxim possible M-8 class quake is yet to come. Government and the utility say it would take 40 years (or probably more) to retrieve the molten fuel from the three reactors. The question is whether the fragile, tightrope-walking conditions on site can possibly be sustained for that length of time.

The serious challenges the Fukushima Daiichi site is facing include the following, but these are by no means exhaustive:

(1) Cooling the molten fuel (corium), whose exact location is uncertain, for 5 to 10 years; and to keep it from re-criticality under frequent aftershocks, big and small.

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[304] TEPCO, "Status of radiation exposure dose of TEPCO's Fukushima Daiichi", 30 April 2013.

[305] Of the 5,000 dosimeters stockpiled in Fukushima Daiichi, only 320 survived the earthquake damage and the flood. TEPCO had to temporary suspend the rule that workers must carry individual dosimeter; the obligation was not resumed before May 2011, see Jiji, 1 April 2011; Tokyo Shimbun, 28 April 2011; Kyodo, 28 April 2011; Yomiuri Shimbun, 30 April 2011.

[306] In March 2011, the limit was temporary relaxed up to 250 mSv for emergency operations in Fukushima Daiichi (not applicable in other sites). The 100 mSv limit was resumed in Fukushima in November 2011. The extraordinary 250 mSv limit is still applicable to certain operations at Fukushima Daiichi.

[307] *Asahi Shimbun*, 21 and 22 June 2012; *Mainichi Shimbun*, 21 and 22 June 2012; *Yomiuri Shimbun*, 23 June 2012.

(2) Circulating the coolant in makeshift, provisional vinyl pipes with non-“rat-safe” power boards[308] and under the remaining threat of another flooding for years to come.

(3) Managing large quantities of radioactive waste water that is continuously building up in the basements of the reactors and turbine buildings.

(4) Ensure that the wrecked reactor buildings with their spent fuel pools between fourth and fifth floor withstand aftershocks, possibly M8-grade shakes.

(5) Conduct surveys to pinpoint where and how the reactor containments (including the torus) are cracked and/or ruptured so that they can be mended and filled with water in order to start retrieving, if ever possible, the fuel debris.

(6) Reduce continued leakage of radioactivity into the sea and the atmosphere to an absolute minimum, before any physical containment is re-established, hopefully in some five years.

(7) Carry through all these high-radiation-exposed operations under extreme shortage of workforce, as most of the skilled operators are rapidly reaching their lifetime dose limit.

On 10 June 2013, TEPCO revised its engineering road map 2015–2023 to start physically retrieving the molten fuel debris out of the reactor containments of Unit-1, -2 and -3 from 2020 onwards.[309]

The State of Nuclear Emergency, declared by then Prime Minister Kan in March 2011, has not yet been lifted. It was lifted for Fukushima Daini in November 2011, but as for Daiichi, the country is still in an extraordinary situation beyond the law; therefore, the prior legal dose limit of additional 1 mSv/y caused by nuclear industry activities remains suspended and large numbers of people, inside and outside the exclusion zones, are told to accept the 20 mSv/y emergency limit without proper justification and legalization.

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308 “Rat stops spent fuel pool cooling system”, Nuke Info Tokyo 154:15, 2013, see www.cnic.jp/english/newsletter/pdffiles/nit154.pdf, accessed on 5 June 2013. Hours-long failures of the spent fuel pool cooling were caused repeatedly by rat invasion into the electricity circuit box. The point is that the indispensable cooling systems still depend on the equipment that was temporarily installed in the wake of meltdown and explosions and have not been replaced with permanent installations due to the desperate shortage of workforce under high radiation. The power system has still poor backups.

309 See www.tepco.co.jp/nu/fukushima-np/roadmap/images/t130610_04-j.pdf (accessed 11 June 2013).

Nuclear Power vs. Renewable Energy

Three of the world's largest four economies (China, Germany and Japan), together representing a quarter of global GDP, are now running their economies with a higher share of renewables than of nuclear.

Christof Rühl
Chief Economist, BP
12 June 2013[310]

To reduce or avoid dangerous climate change, the move towards a low- or zero-carbon and fossil-fuel-independent energy sector must be both rapid and global. Given the diversity of energy services—cooking, heating and cooling, lighting, communication, mobility, motor torque, etc.—there is no silver bullet or single technology that will create a low-carbon energy future. Therefore a number of factors will determine the relative roles and ranking of different technologies, notably: potential for rapid global deployment, other non-fuel and CO_2 resource constraints, compatibility with existing systems and other technologies, public and political support, and the relative and projected economics. Many analysts consider energy efficiency the top scorer on all these metrics, so it should generally be bought before but together with renewables. However, aggregated statistics on technological (or even total) energy savings are not available—efficiency technologies and their effects are poorly tracked in most countries—so we focus here on the better-publicized and also important parallel progress in renewable supplies, omitting a number of other potent competitors to central power stations including cogeneration (combined-heat-and-power).

Investment

According to an assessment by Bloomberg New Energy Finance (BNEF), global investment in clean energy—largely renewable energy, excluding large hydro, but also including a small volume of investment into Carbon Capture and Storage (CCS)—was $268 billion in 2012, the second highest ever level, down from $300 million in 2011, but still five times the 2004 total of $52 billion, as can be seen in Figure 18. The largest percentage of the funding was for asset finance of utility-scale renewable energy projects, such as wind farms, solar parks, and biofuel plants. This received $148.6 billion, down from $180 billion in 2011. The next largest investment segment was for small-scale project investment, primarily rooftop solar PV, $80.2 billion, up from $76.5 billion in 2011[311].

Figure 18 compares the annual investment decisions for the construction of new nuclear compared to renewable energy since 2004. In the absence of comprehensive, publicly available investment estimates for nuclear power by year, the total investment costs have been included in the year in which construction was started, rather than spreading out the investment over the construction period. Furthermore, the nuclear investment figures do not include revised budgets if cost overruns occur. Over this period the total investment in nuclear is nearly an order of magnitude lower than that for clean energy, which is descibed by BNEF as renewable energy, not including big hydro, and CCS.

China has been by far the largest investor in renewable energies in 2012 with over $65 billion. Some big players reduced expenditures significantly over the previous year, including the U.S., Germany, Italy and India. On the other hand, some countries had very large growth rates. South Africa boosted spendings by a factor of two hundred to $5.5 billion, while Japan increased investements by three quarters (see Table 6).

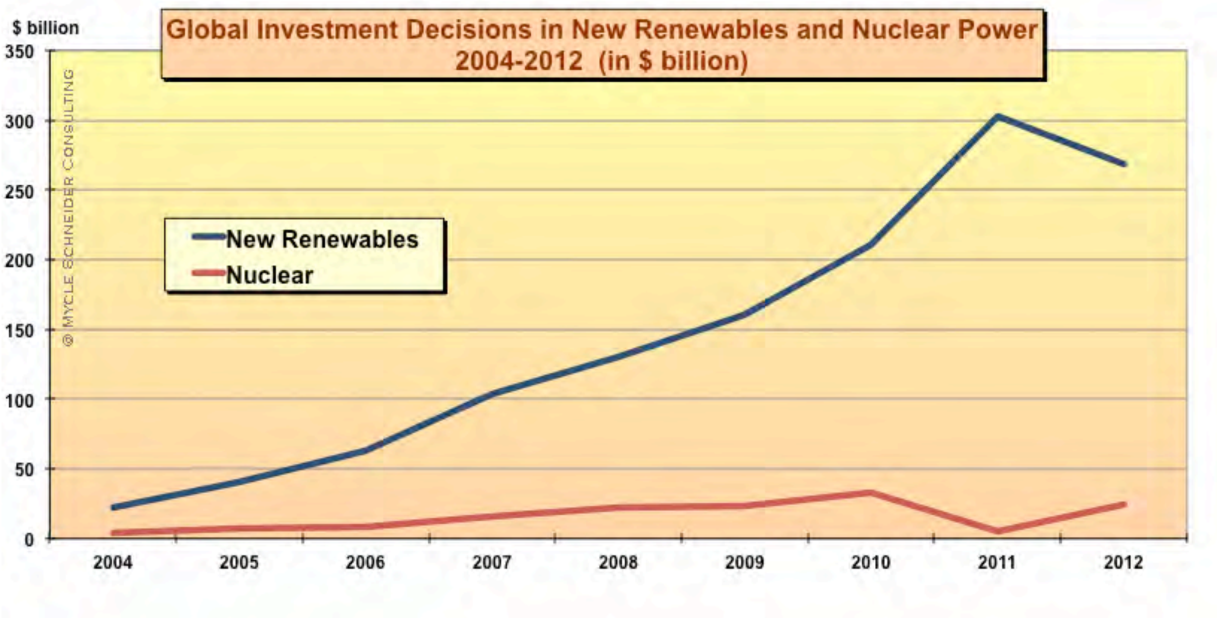
310 Rühl, C., "Energy in 2012 – Adapting to a changing World", Launch of the BP Statistical Review of World Energy, 12 June 2013.

311 BNEF, "New Investment in Clean Energy Fell 11% in 2012", Bloomberg New Energy Finance, 14 January 2013.

The decline in global investment in renewable energy capacity has continued in 2013, and in the first quarter of the year the figure is estimated at $40 billion, the lowest in any quarter since the first quarter of crisis year 2009.[312] But this does not mean less renewable capacity is being installed. Why not?

While these investment volumes are important to watch, it is essential to consider how much can be built per invested dollar. The costs of equipment are changing constantly and are generally declining. Since 2008 the world market cost of photovoltaic (PV) modules have fallen by 80%—and 20% in 2012 alone—while prices for wind turbines, a more mature technology, have fallen 29% since 2008[313]. This is in contrast with nuclear power, where the costs have risen considerably. For example the EPR under construction in France, Flamanville-3, was estimated to cost €4 billion in 2008, but by 2013 it had risen to €8.5 billion (see Nuclear Economics Chapter for details). The trend is highly relevant, both for investor confidence and in relation to what the investment can actually buy in terms of installed capacity.

Figure 18: Global Investment Decisions in Clean Energy and Nuclear Power 2004-12 ($ billion)



Source: BNEF 2013 and WNISR original research, 2013

Table 6: Renewable Energy Investment in Top 10 Countries 2011-2012 (in billion US$)[314]

Country	2012	2011
China	65.1	54.1
United States	35.6	56,8
Germany	22.8	31.3
Rest of EU*	16.3	17.7
Japan	16.3	9.3
Italy	14.7	30.1
U.K.	8.3	10.0
India	6.9	10.2
South Africa	5.5	0.03
Brazil	5.3	7.8

Note: *Rest of EU is including all of the EU countries besides Germany, Italy and the U.K.

[312] Frankfurt School-UNEP Centre/BNEF, "Global Trends in Renewable Energy Investment 2013", June 2013.
[313] BNEF, "Bloomberg New Energy Finance Summit", Michael Liebreich, 23 April 2013.
[314] Note that earlier 2011 figures have been revised by BNEF, some considerably. China's expenditures, for example, were raised from $45.5 billion (as represented in WNISR 2012) to $54.1 billion. Sources, BNEF 2013, according to PEW, "Who is Winning the Clean Energy Race?", PEW Charitable Trust, April 2013.

As documented hereunder, the 2011–12 drop in global renewable investment actually supported a substantial *in*crease in the amount of renewable capacity added, continuing years of consistently strong growth, whereas nuclear net additions, as reported earlier, are continuing to fluctuate in recent years between negative and mildly positive.

Installed Capacity

The commissioning of new electricity-generating facilities involves two major phases, pre-development and construction. Both affect the speed of technology deployment. The pre-development phase can include a wide range of activities such as conducting extensive consultations, obtaining the necessary construction and operating licenses, including public consent, and creating the financing package. In some cases, technology deployment may be sped up through the use of generic safety assessments. Alternatively, pre-development may take longer than expected because of local site conditions, lack of available skilled workforce, or new issues coming to light.

The IAEA estimates that starting a new nuclear program in a country without experience can take between 11 and 20 years, and the French safety authorities assume a minimum of 15 years to set up an appropriate framework. Even where countries have nuclear experience, the IEA has estimated a pre-development phase of approximately eight years for nuclear power.[315]

It is important to note the differences in construction of a wind farm, and many other renewable energy schemes, compared to large fossil-fueled or nuclear power stations. The European Wind Energy Association (EWEA) likens building a wind farm to the purchase of a fleet of trucks: the turbines are bought at an agreed fixed cost and on an established delivery schedule, and the electrical infrastructure can be specified well in advance. Although some variable costs are associated with the civil works, these are very small compared to the overall project cost.[316] The construction time for onshore wind turbines is relatively quick, with smaller farms being completed in a few months, and most well within a year. The contrast with nuclear power, and even with conventional fossil fuel power plants, is significant.

These investments are resulting in grid connections and operation of new capacity, and this slowly changes the electricity mix. Figure 19 shows the extent of solar, wind and nuclear capacity that has been added to the global grid since 2000. What is clearly demonstrated is that nuclear power capacity has remained largely constant over the past decade, whereas the two renewable energy sources, solar and wind, are increasing steadily and rapidly. Globally the average annual growth rates during 2000–2012 for onshore wind have been 27 percent and for solar PV 42 percent. This resulted in 2012 alone in 32 GW[317] of solar being added to the grid, 45 GW of wind[318] versus a net addition of 1.2 GW of nuclear[319].

[315] IEA, "Nuclear Power in the OECD", Paris, 2001.

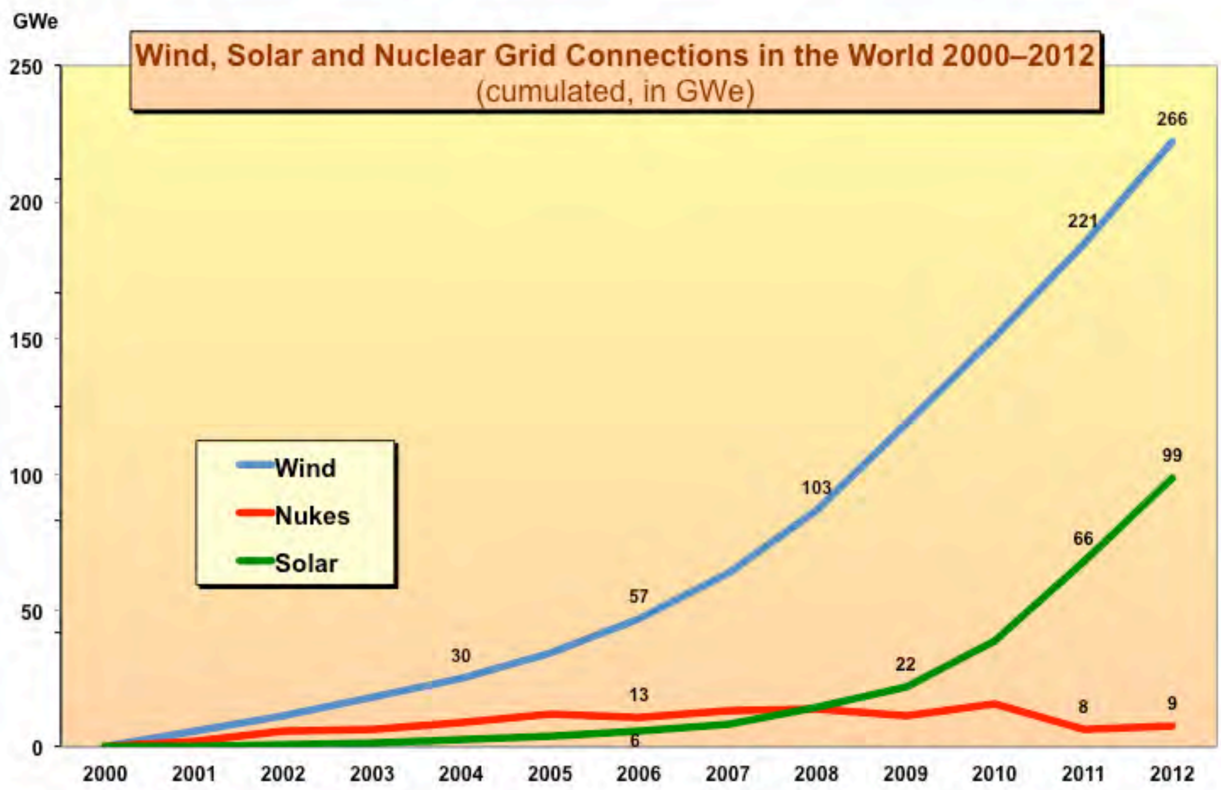
[316] European Wind Energy Association (EWEA), "Wind Energy, The Facts: Volume 1, Technology", Brussels, 2003.

[317] CleanTechnica.com, "Solar PV Installations Hit 32 GW In 2012, 35 GW Projected For 2013, According To HIS", 5 February 2013, see http://cleantechnica.com/2013/02/05/solar-pv-installations-hit-32-gw-in-2012-35-gw-projected-for-2013-according-to-ihs/, accessed 8 May 2013.

[318] GWEC, "Global Statistics for 2012", Global Wind Energy Council, http://www.gwec.net/global-figures/graphs/, accessed 8 May 2013.

[319] IAEA. "Power Reactor Information System" (PRIS), International Atomic Energy Agency. The IAEA figure has been adjusted by removing from the figures of the 6 remaining reactors at two Fukushima power plants in Japan, which we consider will not be restarted. But includes uprates according to PRIS.

Figure 19: Nuclear, Wind and Solar Capacity Increases in the World 2000-2012 (MW)



Source: IAEA-PRIS, BP, 2013

Electricity Generation

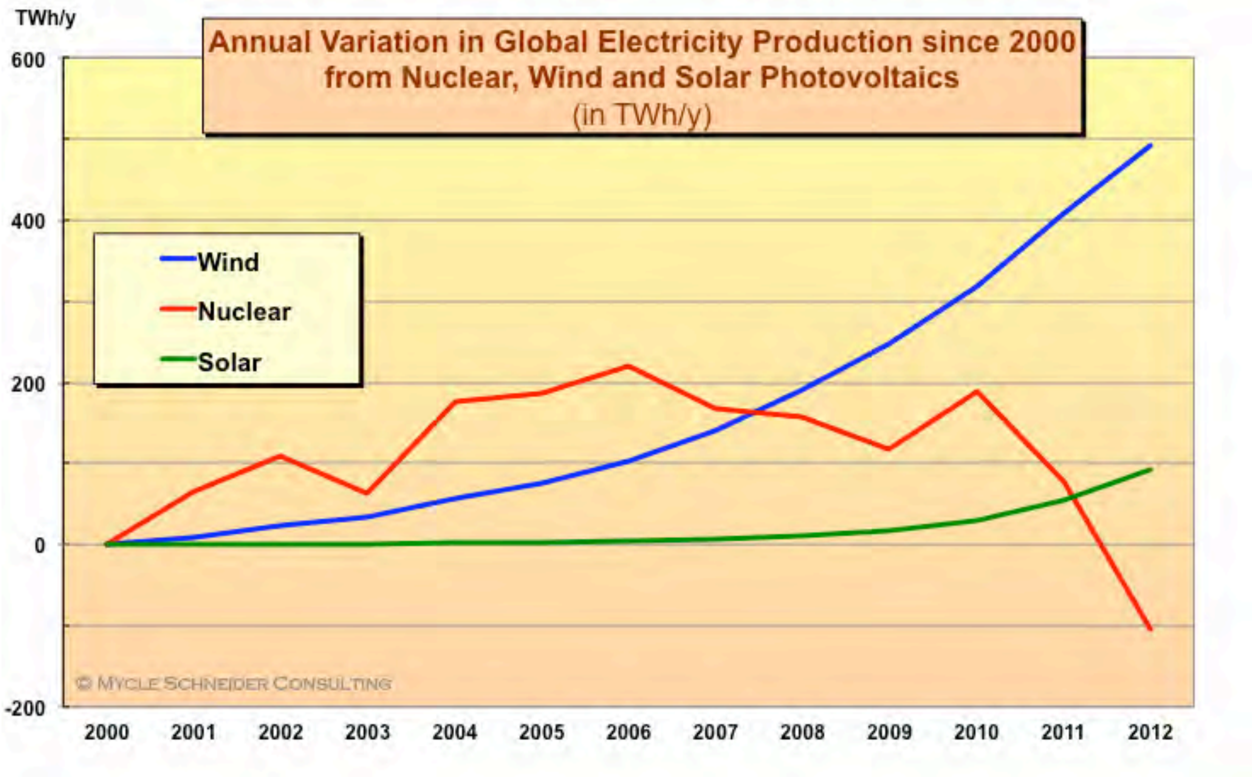
Skeptics of renewable energy highlight the variable output of some technologies (windpower and photovoltaics—but not all solar power, since solar-thermal-electric plants typically have built-in heat storage so they can run into or through the night). A consequence of variability is the lower output per installed MW over the year than that of traditional fossil-fueled or nuclear power stations. In fact, obviously no power plant operates continually. Most nuclear plants have experienced extended unplanned shutdown periods, many exceeding a year. Despite their specific variable characteristics, wind and photovoltaic power are now becoming significant, both nationally and globally.

The continual deployment of modern renewable energy is reducing dependency on fossil fuels and reducing importers' security-of-supply concerns. Furthermore, the development of renewables is helping to reduce greenhouse gas emissions. According to the IEA, positive progress has been made on the deployment of renewables, which are broadly on target to make the necessary contribution to meet the two-Celsius-degree target set by the UNFCCC in the Cancún Agreement[320]. In particular onshore wind is now able to compete "without special support in electricity markets endowed with

[320] At the United Nations climate change conference in Cancún, Mexico, in December 2010, delegates agreed that "climate change is one of the greatest challenges of our time and that all Parties share a vision for long-term cooperative action." For the first time under the U.N. climate framework, participants acknowledged that "deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2°C above pre-industrial levels." - United Nations Framework Convention on Climate Change, "Outcome of the Work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention," Draft decision, COP 16 (Cancún, Mexico: 2010), at http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf.

steady winds and supportive regulatory framework".[321] On the other hand, the IEA notes that nuclear power is "below levels required to achieve the 2 degree scenario objectives. In addition, increasing public opposition could make government ambitions for nuclear power's contribution to their energy supply harder to achieve".

Figure 20: Annual Variation in Global Electricity Production from Nuclear and Selected Renewables (TWh/y)



Source: BP 2013

China, EU, Germany, U.S.

In **China**, electricity demand has grown remarkably over the last decade, and as a result between 2000 and 2010 coal, which is by far the dominant source, increased its installed power capacity by around 460 GW—twice the total coal capacity currently in the EU.

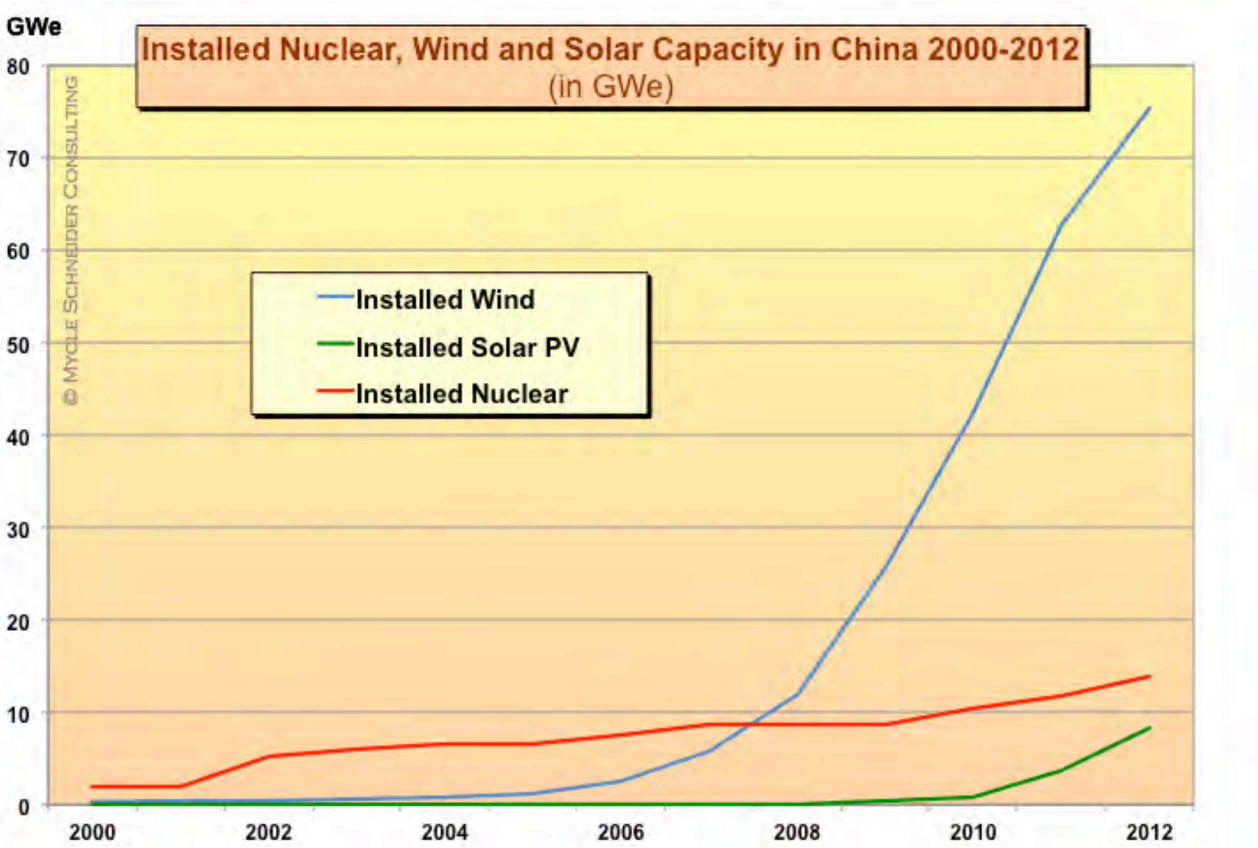
While China is reknowned for its use of coal, half the world's total, it has also become the world's leading producer and deployer of renewable energy. As can be seen in Figure 22, wind power has had a phenominal growth rate over the past decade, going from an installed capacity of less than 6 GW in 2007 to over 75 GW in 2012. Furthermore, it is not only in installed capacity that wind has achieved record increases; its corresponding electricity production is also impressive. In fact, in 2012 wind overtook nuclear power for the first time for the total amount of electricity produced in China. Overall in 2012, China increased electricity production by 5.5 percent, of which the use of nuclear energy increased by 12.6 percent, wind power by 35 percent, and solar PV by 400 percent[322]. What was also remarkable in 2012 was the extent to which the expansion of wind power was even larger than that of coal. As thermal power use, nearly synonymous with coal, grew by only about 0.3 percent in China during 2012, an addition of roughly 12 terawatt hours (TWh) more electricity, wind power production

[321] IEA, "Tracking Clean Energy Progress – Energy Technology Perspectives 2012 excerpt as IEA input to the Clean Energy Ministerial", International Energy Agency, April 2013

[322] CEC "2012 China's Power Industry Overview, China Electricity Council", 22 February 2013, http://www.cec.org.cn/; and REN21, "Renewables 2013 – Global Status Report", June 2013, see http://www.ren21.net/REN21Activities/GlobalStatusReport.aspx.

expanded by about 26 TWh[323]. In other words, in 2012 China increased electricity production more than twice as much (in absolute terms) from wind alone as from coal or nuclear power. In India, too, modern renewable energy sources (wind, solar, biomass) generated 51.2 TWh during the fiscal year 2011-2012[324], about 5.5% of the total electricity generated in the country, as compared to nuclear power that generated 3.5% of the total.[325] Preliminary estimates for 2012-13 are 6.4% of the total from renewable energy and 3.7% from nuclear energy.

Figure 21: Installed Capacity in China from Nuclear, Solar and Wind



Source: BP 2013, PRIS and GWEC

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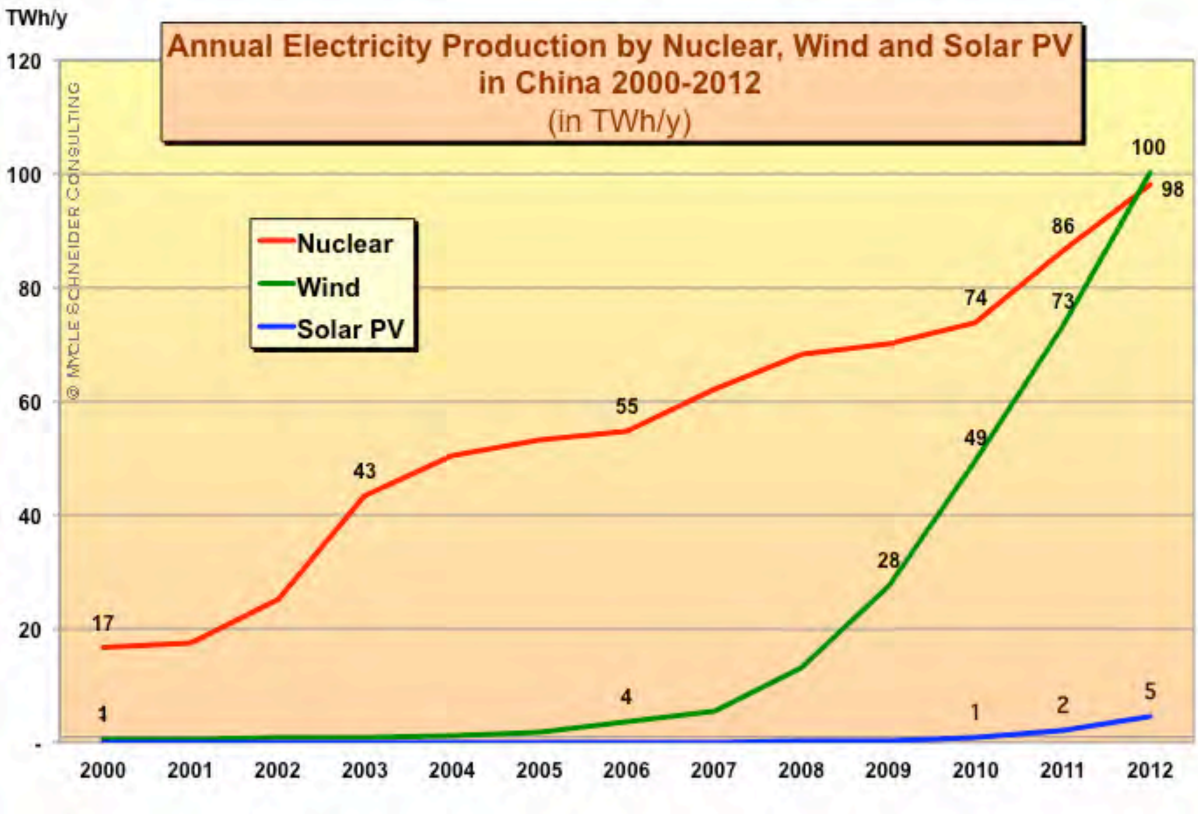
[323] Shua, L. "China's Wind Power Production Increased More Than Coal Power Did for the First Time Ever in 2012", blog on Thinkprogress.org, 20 March 2013.

[324] 1 April 2011 to 31 March 2012.

[325] These figures are approximate though they clearly capture the current and emerging picture. Different agencies in India seem to report different figures and no single agency reports total electricity generation from renewables, nuclear, and all sources. There are slight discrepancies in the figures reported for each of these quantities. The figures are from http://www.cea.nic.in/executive_summary.html and http://www.cea.nic.in/reports/articles/god/renewable_energy.pdf and http://pib.nic.in/newsite/pmreleases.aspx?mincode=28, accessed 7 July 2013.

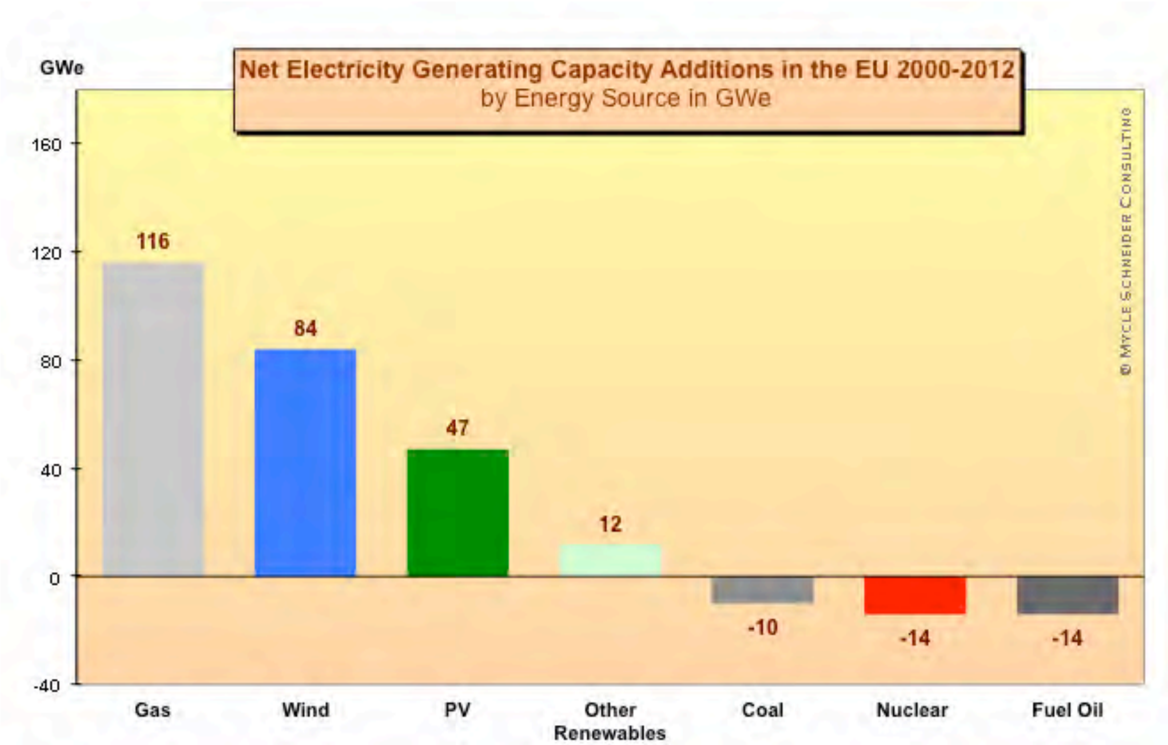
Figure 22: Annual Electricity Production in China from Nuclear, Wind and Solar



Source: BP 2013

In the **European Union**, the introduction and implementation of the renewable energy directive is leading to its greater use, rising from 7.9 percent in 2004 to 13 percent in 2011 for energy as a whole. In the electricity sector it is estimated that in 2012 renewables have contributed around 22 percent. This increase in production is likely to continue, as in 2012, 37 percent of the new power capacity added was solar PV and 27 percent of it was wind power[326]. Figure 23 shows the changes in generating capacity in the EU since 2000. In addition to the growth in renewable energy there has been an increased installation of gas power plants, in part due to their ability to "load follow" and therefore complement the more variable production from some renewables and in part to replace the closure of coal and nuclear plants as they reach the end of the operating lives or due to their early retirement on environmental or economic grounds.

Figure 23: Net Electricity Generating Installations in the EU 2000–2012 GW



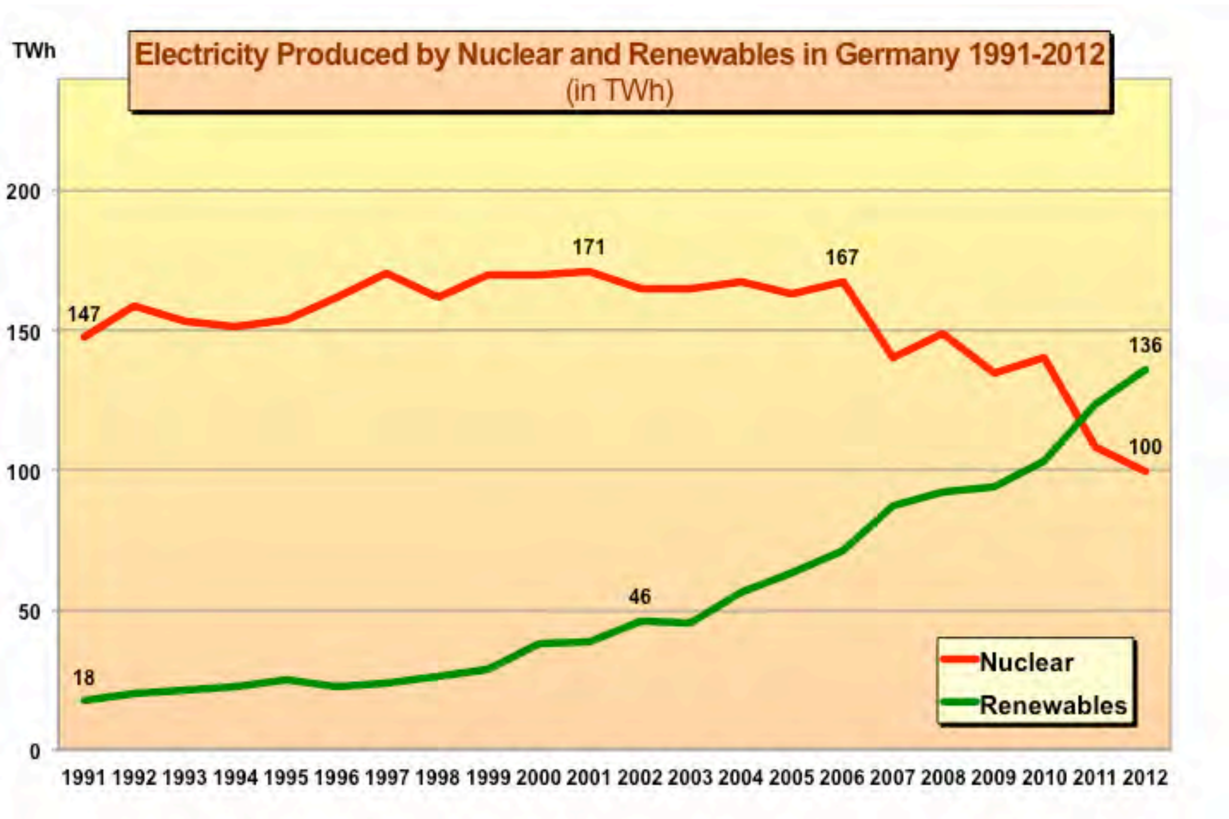
Source: EWEA 2013

[326] EWEA, "Wind in Power, 2012 European statistics", European Wind Energy Association, February 2013.

In 2012, the combined installed renewable electricity capacity in **Germany** reached 76 GW[327], that is far more than the available French nuclear capacity (63.1 GW). Of course, French nuclear plants generated 407 TWh, while German renewables generated "only" 136 TWh (gross) of electricity, compared to 100 TWh (gross) provided by German nuclear plants or the equivalent to one third of French nuclear power generation in 2012; but the German renewables growth rate remains very significant (+15.5 percent) while German nuclear generation dropped by 8 percent below 100 TWh for the first time in three decades and French nuclear generation dropped by 3 percent.[328]

Total renewables output represents now 23 percent of the German power generation, up from 3 percent in 1991. The growth rate in recent years has been particularly impressive in the solar power sector. Installed photovoltaic capacity increased by a factor of five since 2008 and solar power generation by a factor of over six to reach 28 TWh in 2012.

Figure 24: German Power Generation of Nuclear and Renewables



Sources: AGEB 2013

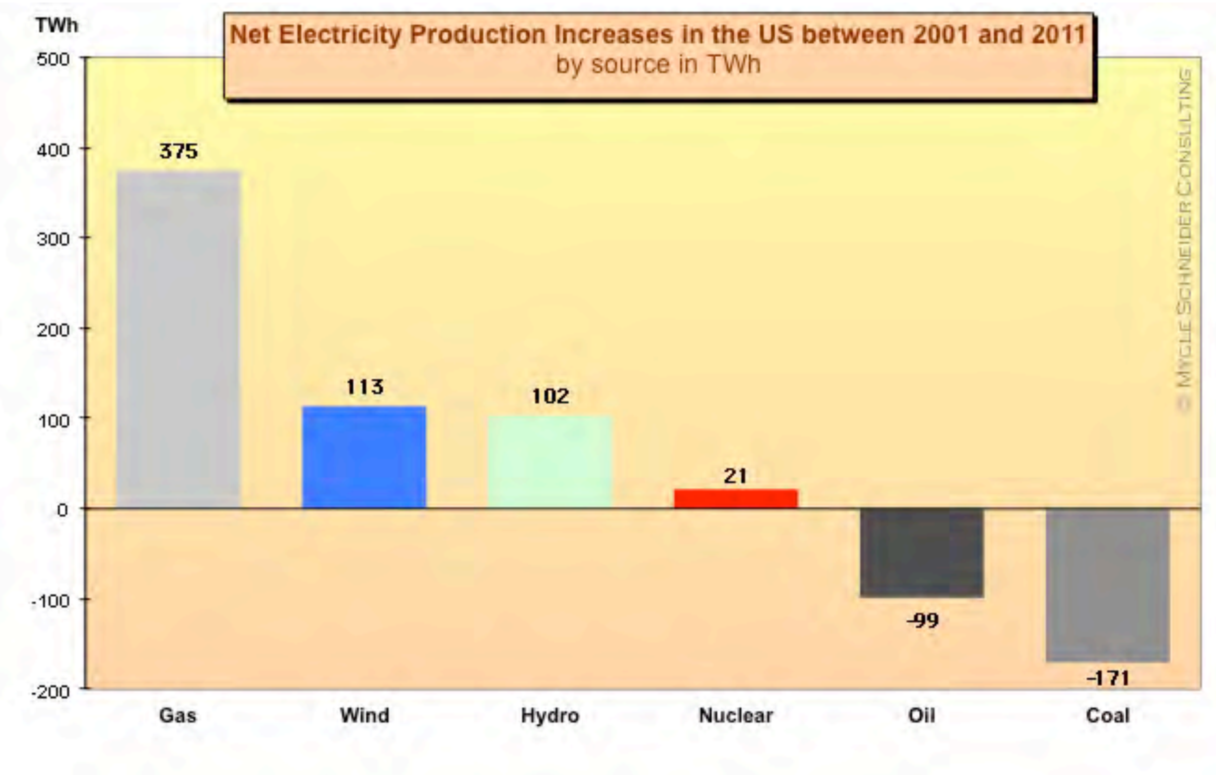
[327] Wind (31.3 GW) and solar plants (32.6 GW) represent 84 percent of the installed capacity; see BMU, "Daten des BMU sur Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2011 auf der Grundlage der Angaben der AGEE-Stat", provisional, 8 March 2012.

[328] French nuclear plants already generated more power in 2002 (415 TWh) than in 2012, while the German renewables tripled production over the same period from 46 to 136 TWh.

In the **United States**, much has been said about the importance of shale gas and how it has fundamentally changed the energy sector. As can be seen in the figure below, the output from gas fired power stations has increased by 374 TWh during 2002–2011, with the continuation of this trend expected in 2012. This is largely at the expense of coal, which saw a decline of 170 TWh in output, a decrease of 10 percent from 2001 and from petroleum fuels, which saw a drop of 90 percent to just 16 TWh. Over this period nuclear power's output increased slightly (by around 3 percent), due to the upgrading of a number of units. However, it is interesting to note that the combined increase in output from hydro power and wind is 60 percent of that of natural gas; the highest growth rate was for wind power, which increased its production from 6 TWh in 2011 to 120 TWh in 2011.

Furthermore, renewables are closing the gap on gas: in 2012, more wind capacity was added than any other generating source, including gas, with U.S. wind capacity rising by 13 GW to a total of more than 60 GW. The annual investment during 2008–2012 is now $18 billion, reaching $25 billion in 2012[329]. The dominance of renewables has continued in the first quarter of 2013 with renewable energy sources (biomass, geothermal, solar, water, wind) accounting for 84 percent of all new domestic electrical generating capacity.[330] Indeed, in the first quarter of 2013, nearly half of total new U.S. utility capacity additions was solar photovoltaics.

Figure 25: Increases in Electricity Production in the U.S. between 2001 and 2011



Source: U.S. EIA 2013

Future Costs

The need to move away from a global energy sector dependent on the use of unabated fossil fuels is as urgent as ever. In May 2013, it was announced that global concentrations of CO_2 in the atmosphere had reached 400 parts per million.[331] While the trajectory of current emissions could, according to the IEA, result in attmospheric concentrations that might lead to global temperature increases of 6 degrees

[329] AWEA, "US Wind Industry Annual Market Report", American Wind Energy Association, 2013

[330] FERC, "Office of Energy Projects, Energy Infrastructure Update" for March 2013, Federal Energy Regulatory Commission.

[331] BBC, "Carbon Dioxide Passes Symbolic Mark", 10 May 2013

above pre-industrial levels. Therefore in order to try and avoid the most severe consequences of climate change, a rapid change in the direction of energy investment is required. As has been demonstrated in the previous parts of this section, nuclear investment and deployment has been outstripped by renewable energy.

A survey of the major power and utility sectors undertaken by PricewaterhouseCoopers in 2012 showed the extent to which these sectors now see renewables as a major competition. Of those surveyed the majority felt that renewables would be able to compete with 80 percent plus thinking onshore wind, biomass and all forms of solar will not need subsidies to compete by 2030. There is less confidence in offshore wind but, even so, 69 percent say it will be competitive by 2030. 66 percent also think marine energy will be competitive by 2030.[332]

On the basis of current conditions there is no reason to believe that this trend will change, and in fact it is likely to accelerate as the costs of renewable energy continue to fall, while as has been shown in the economics section, the costs of nuclear continue to rise. This extent of the changes between the two sectors is seen in Europe when comparing the situation of solar PV in Germany and nuclear power in the U.K.

In the U.K., as described in more detail in other parts of this report, the Government has been in negotiations with French utility EdF for a guaranteed price of electricity for a fixed period of time. The details of the protracted negotiations are confidential; press reports suggest that EdF is asking for a price guarantee of just under £100/MWh (€118/MWh) for a 40-year period. This electricity price is based on an estimated construction cost of £12 billion (€14 billion) for two EPR 1.6 GW reactors at Hinkley. As noted, EdF's estimated cost of an EPR nuclear reactor in 2006 was around €3 billion. This sharply contrasts with the rapid falls in the costs of PV and wind turbines in Germany. PV installation costs in particular have plunged by over 70 percent in seven years. Total installed costs for German photovoltaics around mid-2012 had reached half the typical U.S. levels, even though both countries source essentially the same equipment, and most German installations were small and midsize rooftop systems, while most U.S. installations were utility-scale groundmounted systems.

This changing unit cost is affecting the price guarantee requirements. The decreases in the German feed-in tariffs for renewables are such that at present the feed-in tariffs for newly installed arrays in Germany are dropping by 1.8 percentage points per month. As of 30 June 2013, the highest price (feed-in-tariff level) is 15.35 €c/kWh for the smallest rooftop arrays with the lowest PV price, dropping to 10.63 €c/kWh for the largest arrays. On the current rate of decline, by June 2014 the highest price is expected to be €c11.71/kWh. While the exact details of the proposed strike price for the Hinkley Point C reactor proposed in the U.K. have not been made public, it is suggested that the price will be fixed (excluding inflation) for potentially up to 40 years at around £95/MWh; this corresponds to around €c11.1/kWh.[333].

Thus as renewable costs continue their downward trajectory, the UK will be tied into a fixed guaranteed price for its electricity stretching over the next four decades. Not only will this have an impact on the domestic consumer but raises questions over the impact on the economic competitiveness of large-scale industrial users.

A recent study by Bloomberg New Energy Finance projects that by 2030, renewable energy investments will increase by 2.5 to 4.5 times, with the "most likely" scenario an annual expenditure of about $630 billion (in nominal terms). The study results suggest that "we are beyond the tipping point towards a cleaner energy future".[334]

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[332] PwC, (2012) "The shape of power to come, Investment, affordability and security in an energy-hungry world", the 12th PricewaterhouseCoopers Annual Global Power and Utilities Survey, 2012.

[333] Renewables International (2013), "Do the math!, The cost of German solar vs Nuclear", 16 May 2013

[334] HydroWorld.com, "Bloomberg: 70% of new global energy through 2030 will be renewable", 1 May 2013, see http://www.hydroworld.com/articles/2013/05/bloomberg--70--of-new-global-energy-through-2030-will-be-renewab.html, accessed 16 June 2013.

Annexes

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 July 2013) 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, provided in parentheses, 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*, May 2013, 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, which supplied 12.4 TWh or 5.1 percent of the country's electricity in 2012 (the historical maximum was 7.4 percent in 1989). The reactors are the only operating nuclear power plants on the African continent.

The state-owned South African utility Eskom launched an effort in 1998 to develop the Pebble Bed Modular Reactor (PBMR), a helium-cooled graphite-moderated reactor based on earlier German designs. What happened then has been summed up by the *Energy Economist* this way: "The project was running about 25 years behind its original schedule, the estimated cost of a demonstration plant had increased 30-fold and a design fit to submit to the regulator had still not been completed."[335] In September 2010, the Government "[dropped the] final curtain on PBMR," a few months after having terminated all public support.[336] Some $1.3 billion had been invested in the project, with more than 80 percent coming from the South African Government.[337]

The failure of the PBMR led Eskom to consider buying additional large Pressurized Water Reactors (PWR). In the longer term, it planned to build 20 gigawatts (GW) of nuclear plants by 2025. However, in addition to escalating cost projections, Eskom faced a challenge of a falling credit rating, reduced by Moody's in August 2008 to Baa2, the second-worst investment grade. In November 2008, Eskom scrapped an international tender because the scale of investment was too high.

In February 2012 the Department of Energy published a Revised Strategic Plan that still contained a 9.6 GW target, or six units for nuclear power by 2030. Startup would be one unit every 18 months beginning in 2022.[338] The South African Government has repeatedly reiterated the 2030 target and Deputy President Kgalema Motlanthe stated, most recently at the "Nuclear Africa 2013" conference, that the country "will continue to develop and promote nuclear energy".[339] However, he also noted:

[335] Energy Economist, "Prospects for nuclear power in 2012", Platts, March 2012.

[336] "Government Drops Final Curtain on PBMR," *World Nuclear News* (WNN), 20 September 2010. The company PBMR, which in September 2010 still claimed on its website that "the South-African project is on schedule to be the first commercial scale HTR in the power generation field," later fired all but nine staff, went into "care and maintenance" mode to safeguard intellectual property, and shut down its website for good.

[337] For an independent historical account of the PBMR, see David Fig, *Nuclear Energy Rethink? The Rise and Demise of South-Africa's Pebble Bed Modular Reactor*, ISS Paper 210 (Pretoria: Institute for Security Studies, April 2010).

[338] DOE, "Revised Strategic Plan – 2011/120-02015/16", February 2012.

[339] Engineering News, "SA looks nearly set to start new nuclear power station build programme", 5 April 2013, see http://www.engineeringnews.co.za/article/sa-looks-nearly-set-to-start-new-nuclear-power-station-building-programme-2013-04-05, accessed 28 April 2013.

"Admittedly, the use of nuclear energy to mitigate greenhouse gases remains controversial. We remain committed to invest in clean energy from multiple sources."

While government support for nuclear power seems little influenced by the events in Fukushima, the construction industry warns that current projects are running late and over budget. Mile Sofijanic, Managing Director at Concor Engineering: "If we follow the trend, could the NPP programme cost, not R300-billion [USD33bn], but R750-billion [USD82bn]? That is not acceptable!"[340] One of the issues identified by Sofijanic: "We have a lack of skills. That is factually correct."

Russia's Rosatom has high hopes for South Africa and offered a full package including extensive human capacity-building and progressive increase of local input. "Localisation will at the initial stage of the project be at 30 percent of production, which will eventually peak at 65 percent", for units seven and eight, said Alexander Kirillov, head of Rosatom's marketing office in South Africa.[341] Apparently, Russia's President Vladimir Putin told his South African counterpart in March 2013 that they would "offer(ed) different funding options" for the nuclear new-build programme, should a Russian bid be chosen.[342]

In June 2012, the Energy Minister stated that Government would make a decision on its nuclear future by the end of the year.[343] By March 2013, the prospects were dim to get to the point even a year later, according to trade journal *Nuclear Intelligence Weekly*:

> South Africa's latest budget seems to leave little room for optimism for those hoping that the government will decide this year to go forward with its proposed 9.6 GW of new nuclear power. The government allocated 709.9 million rand ($78.4 million) for nuclear-related programs and subsidies, less than half the 1.623 billion it allocated for clean energy programs and subsidies.[344]

This may reflect a long-awaited shift towards faster, simpler, lower-cost options. Anton Eberhard, a professor at the University of Cape Town's Graduate School of Business and a member of the National Planning Commission, concluded from recent modelling:

> South Africa can achieve electricity supply security without investing in further nuclear power. Alternative power sources are cheaper and they can also help us achieve our Copenhagen pledges to reduce carbon emissions.[345]

Eberhard also stressed that the Independent Power Producers (IPP) renewable energy procurement program was "highly successful" and "raised R47bn [USD5bn] in its first round". Meanwhile, the Energy Minister's Statement in "response to the UN Secretary General's call for sustainable energy for all (SE4ALL)" does not contain the term "nuclear".[346]

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[340] Mile Sofijanic, Managing Director at Concor Engineering, quoted in Engineering News, "SA looks nearly set to start new nuclear power station build programme", 5 April 2013, see http://www.engineeringnews.co.za/article/sa-looks-nearly-set-to-start-new-nuclear-power-station-building-programme-2013-04-05, accessed 28 April 2013.

[341] ROSATOM, "ROSATOM to promote its nuclear technology on the South African market within the 5th BRICS Summit", 25 March 2013, see http://www.engineeringnews.co.za/article/sa-looks-nearly-set-to-start-new-nuclear-power-station-building-programme-2013-04-05, accessed 28 April 2013.

[342] Engineering News, "Moscow willing to finance SA nuclear plants if Russian bid prevails", 26 April 2013, see http://www.engineeringnews.co.za/article/moscow-willing-to-finance-sa-nuclear-plants-if-russian-bid-prevails-2013-04-26, accessed 28 April 2013.

[343] Business Report, "Nuclear plans ready by year end – Peters", Business Report, 5 June 2012.

[344] NIW, 8 March 2013.

[345] Business Day, "Nuclear power is neither necessary nor cost-effective", 19 March 2013; see http://www.bdlive.co.za/opinion/2013/03/19/nuclear-power-is-neither-necessary-nor-cost-effective, accessed 29 April 2013.

[346] Dipuo Peters, "Remarks by the Minister of Energy on Response to the UN Secretary General's call for sustainable energy for all (SE4ALL)", New York, 22 April 2013, see http://www.energy.gov.za/files/media/speeches/2013/RemarksByTheMinisterOfEnergySE4ALL_22042013.pdf, accessed 28 April 2013.

The Americas

Argentina operates two nuclear reactors that, as in 2011, provided 5.9 TWh or 4.7 percent of the country's electricity in 2012 (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. (An advisor to President Galtieri once said at a press conference that his country had even built a duplicate, unsafeguarded, reprocessing plant. Argentina also reopened its uranium enrichment plant in 2010, and was revealed on 1 July 2013[347] to have exported 80–100 tons of uranium oxide to Israel, presumably for its nuclear weapons program.) Nevertheless, the two nuclear plants were supplied by foreign reactor builders: Atucha-1, which started operation in 1974, was supplied by Siemens, and the CANDU type reactor at Embalse, which was supplied by the Canadian 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 operate for potentially 25 more years.[348] Reportedly, contracts worth $440 million were signed in August 2011 with the main work to start by November 2013. Work is expected to take five years at a total cost of $1.37 billion.[349]

Atucha-2 is officially listed as "under construction" since 1981. In 2004, the IAEA estimated that the start-up of Atucha-2 would occur in 2005. Since then, the IAEA has kept adjusting the expected "first grid connection" date, which, as of 6 July 2013 is still given as 1 July 2013, exactly 32 years after construction start. In June 2013, the Government announced that the project would be completed within two months.[350] That date came and went. The President "pre-started" the plant in a 2011 "inauguration" ceremony, but it apparently remains under construction two years later.

The presidents of Argentina and Brazil, Fernández de Kirchner and Lula da Silva-whose countries had long been potential military nuclear rivals-, met in February 2008 and agreed to "develop a program of peaceful nuclear cooperation that will serve as [an] example in this world."[351] In early May 2009, Julio de Vido, Argentina's Minister of Planning and Public Works, stated that planning for a fourth nuclear reactor would be under way and that construction could start as early as within one year.[352] It did not. Neither a siting decision, nor a call for tender, has been reported to date.

After repeated delays construction of a prototype 27 MWe PWR, the domestically designed and built CAREM25 (a type of pressurized-water Small Modular Reactor with the steam generators inside the pressure vessel), was scheduled to begin in the first half of 2013 (but was not reported) near the Atucha site with fuel loading planned for the second half of 2017.[353]

The Argentinian public's opposition to nuclear power was only reinforced by Fukushima. In a September 2012 update of a 24-country IPSOS study, 71 percent of the Argentinians polled opposed nuclear new-build, a score just below Italians, Germans and Mexicans.[354]

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[347] W. Burr & A. Cohen, "Israel's Secret Uranium Buy," *Foreign Policy*, 1 July 2013, www.foreignpolicy.com/articles/2013/07/01/israels_secret_uranium_buy

[348] "Argentina's Embalse Nuclear Plant to Get 25-year Extension," PowerGenWorldwide.com, 5 August 2010.

[349] Research and Markets, "Nuclear Power Market in Argentina", May 2012.

[350] iEco, "Prometen que en dos meses inaugurarán Atucha II", 27 June 2013.

[351] "Argentina and Brazil Team Up for Nuclear," *WNN*, 25 February 2008. Both countries have a long way to go to make their programs exemplary. Their industrial as well as their non-proliferation record has been far from convincing.

[352] "Argentina to Reinforce Nuclear Energy by Adding 700 MW and Building Fourth Nuclear Plant," Marketwire.com, 7 May 2009.

[353] CNEA, "Proyecto 'CAREM'", undated, see http://www.cnea.gov.ar/proyectos/carem/cronograma/cronograma.php, accessed 1 May 2013.

[354] IPSOS 2012, op.cit.

Brazil operates two nuclear reactors that provided the country with 15.2 TWh (the historic maximum) or 3.1 percent of its electricity in 2012 (down from a maximum of 4.3 percent in 2001). The record electricity generation, which still contributes only modestly to the power supply in the country, is due to an excellent load factor of 91 percent (+5 percent compared to 2011, 28 percent better than the lifetime load factor).

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 covered by the program, Angra-2, was finally connected to the grid in July 2000, 24 years after construction started.

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 indicated that a "new" construction start occurred on 1 June 2010. In early 2011, the Brazilian national development bank BNDES approved 6.1 billion Reias ($3.6 billion) for work on the reactor, mainly to be carried out by AREVA.[355] The IAEA now envisages commercial operation for 1 January 2016. Other sources indicate "commissioning" planned for July 2016.[356]

In January 2011, Brazil's Energy Minister Edison Lobao stated that the Government planned to approve the construction of four additional reactors "this year."[357] Right after 3/11, Lobao assured: "We have no need to revise anything, except for learning from what happened in Japan, and taking a look at future proceedings."[358] 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 Marcio Zimmermann stated. "Demand is met with hydro-electrical power and complementary energy sources such as wind, thermal and natural gas." According to press agency AFP, the official also announced that over the coming decade the level of renewable energy would double from 8 to 16 percent.[359]

Public opinion is still helping the government to look for other solutions than nuclear. In the IPSOS's updated 24-country study support for nuclear energy increased by 10 percent but 63 percent of the population polled remain opposed to nuclear energy in general.[360]

Canada operates 19 reactors, all of which are CANDU (CANadian Deuterium Uranium), providing 90 TWh or 15.3 percent of the country's electricity in 2012 (identical to 2011, down from a maximum of 19.1 percent in 1994). Two reactors have been restarted in 2012 after 15 and 17 years shutdown periods. On 28 December 2012, Gentilly-2, Québec's only remaining nuclear reactor, was closed.

There have been significant delays in restarting six of originally eight reactors in long-term-shutdown (LTS). In December 2012, the LTS status of the two 40-year old Pickering-2 and -3 was "retroactively

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

356 NIW, "Potential and Existing Global Nuclear Newbuild Projects Open to International Vendors", 15 March 2013.

357 "Brazil to Approve Construction of Four Nuclear Power Plants in 2011," www.neimagazine.com, 10 January 2011.

358 Buenos Aires Herald, "Brazil to continue nuclear energy investments despite Japan crisis", 15 March 2012; see http://www.buenosairesherald.com/article/61644/-brazil-to-continue-nuclear-energy-investments-despite-japan-crisis, accessed, 25 May 2012.

359 WNISR, "Brazil Abandons New Build Plans", 11 May 2012, see http://www.worldnuclearreport.org/Brazil-Abandons-New-Build-Plans.

360 IPSOS 2012, op.cit.

changed to Permanent Shutdown" in May 2007 and October 2008 respectively. In January 2010, operator Ontario Power Generation (OPG, Ex-Ontario Hydro) requested a five-year license renewal for the four Pickering-1 to -4[361] reactors, but in July 2010 the Canadian Nuclear Safety Commission (CNSC) decided to limit the license to three years. For all remaining six Pickering units, the licenses expired on 30 June 2013.[362] However, these licenses were extended for two months (to August 2013) in late June 2013.[363] The two other units that had been in long-term shutdown, Bruce-1 and -2, were reconnected to the grid on 19 September and 16 October 2012 respectively.

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 Licence" for the Darlington project, "a first in over a quarter century".[364] The next step in the licensing procedure is the submission by OPC of an application for a construction license that will undergo full public hearings.

The province of New Brunswick has abandoned the option of adding a second nuclear reactor at its Point Lepreau site; meanwhile, a massive refurbishment project on the first unit was CAD1 billion over its CAD1.4 billion budget and three years behind schedule. The unit was shut down in April 2008 and was restarted on 26 October 2012.[365]

In June 2011, the Canadian Government sold the commercial reactor division of Atomic Energy of Canada (AECL) to CANDU Energy, a wholly owned subsidiary of engineering company SNC Lavalin for CAD15 million plus royalty payments from potential future new-build and refurbishment projects. There is no assurance that such projects will materalize.

In **Mexico,** two General Electric 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 2012, nuclear power produced 8.4 TWh or 4.7 percent of the country's electricity (down from a maximum of 6.5 percent in 1995). An uprating project carried out by Iberdrola between 2007 and early 2011 boosted the nameplate capacity of both units by 20 percent to reach 765 megawatts (MW) each. However, work continued until February 2013 while the plant remained officially in operation but the average load-factor of the two reactors plunged from 84 percent in 2011 to 64 percent in 2012. The power plant is owned and operated by the Federal Electricity Commission (Comisión Federal de Electricidad).

In March 2012, former Energy Minister Jordy Herrera stated: "We have to put the option of building and expanding our nuclear plants on the table".[366] His successor, Pedro Joaquín Coldwell, who was appointed in November 2012, in a speech to a recent OECD conference, stressed the "extraordinary potential" of Mexico's energy industry, "particularly in the renewable and fossil fuels sectors".[367] He did not mention nuclear power at all.

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[361] Also called Pickering A reactors

[362] NEI, "Pickering A Gets 3-year Licence Extension," www.neimagazine.com, 2 July 2010.

[363] CNSC, "CNSC Extends Operating Licences for Pickering A and B Nuclear Generating Stations, 24 June 2013, see http://www.suretenucleaire.gc.ca/eng/mediacentre/releases/news_release.cfm?news_release_id=462, accessed 24 June 2013.

[364] OPG, "Joint Review Panel issues Licence to Prepare Site", 17 August 2012, see http://www.opg.com/nb/index3.asp, accessed 8 May 2013.

[365] WNISR, "Canadian Nuclear Power at Full Capacity for the First Time in Nearly Two Decades", 28 October 2012, see http://www.worldnuclearreport.org/Canadian-Nuclear-Power-at-Full.html.

[366] NIW, "Lame Duck Energy Minister Proposes More Nuclear Power", 16 March 2012.

[367] Pedro Joaquín Coldwell, Mexico's Energy Ministry, Presentation in the panel "Efficient Energy Policy", at the Mexico Forum 2013, organized by the OECD, 9 January 2013, see http://www.energia.gob.mx/portal/Default.aspx?id=2363, accessed 9 May 2013.

Also, public opinion remains a major headache for the nuclear industry in the country with 74 percent opposing nuclear power in general, according to a September 2012 update of an IPSOS 24-country survey.[368]

United States

The **United States** has more operating nuclear power plants than any other country in the world, with 100 commercial reactors currently operating. This is the lowest number of operating reactors since Chernobyl year 1986. The highest number with 108 operating units was reached in 1990.[369] Four units were closed in the first half of 2013, the first time reactors were shut down since 1998.

The U.S. reactor fleet provided 770.7 TWh in 2012, a 2.5 percent drop over the previous year and 4.5 percent less than in the record year 2010. The average load factor dropped by over 3 percent to 83.2 percent compared to 2011.

The production decline is partially attributed to extended outages of four units that were down most of the year and to a higher level of refueling outages. In 2010, only 49 units were refueled. There have been only three other times since 1995 that fewer than 60 units refueled during a given year (2001, 2004, 2007).[370] Nuclear plants provided 19 percent of U.S. electricity in 2012 (down from a maximum of 22.5 percent in 1995).

First Reactor Closures in 15 Years

In February 2013, nuclear operator Progress Energy, now owned by Duke Energy, decided not to complete repairs and uprating of its 36-year old Crystal River reactor that had been offline since late 2009. This was the first plant closure in the U.S. since 1998. The 825 MWe PWR in Florida had been shut down for regular refueling, maintenance and steam generator replacement when significant deterioration (delamination or cracks) in the concrete containment was identified. Repair was evaluated as a possible option but by 2012 it was concluded that the "nature and potential scope of repairs brought increased risks that could raise the cost dramatically and extend the schedule".[371] Trade journal *Nucleonics Week* reported that costs of repairing the containment could have ranged between $1.5 billion and "the worst case", new walls and dome, $3.4 billion.[372] Work could have stretched between 35 months and 96 months, it was estimated. Under those conditions, Duke Energy's CEO Jim Rogers concluded: "We believe the decision to retire the nuclear plant is in the best overall interests of our customers, investors, the state of Florida and our company."[373] Duke Energy intends to put the plant into safe enclosure (SAFSTOR) in order to fully decommission it in 40-60 years.

On 7 May 2013, the second shutdown decision in 15 years in the U.S. led to the permanent closure of the Kewaunee nuclear power plant in Wisconsin. The plant owner Dominion, "one of the nation's largest producers and transporters of energy"[374] had intended to sell the facility but failed to identify a buyer. The 39-year old 566 MWe single unit reactor was first connected to the grid on 8 April 1974. The decision is particularly remarkable because "despite its operating license being extended for a further 20 years until 2033, no buyer was found", as the nuclear lobby publication *World Nuclear*

[368] IPSOS, op.cit.

[369] Some statistics indicate 111 units as the maximum. This is because 3 additional units were in long-term-shutdown for many years, which we do not count here as "in operation" in 1990. They were restarted in 1991, 1995 and 2007. The 108 number was reached also in 1991, 1995 and 1996.

[370] Nucleonics Week, "Fewer US units to refuel this year than in 2012", 10 January 2013.

[371] Duke Energy, "Crystal River Nuclear Plant to be retired; company evaluating sites for potential new gas-fueled generation", 5 February 2013, see http://www.duke-energy.com/news/releases/2013020501.asp, accessed 10 May 2013.

[372] Nucleonics Week, "Decision to repair or retire Crystal River-3 may come in spring", 10 January 2013.

[373] Duke Energy, op.cit.

[374] Self-presentation on the Dominion website, see https://www.dom.com/about/index.jsp, accessed 23 June 2013.

News (WNN) notes.[375] Indeed, the NRC had issued a lifetime extension only in February 2011[376]. Dominion had bought Kewaunee in July 2005. Dominion has stated in the past that the decommissioning fund of $392 million, transferred when it purchased the plant, would be sufficient to cover the costs. However, as in the case of Crystal River, the reactor will be placed in SAFSTOR.

On 7 June 2013 Southern California Edison (SCE) announced that despite spending over $500 million on repairs and replacement power it would permanently close units 2 and 3 at the San Onofre Nuclear Generating Station (SONGS) after losing a 16 month battle to restart. Unit 1 at the station was closed in 1992. Californian Senator Barbara Boxer, Chairman of the Environment and Public Works Committee, said of the decision: "This nuclear plant had a defective redesign and could no longer operate as intended. Modifications to the San Onofre nuclear plant were unsafe and posed a danger to the eight million people living within 50 miles of the plant".[377] When announcing the closure Ron Litzinger, SCE's President said: "We think that our decision to retire the units will eliminate uncertainty and facilitate orderly planning for California's energy future."[378]

Aging Reactor Fleet

The last reactor in the US to be completed—in 1996—was Watts Bar-1, near Spring City, Tennessee. In October 2007 the Tennessee Valley Authority (TVA) announced that it had chosen to complete the two-thirds-built 1.2 GW Watts Bar-2 reactor.[379] Questions persist about whether this will prove feasible, let alone economic. Questions persist about whether this will prove feasible, let alone economic.

The lack of new reactor startups leads to the continuous aging of the fleet. Average age stands at 33.4 years (as of May 2013), amongst the highest in the world, with 22 units—every fifth reactor—operating for at least 40 years (up to 44 years). Projects are being developed and implemented to allow reactors to operate for potentially up to 60 years. As of June 2013, 72 of the 100 operating U.S. units have received an extension, another 18 applications are under review by the NRC, and 9 have submitted letters of intent covering a period up to 2019.[380]

First Construction Starts in 35 Years

The George W. Bush administration's National Energy Policy set a target of two new reactors to be built by 2010, but this objective was not met. To reduce uncertainties about new construction, a two-stage license process was developed. Designs of reactors can first receive generic approval, then utilities need only seek a combined Construction and Operation License (COL) that does not involve questioning of the reactors' designs.

As of May 2013, the NRC had received 18 licensing applications for a total of 28 reactors. This situation did not change over the past year. (See detailed list in Annex 3 of WNISR 2012). All the applications were submitted between July 2007 and June 2009. Of the 28 reactor projects, eight were subsequently suspended indefinitely or cancelled and at least 16 were delayed.[381]

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375 WNN, "Kewaunee enters retirement", 7 May 2013, see http://www.world-nuclear-news.org/C-Kewaunee_enters_retirement-0705134.html, accessed 10 May 2013.
376 WNISR, "U.S. Nuclear Plant to Close After Failing to Attract a Buyer", 25 October 2012, http://www.worldnuclearreport.org/US-Nuclear-Plant-to-Close-After.html
377 NBC, "Socal Edison Retiring San Onofre Nuclear Generating Station", 7 June 2013, see http://www.nbcsandiego.com/news/local/San-Onofre-Nuclear-Plant-Closing-Retiring-SONGS-Oceanside-Reactor-210565761.html#ixzz2VY1EBvlb, accessed 6 July 2013.
378 ENS-Newswire, "California's Damaged San Onofre Nuclear Plant to Be Retired", 7 June 2013, see http://ens-newswire.com/2013/06/07/californias-damaged-san-onofre-nuclear-plant-to-be-retired/, accessed 6 July 2013.
379 For details, see section on Watts Bar-2 in chapter "Unfulfilled Promises" in WNISR-2012, http://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-54.html#unpro.
380 U.S. Nuclear Regulatory Commission (NRC), "Status of License Renewal Applications and Industry Activities", see www.nrc.gov/reactors/operating/licensing/renewal/applications.html, accessed 9 May 2013.
381 USNRC, "Combined License Applications for New Reactors", see

On 9 February 2012, for the first time in nearly three and a half decades, the NRC granted a COL for Vogtle-3 and -4 units in Georgia. On 30 March 2012, South Carolina Electric & Gas (SCE&G) received the second COL for units 2 and 3 at its Summer site. In an unprecedented move, Gregory B. Jaczko, then Chairman of the NRC, voted against the opinion of the four other Commissioners, stating that the decision was being taken "as if Fukushima never happened".[382] Jaczko subsequently resigned from his NRC position and is currently writing a book about his experience.

SCANA Corporation, owner of SCE&G, announced the official construction start of the Virgil C. Summer Unit 2 on 11 March 2013, the second anniversary of the Fukushima disaster. On 15 March 2013, first concrete was poured for Vogtle-3. These were the first time in 40 years that a reactor project was started that was subsequently connected to the grid – if indeed that ultimately occurs.

As of May 2013, the NRC had granted four Early Site Permits (ESP) and received two additional applications that are under review.[383] This situation has not evolved over the past two years. ESPs are independent of the construction/operating license.[384] Only the Vogtle project has received an ESP, a COL *and* a certified design at this stage. The Summer reactors, which received the only other COL and were to start up in 2016 and 2017, have been experiencing repeated delays. Both projects, Summer and Vogtle, "face significant challenges in maintaining the project forecast at or below" budget, the monitor stated.[385] The *Economist* recently reported that Vogtle is "now perhaps 18 months behind schedule and $737 million over budget. That does not include a further $900 million that is the subject of legal dispute, plus the extra financing costs that will come with these overruns."[386]

New-build Projects in Trouble

By the end of 2008, nuclear utilities had applied for $122 billion in loan guarantees, and in May 2009 the DOE short-listed four companies for the first group of loan guarantees:

- Southern Nuclear Operating Co. for the two AP1000s at the Vogtle nuclear power plant;
- South Carolina Electric & Gas for two AP1000s at the Summer site;
- NRG Energy for two ABWRs at the South Texas Project site in Texas and
- Constellation for one EPR at the Calvert Cliffs site in Maryland.

By then, the limit for coverage of loan guarantees had been increased from 80 percent of the debt to 80 percent of the total cost. In February 2010, Southern's Vogtle project was the first to have been awarded a conditional loan guarantee ($8.3 billion) for a nuclear power plant project worth an estimated $14 billion. The reactors were supposed to start operating by 2016 and 2017. As stated above, the first units at the Vogtle and Summer sites are now under construction.

The other two projects are in trouble. Constellation Energy abandoned the application for a loan guarantee for the Calvert Cliffs-3 project after discovering a "shockingly high estimate of the credit subsidy cost" (11.6 percent or $880 million)-a fee legally required to recompense taxpayers for the fair market value of the risk they would undertake by issuing the guarantee.[387] Constellation has since been absorbed by Exelon, and on 1 November 2012, the NRC issued an order terminating the adjudicatory

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http://www.nrc.gov/reactors/new-reactors/col.html, accessed 9 May 2013.

[382] MSNBC, "U.S. licenses first nuclear reactors since 1978", 9 February 2012.

[383] ESP granted: Clinton (Exelon), Grand Gulf (SERI), North Anna (Dominion), Vogtle (Southern). ESP under review Victoria County Station (Exelon), PSEG Site (PSEG).

[384] NRC, "Early Site Permit Applications for New Reactors," see www.nrc.gov/reactors/new-reactors/esp.html, accessed 23 June 2013.

[385] Bloomberg, "Southern's Nuclear Reactors May Be Delayed, Monitor Says", 1 June 2012.

[386] Economist, "Nuclear power – Fracked off", 1 June 2013, see http://www.economist.com/news/united-states/21578690-thanks-cheap-natural-gas-americas-nuclear-renaissance-hold-fracked, accessed, 2 June 2013.

[387] Michael J. Wallace, Chairman of Constellation Energy Nuclear Group, letter to Dan Poneman, DOE, 8 October 2010.

proceeding on the combined license application for Calvert Cliffs 3.[388] On 30 August 2012, the NRC had given French state utility EDF 60 days to find a U.S. based partner for the project to build an EPR at the Calvert Cliffs site in Maryland. Majority ownership, control or domination of a nuclear power plant by a foreign entity is illegal in the U.S.[389] EDF failed to identify a new partner after Constellation had pulled out. EDF lost over $1 billion in this unsuccessful U.S. adventure.

The South Texas Project (STP) is facing the same problem as Calvert Cliffs 3. Nuclear merchant (unregulated) utility NRG, the majority shareholder announced in April 2011 that it was withdrawing from the project, writing down a $481 million investment and excluding any further investment. NRG CEO David Crane said that the Fukushima aftermath was "dramatically reducing the probability that STP 3 and 4 can be successfully developed in a timely fashion."[390] The proposal was to build two Advanced Boiling Water Reactors (ABWR) at STP, through a company called Nuclear Innovation North America (NINA). NINA was originally a joint venture between Toshiba American Nuclear Energy Corporation (TANE) and NRG. However, after NRG pulled out of the project and according to the NRC letter to NINA "that, although TANE owns about 10 percent of NINA, its overwhelming financial contributions give it significantly more power than is reflected by this ownership stake".[391] According to Brett Jarmer, an attorney for a coalition of groups opposing the license, "federal law is clear that foreign controlled corporations are not eligible to apply for a license to build and operate nuclear power plants. The evidence is that Toshiba is in control of the project and this precludes obtaining an NRC license for South Texas Project 3 & 4".[392] Considering the fate of the Calvert Cliffs project, it will be extremely difficult for Toshiba to identify a new U.S. investor.

In early May 2012, Progress Energy, later taken over by Duke Energy, announced that it was delaying its Levy project in Florida for two AP1000 reactors by three years to start-up the first unit in 2024 and the second 18 months later. The "shift in schedule will increase escalation and carrying costs and raise the total estimated project to between $19 and $24 billion", from a 2008 price tag of $17 billion, the company announced.[393] On 3 May 2013, Duke Energy announced that it had withdrawn the 1998 license request for the construction and operation of two 1000 MWe reactors at the Shearon Harris plant in North Carolina. The company informed the NRC that the plant was no longer needed due to sluggish demand growth forecasts. However, others contest the explanation and suggest that Duke have consistently exaggerated demand growth projections and that the changes in the energy market mean that utilities can no longer keep locking out competitors, especially rooftop solar.[394]

Gas prices in the U.S., due to the accelerated development on non-conventional gas, remain low and increase the uncertainty over the economics of building new nuclear plants. "Let me state unequivocally that I've never met a nuclear plant I didn't like," said John Rowe, former chairman and CEO of Exelon Corporation, the largest nuclear operator in the U.S. with 22 nuclear power plants. "Having said that, let me also state unequivocally that new ones don't make any sense right now."[395] One year after John Rowe's statement, renewables have spectacularly increased their role as a serious competitor in the power market. In the first three months of 2013, of the 1,546 MWe newly connected

[388] see WNISR, EDF's US Calvert Cliffs 3 Project "Terminated"

[389] see WNISR, Final Blow to EDF's US Adventure?

[390] WNN, "NRG Withdraws From Texan Project", 20 April 2011.

[391] WNN, "NINA falls foul of foreign ownership law", 1 May 2013, see http://www.world-nuclear-news.org/NN-NINA_falls_foul_of_foreign_ownership_law-0105137.html, accessed 6 July 2013.

[392] PR Newswire, "Foreign Ownership Could Halt Licensing Of South Texas Project Nuclear Reactors; NRC Says NINA Doesn't Meet Their Requirements", 1 May 2013

[393] WNN, "Levy nuclear project moved back by three years", 2 May 2012.

[394] NC Warn / Marketwatch.com, "Demise Of New Harris Nukes Is An Important Public Victory Towards A Clean Energy Revolution", 3 May 2013, http://www.marketwatch.com/story/demise-of-new-harris-nukes-is-an-important-public-victory-towards-a-clean-energy-revolution-2013-05-03, accessed 6 July 2013.

[395] Forbes, "Exelon's 'Nuclear Guy': No New Nukes", 29 March 2012.

to the U.S. grid, 82 percent were renewables (and 47 of the 82 percent was solar), the rest natural gas plants[396]—no coal, no nuclear (see also the section Nuclear vs. Renewables).

Public opposition has also been growing over the past year, according to a March 2012 poll by ORC International. While supporters of new-build stagnated at 46 percent, opponents increased their share from 44 to 49 percent. At the same time, people were split over lifetime extensions with 49 percent in favor and 47 percent opposed. On the other side, 77 percent of the respondents favor the shift of loan guarantees from nuclear to renewable energies.[397]

"The long-term outlook for nuclear generation depends on lifetime of existing capacity", is the title of an extract of the *Annual Energy Outlook 2013* of the U.S. Department of Energy (DOE).[398] The title suggests that even the long-term future of nuclear power is not mainly characterized by the number of new-build projects but by the longevity and number of surviving plants. The DOE has built four scenarios and concludes:

> Projected reliance on nuclear power in 2040 varies across cases, providing between 10% and 20% of projected total electricity generation with total capacity between 63 GW and 133 GW.

This compares with the current installed capacity of about 100 GW. In the Reference Case of its *Annual Energy Outlook 2013*, DOE projects an increase in installed nuclear capacity of about 19 GW to 2040, of which only 5.5 GW is new-build capacity and the rest would come from uprates. The DOE "assumes that the operating lives of most of the existing U.S. nuclear power plants will be extended at least through 2040".[399] Many of the plants would have passed 60-years of operation by then an astonishing assumption considering the characteristics of the recent Crystal River and Kewaunee closures. This assumes that such elderly plants will remain economic to run and to keep fixing when most of them have trouble competing today and when a need for major repairs is often a reason to shut them down immediately. Energy analyst Amory B. Lovins, analyzing recent industry operating-cost data, comes to the conclusion: "For economic or other reasons, the gradual phase-out of unprofitable nuclear power plants, already quietly under way, may accelerate."[400]

While the new U.S. Secretary of Energy Ernest Moniz is considered a supporter of nuclear power, as was his prececessor Steven Chu, Government support has remarkedly cooled off. In his February 2013 State of the Union speech to Congress, President Barack Obama "highlighted the potential for solar, wind and even natural gas – but nuclear power received not a single mention", complains the industry's *World Nuclear News*.[401] It has simply been overtaken in the marketplace.

Asia

China

China started construction of its first commercial reactor only in 1985, but its nuclear sector is developing fast, with 28 reactors under construction (40 percent of the world's total). However, despite this potentially large planned increase as of July 2013, China has only 18 reactors (14 GWe) in operation, which in 2012 provided 92.65 TWh or 2 percent of the country's electricity, the lowest

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[396] Kenneth Bossong, "Renewables Provide 82% of New US Electrical Generating Capacity in 1Q2013", see http://www.renewableenergyworld.com/rea/news/article/2013/04/renewables-provide-82-of-new-us-electrical-generating-capacity-in-1q2013, accessed 10 May 2013.

[397] ORC International, "One Year After Fukushima – American Attitudes About Nuclear Power", commissioned by Civil Society Institute, March 2012.

[398] USDOE-EIA, "The long-term outlook for nuclear generation depends on lifetime of existing capacity", 25 April 2013, see http://www.eia.gov/todayinenergy/detail.cfm?id=10991, accessed 10 May 2013.

[399] idem.

[400] Amory B. Lovins, "The economics of a US civilian nuclear phase-out", Bulletin of the Atomic Scientists, 1 March 2013, see http://bos.sagepub.com/content/69/2/44, accessed 12 May 2013.

[401] WNN, "Obama neglects nuclear in state of the union", 13 February 2013, see http://www.world-nuclear-news.org/EE-Obama_neglects_nuclear_in_state_of_the_union_130213a.html, accessed 17 May 2013.

nuclear share of any country. The maximum of 2.2 percent was reached 10 years ago in 2003. All of the units under construction are scheduled to come online before 2018 and would bring the total to 46 reactors (42 GWe).

During 2013 China plans to add 52 GW of non-fossil fueled generating capacity, comprising 21 GW of hydro, 18 GW of wind, 10 GW of solar and 3 GW of nuclear power[402]. By comparison the total fossil fueled capacity expected to be introduced in 2013 is 40 GW.[403] During the first six months of 2013, construction did not start on any new nuclear power plant. Thus non-hydro renewables are closing in on coal-fired plant construction, and their lines should cross shortly, as the government recently raised its 2015 PV installed-capacity target to an astonishing 40 GW to soak up surplus production capacity, mostly in China.

In 2010, a revision to the National Nuclear Power Middle and Long Term Development Plan 2005-2020, was under consideration in 2010, when some officials predicted that a likely target for 2020 would be 80 GW in operation together with a further 50 GW under construction.[404] However, in January 2011, the State Council Research Office (SCRO), which makes independent policy recommendations to the State Council, suggested that the 2020 target should be restricted to 70 GW of nuclear power in operation, with another 30 GW under construction, so as to ensure quality control in the supply chain. It cautioned against the launch of new Gen-II projects, and emphasized the need for a greater deployment of Gen-III+ projects, notably AP1000s, and that going too fast could threaten the long-term health of the sector.[405]

Safety concerns of the domestic designs were also highlighted in a cable from the U.S. embassy in Beijing from 2008, released by Wikileaks, which stated that the Gen-II CPR-1000 design were copies "of 60's era Westinghouse technology that can be built cheaply and quickly"[406] —so by the time some of those reactors reached the end of their lives, their design would be a century old. (To be sure, that characterization may have reflected eagerness to sell newer U.S. technologies instead.) Similar concerns have been expressed by Tange Zede a member of the State Nuclear Power Technology Corp (SNPTC) who reportedly said the CPR-1000 could not even meet the national safety standards issued in 2004, let alone the most up-to-date international standards. Zede stated that "unless, the constructed Gen-II reactors are renovated, they should not be allowed to load fuel and start operation"[407].

Furthermore, the SCRO report advised that since goals to increase the localization of AP1000s has proven difficult, efforts needed to be made to de-bottleneck the domestic supply chain for AP1000s. In addition, the SCRO recommended that the National Nuclear Safety Administration, responsible for implementing safety regulations, be removed from the authority of the China Atomic Energy Authority, whose aim is to promote the nuclear industry[408].

Contrary to perceptions, Fukushima had a significant impact on nuclear development in China. On 14 March 2011, Xie Zhenhua, vice chairman of the National Development and Reform Commission, stated that "[e]valuation of nuclear safety and the monitoring of plants will be definitely strengthened."[409] Then an account of a mid-March 2011 State Council meeting chaired by Premier Wen Jiabao states: "We will temporarily suspend approval of nuclear power projects, including those

[402] Other sources expect 5 GW of new nuclear capacity to start up in 2013, 10 GW in 2014 and 8 GW in 2015, see Annex 7 for details.

[403] NIW, Briefs-China, 8 March 2013.

[404] Bo, Y, "China Nuclear Energy Development", China Nuclear Energy Association, June 2012, published by the International Atomic Energy Agency, http://www.iaea.org/nuclearenergy/nuclearknowledge/schools/NEM-school/2012/Japan/PDFs/week1/3-3_Yang_ChinaNuclearEnergyDevelopment.pdf

[405] WNN, "Maintain nuclear perspective, China told", 11 January 2011

[406] Wikileaks, "Viewing cable 08Beijing3362, Effective Nuclear Advocacy in China" http://www.wikileaks.org/cable/2008/08/08BEIJING3362.html

[407] NIW, "Despite Inspections, Post Fukushima Impact on Newbuild is Minimal", 30 January 2012

[408] WNN, "Maintain nuclear perspective, China told", 11 January 2011

[409] Archana Chaudhary, "Nuclear Accident Forces China Policy Review as India Sees Safety Backlash," Bloomberg.com, 14 March 2011.

in the preliminary stages of development.... We must fully grasp the importance and urgency of nuclear safety, and development of nuclear power must make safety the top priority."[410] As a result, a new China National Plan for Nuclear Safety with short-, medium- and long-term actions was ordered and approval for new plants remained suspended until it was approved.[411]

In May 2012, the State Council announced it had finished inspecting the country's existing nuclear plants, and gave preliminary approval to both a revised 2020 nuclear strategy and a post-Fukushima safety plan. The revised 2020 nuclear strategy is expected to propose a target of 60-70GWe by 2020[412]. The new much stricter standards for new nuclear construction—especially the call for elimination of the potential for large radiation releases in units built beyond 2016—suggest that utilities may abandon Gen II plants and switch to next-generation designs[413], which will delay construction. Despite this, existing designs, were given construction approval at Fuqing 4 and Yangjiang 4 in November 2012 as well as a High Temperature Gas reactor at Shidao Bay in December 2012. This raises concerns about how effective the new regime will be with critics saying that the industry's rules and guidelines are a decade out of date, and that there is no coherent legal system to govern the use of nuclear energy.[414] But, as of early July 2013, no construction starts have occurred since then.

Safety concerns of the current and future reactor fleet have been raised by Academician He Zuoxiu, a former state nuclear physicist, who argues that the pace of nuclear development and the diversity of reactor designs is leading to insufficient actual operating experience, as such he predicts that the "most probable" period for a nuclear accident in China is between 2020 and 2030.[415] He had earlier compared China's aggressive nuclear power plans with Mao's disastrous "Great Leap Forward," and urged building new reactors at a more measured pace, with strong attention to safety, and only on the coast (a policy that has reportedly been quietly adopted) but with tsunami protection.[416]

Furthermore, public acceptance of new reactors can no longer be taken for granted -a factor of rapidly increasing relevance in modern China. Historically, nuclear protests had mainly occurred in Hong Kong against the Daya Bay facility (both before and after the transfer of sovereignty). However, after Fukushima, greater public concern coupled with reactors being proposed in up to 16 provinces made wider public engagement on the issue likely. In particular, concerns have been raised over the safety and public support for inland nuclear power plants. Despite considerable investment in the preparation for construction projects at Taohuajiang, Pengze and Dafan remain suspended and it is now stated that no further approval will be given for the construction of inland projects[417]. The Pengze nuclear power plant has been subject to on-going local opposition[418], which is spreading to other projects in the region[419].

China's importance to global new-build is not solely due to construction numbers but the types of reactors now being built, based on the world's major reactor vendors most advanced designs. Westinghouse is building four AP1000 Generation III+ reactors at Sanmen and Haiyang. Construction

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410 The Guardian "China Suspends Approval for Nuclear Power Plants" 16 March 2011.

411 WNA, "Nuclear Power in China", May 2012, see http://www.world-nuclear.org/info/inf63.html, accessed 30 May 2013.

412 Reuters, "China Cabinet Approves Nuclear Safety Plan", 31 May 2012, see http://www.reuters.com/article/2012/05/31/china-nuclear-safety-idUSL4E8GV42Z20120531 accessed, 30 May 2013.

413 Zhou, Y, "China Responds to Fukushima", Bulletin of Atomic Scientists, 28 June 2012

414 Wang Q, "Nuclear Safety Lies in Greater Transparency", Nature, 28 February 2013

415 Zuoxiu H, "Chinese nuclear disaster "highly probable" by 2030", China Dialogue, 19 March 2013

416 Hu Zuoxiu, "China must alter nuclear policy (1)," *China Dialog*, 12 Oct 2011, www.chinadialogue.net/article/show/single/en/4576, accessed 8 July 2013.

417 China.org.cn, "No restart for three inland nuclear power plants", 26 February2013

418 Yoshioka K, "Fukushima disaster sparks opposition to nuclear plant in China", 2 March 2012.

419 Zheng C, "Ex-officials battle plan to build Nuclear Project", Caixin Online, 9 March 2013 http://english.caixin.com/2012-03-09/100366298_1.html

began in April 2009 at Sanmen and at the time it was said that operation would begin in August 2013[420], although delays of six to twelve months are reported[421]. For the first unit at Sanmen, this is said to be due to design changes post-Fukushima, while for the remaining three units due to supply chain issues relating to increasing local content. In 2009, it was said they would cost $1,940/kW, but the latest figures range from €2,300 to €2,600/kW[422], it is higher than the reported costs for the CRC 1000 at $1,800/kW[423]. It is suggested that the domestic content across the series of the four reactors will increase from 30 percent to 70 percent. When purchasing the four reactors China acquired domestic rights to much of the core AP1000 technology (but not the instrument and control technology) and the right to sell overseas its own version of the AP1000 with capacities over 1350 MW. Work is underway on the construction of the first domestic hybrids, the CAP 1400, a co-operation between Westinghouse, the State Nuclear Power Technology Corporation (SNPTC) and Shanghai Nuclear Engineering Research & Design Institute (SNERDI), with construction expected to start in 2014[424].

In November 2007 AREVA announced the signing of a €8 billion ($11.6 billion) contract with the China Guangdong Nuclear Power Group, (CGNPC) for the construction of two EPRs in Taishan in Guangdong Province, and that it will provide "all the materials and services required to operate them"[425]. It is said that the cost of the reactors in this deal was €3.5 billion[426]. At the start of construction this was 40 percent below the starting price of construction of EPRs in Europe.[427] The power plant will be jointly owned by EdF (30 percent) and CGNPC (70 percent). At the time of the start of construction, the first of these reactors was expected to be completed in October 2013. The latest press statement suggests that unit 1 should begin operating in 2014, with unit 2 following in 2015[428].

In April 2013 China and France signed a series of agreement to cement their relationship on nuclear issues. This included co-operation on the further development of nuclear reactors and preliminary agreements for the sale of equipment for an 800 tonne/year reprocessing facility.[429]

China has also been broadening its ambitions to export nuclear reactors. The most consistent example is in Pakistan, where despite its being outside the regime of the Non-Proliferation Treaty (NPT), China has supplied equipment for the two reactors at Chashma, the second of which only entered commercial operation in May 2011. Construction of units 3 and 4 was said to have begun at the end of 2011 with the engagement of China Zhongyuan Engineering as the general contractor and China Nuclear Industry No 5 as the installer, with finance also coming from China and completion expected in 2016 and 2017.[430] CGNPC has been in negotiations with Romania's state-owned Nuclearelectrica to invest in the completion of units 3 and 4 of the Cernavoda plant in Romania, since other potential partners, including CEZ (Czech Republic), GDF of France, RWE of Germany and Iberdrola (Spain) have pulled out.[431]

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[420] WNN, "First Concrete at Sanmen", 20 April 2009

[421] NIW, "China, Behind the Sanmen-1 Delay", 7 December 2012

[422] NIW, "Wang Declares AP1000s Back on Track", 23 March 2012

[423] NIW, "AP-1000s Delayed by 6-12 Months SNPTC Says", 17 January 2012

[424] Nucleonics Week, "Westinghouse sees new Chinese AP1000 I&C contracts this year", 14 February 2013

[425] AREVA, "China: AREVA and CGNPC Sign the Biggest Contract Ever in the History of Nuclear Power and Enter into a Long-term Commitment. AREVA and CNNC Strengthen Their Links," press release (Paris: 26 November 2007).

[426] WNA, "Nuclear Power in China", 21 March 2013

[427] Wang Q, "Nuclear Safety Lies in Greater Transparency", Nature, 28 February 2013

[428] WNN, "First Fuel Produced for Chinese EPR", 11 March 2013

[429] WNN, "China Approaches Reprocessing Commitment", 26 April 2013

[430] WNN, "Chasma 3 gets its dome", 22 March 2013

[431] AFP, "China's Guangdong mulls investing in Romanian nuclear plant", 31 October 2012

In recent months, the Chinese industry has also reportedly connected with many other projects around the world. The April 2012 visit of Turkish Prime Minister Erdogan to Beijing was used to discuss China's assistance for a proposed nuclear power station at Sinop.

In January 2013, CNNC and Nucleoeléctrica Argentina SA signed two nuclear agreements, and discussed further plans on the construction of fourth unit at the Atucha nuclear power plant.[432] It is unclear how many of these proposals will come to fruition, nor whether they would help China's domestic nuclear additions by spreading capital costs or perhaps hurt them by diverting scarce technical resources and attention.

As with most energy sectors, what happens in China about nuclear power has global impact. In many quarters there is significant confidence that ambitious targets for domestic construction will be met, but this should be tempered given the remaining strategic questions over nuclear safety standards, engineering and skills bottlenecks, increasing environmental opposition, siting problems, and even basic economics. Despite China's central planning system, its world-leading wind and solar achievements and their steeply falling price must be expected to put increasing competitive pressure on new-build nuclear prospects, just as in market economies if perhaps through different channels.

India operates 20 nuclear power reactors with a total capacity of 4.4 GW; the majority of these have a capacity of 220 MW per unit. In 2012, nuclear power provided a record 29.6 TWh that covered just 3.6 percent of India's electricity, slightly below the record level of 3.7 percent already achieved in 2001/02 when nuclear generation was only around 17 TWh.

India lists seven units as under construction with a total of 4.8 GW. Most currently operating reactors experienced construction delays, and operational targets have rarely been achieved. India's lifetime nuclear load factor is only 59.3 percent as of the end of 2012, the lowest of any country operating more than two units.

India's 1974 nuclear weapons test triggered the end of most official foreign nuclear cooperation, including invaluable Canadian assistance. The nuclear weapons tests in 1998 came as a shock to the international community and triggered a new phase of instability in the region, including a subsequent nuclear test series by Pakistan. Various (and different) international sanctions were imposed on the two countries.

This state of affairs started to change under U.S. Bush administration's announcement in 2005 of what became known as the U.S.-India deal. Following intense lobbying by the United States, supported by France and Russia, the IAEA approved a "safeguards agreement" with India in August 2008, and on 6 September 2008 the Nuclear Suppliers Group (NSG), a 45-country group regulating international commerce to prevent the proliferation of nuclear weapons, granted an exception to its own rules. Thus, although India is a non-signatory of the NPT, has developed and maintains a nuclear weapons program, and refuses full-scope safeguards,[433] it is still permitted to receive nuclear assistance and to carry out nuclear commerce with other nations. The reasons for this deviation from the previous nonproliferation consensus appear to be geopolitical and commercial. France has abstained from any criticism of India's nuclear weapons program and has strongly encouraged the NSG to grant India access to international cooperation. A French parliamentary report states:

> Grateful for these diplomatic positions in its favour and conscious about the French technological excellence in this sector, India has logically chosen to make France one of its principal partners.[434]

[432] Powell H, "China/Latin America: Argentina and China sign further nuclear agreements", Plusa Merica, 21 February 2013 http://www.pulsamerica.co.uk/2013/02/21/chinalatin-america-argentina-and-china-sign-further-nuclear-agreements/

[433] Comprehensive inspection and verification that all nuclear materials and all nuclear facilities have been used for declared purposes only.

[434] Eric Woerth, "Rapport fait au nom de la Commission des Affaires Etrangères sur le Projet de Loi n°4021, autorisant l'approbation de l'accord entre le Gouvernement de la République française et le Gouvernement de la

However, the report also highlights "the problems generated by the law on civil responsibility" that the Indian Parliament voted in September 2011, in particular because the supplier could be held liable for potential accidents under some circumstances. Furthermore, a petition filed by prominent lawyer Prashant Bhushan has requested the Indian Supreme Court to declare the liability legislation "unconstitutional and void ab initio" [meaning to be treated as invalid from the outset]. The outcome could mean the application of "absolute liability" to nuclear plants. Vendors will then be faced with the question "whether they are confident enough in the safety of their reactors to risk potential bankruptcy".[435] In other words, in India, unlike virtually all Western countries, reactor owners or operators may need to shoulder responsibility for any harm caused by major accidents at their plants, rather than having their liability limited by special laws unique to their technology.

In addition, an August 2012 report by the Comptroller and Auditor General of India raises the issue of the independence of the Atomic Energy Regulatory Board (AERB). The report points to a number of inadequacies of the nuclear regulatory system in India. Even the international nuclear lobby's *World Nuclear News* noted:

> Other abnormalities in Indian regulation include the lack of a requirement for nuclear power plant owners to have decommissioning plans and secured funds for the work.[436]

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.[437] The contract reportedly would be worth some €7 billion ($10 billion) for *two* EPRs[438], a surprisingly low figure considering that the cost-estimate for the French and Finnish EPRs has escalated to €8.5 billion *each*. (See Economics section.)

Even before the agreement was signed, as on other sites, opposition against the Jaitapur project was massive. The Fukushima events triggered a significant increase in opposition. Two Russian-built reactors at Kudankulam were mostly completed before 3/11, "since when the sudden growth of a powerful local protest movement has effectively brought commissioning to a standstill".[439] The Indian Government, however, appears intent on starting up the reactors, already years behind schedule. In May 2013, India's Supreme Court paved the way for the commissioning of the reactors, which had been legally challenged by citizens' groups, arguing that the plant is "in the largest interest of the nation particularly the State of Tamil Nadu".[440] Meanwhile the state of West Bengal has scrapped another project for up to six Russian reactors at the coastal site of Haripur.[441]

The current five year plan counts on doubling the currently installed capacity and starting construction of a further 19 units. Princeton University's M.V. Ramana concludes a milestone historical assessment of the Indian program with a question and answer:

> Is a rapid and large-scale expansion of nuclear power in India, along the lines projected by the Department of Atomic Energy (DAE), feasible? The answer that emerges in the course of our excursion through the history of how the nuclear project has materialized in the country is that is is very unlikely

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République de l'Inde relatif à la répartition des droits de propriété intellectuelle dans les accords de développement des utilisations pacifiques de l'énergie nucléaire", Assemblée Nationale, 18 January 2012.

435 Suvrat Raju, M.V. Ramana, "A New Twist in the Saga of India's Liability Law", NIW, April 2012.

436 WNN, "India's nuclear regulation must improve", 24 August 2012, see http://www.world-nuclear-news.org/RS_Indias_nuclear_regulation_must_improve_2408121.html, accessed 12 May 2013.

437 AREVA, "India: Agreements Between AREVA and NPCIL for the Supply of Two EPR Reactors and Fuel for 25 Years," press release, 6 December 2010.

438 "India Signs $9.3 Billion Deal for Areva to Build Two Nuclear Power Plants," Bloomberg.com, 6 December 2010.

439 WNN, "Cabinet clears way for Kudankulam", 19 March 2012, see http://www.world-nuclear-news.org/NN-Cabinet_clears_way_for_Kudankulam-1903127.html, accessed 30 May 2012.

440 WNN, "Kudankulam's public interest ruling", 7 May 2013, see http://www.world-nuclear-news.org/NN-Kundankulams_public_interest_ruling_0705137.html, accessed 14 May 2013.

441 Nucleonics Week, "West Bengal eliminates Haripur as second VVER site: reports", 25 August 2011.

> and probably impossible. The principal reasons, among many, for this conclusion are the technical implausibility of the DAE's plans, its inability as an organization to learn lessons from its earlier failures, and local opposition.[442]

Trade journal *Nuclear Intelligence Weekly* put it more bluntly: "There's no reason to believe that the country can keep this schedule, of course." Indeed, Indian nuclear planning has been always overly optimistic, not to say unrealistic. In 1984 a target of 10 GW was set for the year 2000. Almost 30 years later, not even half of that capacity has been installed. Projections for the future seem even more astounding (see Table 7).

Table 7: Nuclear Power in India: Planning, Projection or Fantasy?

Indian Forecasting	Capacity „planned“	Capacity installed	Share realized
in 1984 for 2000	10 GW	2.7 GW in ca. 15 years	27%
in 2005 for 2012	11 GW	4.8 GW in ca. 30 years	43%
in 2012 for 2017	10 GW	10 GW max in ca. 35 years	?
in 2012 for 2023	27 GW	+12.7 GW in ca. 10 years?	?
in 2012 for 2032	63 GW	+58 GW in ca. 20 years?	?
in 2009 for 2050	470 GW	x 100 in 40 years?	?

 Sources: various, assembled by MSC

In contrast, Indian entrepreneurs—largely in the vibrant private sector rather than large state-owned enterprises and agencies—have proven adept at rapidly scaling competitive, modular, short-lead-time, renewable technologies. India added 2.3 GW of wind turbines in 2012 (the fourth largest addition in the world) and now has an installed capacity of wind power of 18.4 GW, compared to 4.8 GW of nuclear capacity with the contribution of the wind sector to electricity supply having overtaken that of nuclear power in 2012.

Japan

In Japan nuclear power in 2012 provided about 17 TWh or 2 percent of total electricity compared to 18 percent in 2011, 29 percent in 2010 and the historic maximum of 36 percent in 1998.

This result, is obviously a consequence of the tragic events of 11 March 2011 known in Japan and overseas as 3/11. The triple disaster earthquake-tsunami-nuclear accident that hit Japan on that day had a profound impact on the nation's and the world's environment, economy and energy policy.

In October 2011 the Cabinet office released an energy white paper that dropped the paragraph on the expansion of nuclear power and instead called for the reduction on the reliance on nuclear power. Furthermore, the paper stated that the Government "regrets its past energy policy and will review it with no sacred cows". [443]

Under Japanese law, every nuclear power plant has to be shut down at least every 13 months for inspection and maintenance. As of 26 March 2012, Japan's main island Honshu was no longer using nuclear power, when unit 6 at Kashiwazaki-kariwa shut down for refueling, maintenance and inspection. Tomari-3 in Hokkaido was the last unit to go offline in Japan and as of 5 May 2012, all 54 Japanese nuclear power reactors were closed. However, in July 2012, two units at the Ohi plant in the Fukui Prefecture were restarted, but they remain the only reactors in operation across the country.

[442] M.V. Ramana, "The Power of Promise – Examining Nuclear Energy in India", Penguin-Viking, 2012, 366 pages.

[443] Bloomberg, "Nuclear Promotion Dropped in Japan Energy Policy After Fukushima", 27 October 2011.

Officially, the Japanese Government declared only four of the Fukushima Daiichi units "permanently shut down", the other 50 units remaining "operational" and two units "under construction" in the international statistics. It is virtually impossible to imagine that all reactors will return to operation. However, once the reactors are declared permanently closed, they become liabilities on the balance sheets of the utilities. Therefore, changing their status will have a profound impact not only on the electricity generation but on the economic viability of the companies, potentially leading to their bankruptcy. Japan is still absorbing former NRC Commissioner Peter Bradford's remark about the financial risk revealed by the Three Mile Island accident: "Wall Street learned that a group of licensed operators no worse than any other could transform a billion-dollar asset into a two billion dollar clean-up in ninety minutes." [444] At Fukushima, the accident was triggered by natural disaster, but the financial reversal was analogous—just one or two orders of magnitude bigger.

On 14 September 2012 the Japanese Government announced that it had adopted an "Innovative Strategy for Energy and the Environment", for a zero nuclear power future by the 2030s[445]. However, due to lack of clarity, the Government statement immediately gave way to speculations as to the schedule for the shutdowns, and the future of the plutonium fuel program and of the reactors under construction.

To further confuse the issue, a statement by the Prime Minster said that "it is rather irresponsible to make a decisive judgment on the unforeseeable future. We must start with a strategy that has both a secure direction and the flexibility to cope with changes in the situation, without wavering from the basic policy and also not excessively restricting future decisions"[446].

No reactors can restart until they have conformed to the new guidelines issued by the Nuclear Regulatory Authority (NRA), which are expected to enter into force in July 2013. The new guidelines make it compulsory for operators to protect against radiation leaking to the environment through a review of existing reactors and their protection against external natural hazards such as tsunamis and earthquakes. This includes a more indepth review of the seismic conditions for the plants, which may permanently exclude the restart of some reactors. Secondly, the reactors must be retrofitted to implement additional measures for severe accident management, such as the prevention of hydrogen explosions[447]. The safety reviews are expected to take at least six months and therefore no significant electricity production from nuclear power will be achieved before 2014, and even then it is likely to be initially only from the more modern PWR designs[448]. It remains unclear to what extent the NRA will accept restarts while upgrading is under way. The change of government from the nuclear-skeptical Prime Minister Naoto Kan (who served during the accident) to the nuclear-friendly Yoshihiko Noda to the nuclear-enthusiastic Shinzo Abe has influence but is far from decisive when many provincial Governors and most of their constituents oppose nuclear restart.

The Japanese Government is facing unprecedented opposition to nuclear power in the country. Opinion polls indicate large majorities in favor of a nuclear phase out. Furthermore, opposition seems to be growing. The update of the IPSOS Mori's post Fukushima global opinion poll found that between April 2011 and September 2012 a further 10 percent of the popoulation went against nuclear power.[449] Massive demonstrations of unprecedented scale have flooded the streets of Japan's cities. At a public event in Osaka on 29 June 2013 in advance of Upper House elections the ruling LDP's Secretary General Shigeru Ishiba was the only lawmaker out of nine to vote "No" to the question about favoring moving towards a non-nuclear future for Japan (see Photo 1).

[444] Peter A. Bradford, 24 March 2009, see http://www.nirs.org/reactorwatch/accidents/bradfordtestimony32409tmi.pdf,

[445] Government of Japan, "Innovative Strategy for Energy and the Environment, The Energy and Environment Council, Government of Japan, 14 September 2012.

[446] Prime Minister Yoshihiko Noda, Energy and Environment Council, 14 September 2012.

[447] Deutsche Welle, "Tough rules for Japanese Nuclear Plants", 24 June 2013.

[448] Jefferies, "Japanese Trading Companies Japanese Nuclear Reactors & New Safety Standards", 24 June 2013

[449] IPSOS 2012, op.cit.

Japanese media, once docile and quietly consored, have turned increasingly critical not only on the mismanagement of the Fukushima disaster, but also the political pressure that has been brought to bear to restart the nuclear reactors. In a stinging editorial the Director of the *Asahi Shimbun* Editorial Board stated on 29 June 2013:

> The nation likely does not have the ability to cope with another accident of a similar scale.
>
> If that is the case, the only alternative will be to reduce the number of nuclear plants as quickly as possible while making safety standards stricter and implementing measures to prepare for the likelihood of another accident.
>
> That is the brutally frank reality Japan now faces.

Following a meeting between the new Japanese Prime Minister Shinzo Abe and French President Francois Hollande to cooperate on the development of a nuclear fuel cycle and the export of nuclear power technology, an editorial in the *Japan Times* stated: "Mr. Abe's decision to move forward with the development of nuclear power technology represents his cynical disregard for the victims of the Fukushima nuclear crisis".[450]

Photo 1: LDP Only Japanese Party to Vote Against Nuclear-Free Japan

Source: Asahi Shimbun, 30 June 2013.

Numerous measures were taken between March and September 2011 to reduce electricity demand. Their estimated costs ranged from a few yen to a few hundred yen per kWh, in other words from very cheap to ridiculously high. Now, "METI is studying a 'Nega-Watt Trade' and other innovative programs" and an in-depth revision of the Energy Conservation Law is under preparation.[451] Japan's target is to cut electricity demand by at least 10 percent by 2030. That target is, according to the *Japan*

[450] Japan Times, "Cease promoting nuclear power", 11 June 2013.
[451] IEEJ, "Japan Energy Brief", n°18, March 2012.

Times "a moderate one that could be exceeded if the government supports and enacts its policies more thoroughly"[452].

In the meantime, fossil fuel imports have increased significantly, in particular a 20 percent in the use of Liquified Natural Gas (LNG) over the past two years. This increase, coupled with increases in other countries in the region, such as China, resulted in a significantly higher regional price of gas, which affected Japanese balance of payments. In April 2013, as a result of higher fuel prices and a weaker Yen, the price per tonne of LNG reached €816, a level not seen since September 2008.[453]

In the meantime, the government introduced feed-in tariffs for renewable energy that are significantly higher than those in Germany or any other country. The tariffs became effective on 1 July 2012 and led to the rapid investment in renewable energy in Japan (chiefly solar, as wind is more constrained by artificial utility rules). In 2012, according to Bloomberg New Energy Finance, the total investment in clean energy in Japan reached $16.3 billion, nearly double the previous year. These investments are essential if Japan is to increase its use sufficiently to meet the 20 percent target by 2020. But there are already growing signs that the local demonstration of competitive renewables is starting to splinter the business community's previously nearly-solid front in support of the old nuclear-centric policy.[454]

One of the key issues for the future of the power sector in Japan will be its reform and in particular the liberalisation of the market. This was to be a three stage process starting with the creation of an independent body to oversee supply and demand, followed by the liberalisation of the retail market and then the separation of retail and power generation, by 2020. However, in June 2013 the bill to introduce the first stage of the process was abandoned in the Upper House of Parliament.[455]

Pakistan operates three reactors that provided 5.3 TWh and 5.3 percent of the country's electricity in 2012, both historic maxima. The nuclear load factor has been close to 89 percent. The third unit, supplied by China, came on line only three days after 3/11. During Chinese Prime Minister Wen Jiabao's visit to Pakistan in December 2010, it was reported that China might build another two 650 MWe reactors in the country.[456] The Pakistan Atomic Energy Commission (PAEC) indicated a target capacity of 8.8 GW with 10 installed units by 2030.[457] Construction of two 315 MWe units started in 2011 at the Chasnupp site with the engagement of China Zhongyuan Engineering as the general contractor and China Nuclear Industry No. 5 as the installer, with finance also coming from China. According to press reports[458], the Finance Ministry has released a modest $4.8 million (465 million Pakistani rupees) for a fesibility and design study into a second reactor for the Karachi site. The first unit at the site, KANUPP, a 125 MW CANDU heavy water reactor, was first connected to the grid in October 1971 and is one of the oldest operating reactors in the world.

In the 1980s, Pakistan developed a complex system to access illegally various components for its weapons program on the international black market, including from diverse European sources.[459] Immediately following India's nuclear weapons tests in 1998, Pakistan also exploded several nuclear devices. International nuclear assistance has been practically impossible, given that Pakistan, like India, has not signed the NPT and does not accept full-scope safeguards, and is currently unlikely to be granted the same exception as India to the NSG's export rules. Some Pakistani experts bitterly complain about the "simply unfair" differential treatment under the international non-proliferation

[452] Japan Times, "Renewable energy policy", 13 May 2013, see http://www.japantimes.co.jp/opinion/2013/05/13/editorials/renewable-energy-policy/, accessed 30 June 2013.

[453] Bloomberg, "Japan Pays Record Price for LNG Imports in April as Yen Weakens", 31 May 2013.

[454] A.B. Lovins, "Asia's Accelerating Energy Revolution", 26 March 2013, http://blog.rmi.org/blog_2013_03_26_2013_Asias_Accelerating_Energy_Revolution

[455] Kyodo, "Japan's drive to reform power sector hits snag amid political feud", 26 June 2013

[456] "Nuclear Energy on Agenda as Chinese Premier Visits Pakistan," *Spero News*, 17 December 2010.

[457] "Ten Nuclear Power Plants Planned," Dawn.com, 12 January 2011.

[458] NIW, 14 September 2012, p.10.

[459] See Mycle Schneider, "Nucléaire: Paris, plaque tournante du trafic pakistanais," *Politis* (Paris), 1989.

regime and consider that “participation in the NSG is essential if Pakistan is to be able to acquire the equipment and expertise needed to build the nuclear plants that will fill this power gap”.[460]

On the other hand, according to Pakistan’s Alternative Energy Development Board, the country has vaste potential resources in wind energy, estimated at 350 GW. Several hundred megawatts of wind projects are currently under development.[461] In January 2013, the Korean Solar Energy Company launched a large 1 GW solar project in Beluchistan that is supposed to help ease power shortages in the region.

On the Korean Peninsula, the **Republic of Korea** (South Korea) operates 23 reactors that provided 143.6 TWh (2.4 percent less than in record year 2011) or 30.4 percent of the country’s electricity in 2012 (down from a maximum of 53.3 percent in 1987). In addition, four reactors are listed as under construction. The first Shin-Uljin unit officially started construction on 10 July 2012. South Korea’s reactors have shown excellent performance in the past, and held the fourth position of lifetime load factors with 86.4percent by the end of 2012. However, due to component and quality control issues, the annual load factor dropped by almost 10 percent in 2012 to 80.7 percent.

Less than a month after 3/11, the Korea Electric Power Corporation (KEPCO) presented plans to double installed nuclear capacity to close to 43 GW by 2030 and bring the nuclear share in the power generation to 59 percent.[462] However, observers see a “dramatic political shift against nuclear power in the year since Fukushima”.[463] The Mayor of Seoul, for example, initiated a program to “save away” the equivalent amount of energy generated by one nuclear reactor. According to an updated 24-country study by IPSOS, general support of nuclear power recovered significantly (+18 percent), but by September 2012 still 51 percent of Korean people polled opposed nuclear energy.[464]

The newly elected Korean Government under President Park Geun-hye, who came into office in December 2012, attempts to support the nuclear industry and to restore public trust after a series of scandals. In April 2012, the CEO of Korea Hydro & Nuclear Power (KHNP) was forced to resign over the cover-up of two significant incidents, a 12-minute station blackout at Kori-1 with two emergency diesels failing to start up on 9 February 2012 and another diesel failure at Yonggwang-2 on 28 March 2012. Both events had not been disclosed for several weeks.[465] In November 2012, a massive quality control scandal broke and up to 74 investigators inquired about tens of thousands of items at the country’s nuclear power plants. In January 2013, the Nuclear Safety and Security Commission (NSSC) announced:

> Over the past 10 years, 13,794 units of 561 items with falsified quality certificates have been supplied to KHNP, and 6,949 units of 341 items were found installed curently in the nuclear power plants. Almost all 5,258 safety-related items supplied with falsified documents were replaced under witness of site investigators.[466]

A total of 20 suppliers and 215 cases of quality record falsification had been identified. In May 2013, the scandal widened into safety-class control-command cables. After an anonymous report had tipped off the NSSC, it was confirmed that test reports had been forged and that the test in fact failed under loss-off-coolant-accident conditions. Two operating reactors, Shin-Kori-2 and Shin-Wolsong-1, were

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460 Zahir Kazmi, “Letter from Pakistan : How an unfair non-proliferation regime undermines nuclear security”, Bulletin of the Atomic Scientists, 30 August 2012; see http://www.thebulletin.org/web-edition/op-eds/letter-pakistan-how-unfair-non-proliferation-regime-undermines-nuclear-security, accessed 15 May 2013.

461 GWEC, “Global Wind Energy Outlook 2012”, November 2012.

462 Ki Hak Kim, “Fueling the Sustainable Future”, 6 April 2011.

463 NIW, “South Korea: Growing Nuclear Skepticism”, 23 March 2012

464 IPSOS, op.cit.

465 NIW, “Kim Out at KHNP Over Reporting Lapses”, 20 April 2012.

466 NSSC, “NSSC to Announce Investigation Results and Preventive Action Plans”, 9 January 2013, see http://www.nssc.go.kr/nssc/english/release/list.jsp?mode=view&article_no=3750&pager.offset=0&board_no=501, accessed 1 June 2013.

shut down, and the maintenance period of Shin-Kori-1 was extended in order to replace the faulty cables. Shin-Kori-3 and -4 as well as Shin-Wolsong-2, all three under construction, also had “forged” quality-control documents and need to replace the incriminated cables.[467]

In December 2009, South Korea succeeded in securing its first major overseas nuclear deal, “snatching” a multi-billion dollar contract with the United Arab Emirates (UAE) from the world’s largest builder AREVA, backed by French state utility EDF, for building of four 1.4 GW reactors. In the meantime, however, cost estimates have soared and financing negotiations have been delayed (see section on UAE in chapter Potential Newcomer).

Taiwan operates six reactors that provided a record 38.7 TWh or 18.4 percent of the country’s electricity in 2012 (down from a maximum of 41 percent in 1988). Two 1.3 GW Advanced Boiling Water Reactors (ABWR) have been listed as under construction at Lungmen, near Taipei, since 1998 and 1999 respectively. Their startup has been delayed many times and they are many years behind schedule. According to the Atomic Energy Council, by April 2013, the first unit was “nearly finished” and operator Taipower was presently carrying out “on-site testing of operating procedures and systems functions”.[468] In March 2012, the Atomic Energy Minister raised doubt over the safety of the plant.[469] In May 2012, media reports gave 2014-15 as the current planned start-up date. Another source has indicated startup of the first unit “no earlier than March next year”, in 2014, “if there are no further problems”.[470] The plant is estimated to have cost USD 9.6 billion so far. According to the Minister of Economic Affairs, the project costs Taipower an estimated NT$400–600 million (USD10–15 million) for each month of delay.[471]

Taiwan’s nuclear program has a certain number of very specific problems. The nuclear plants are located in areas with high population density, high seismicity and tsunami risks. In addition, with the absence of a long-term waste strategy, the spent fuel pools are filling up and, in spite of re-racking and dense-packing, the first pools are expected to be full by 2014.[472] “The confidence of residents are [sic] feeble on nuclear safety issue”, admitted Taipower Vice-President Hsu Hwai-Chiung in July 2011. “The license renewal of NPPs will be suspended until National Energy Policies are clear in near future.”[473]

The Taiwanese public is increasingly critical towards the country’s nuclear power program and on 9 March 2013 over 200,000 people demonstrated in various cities against the startup of the Lungmen plant. An opinion survey released in late March 2013 indicated a 73 percent majority in favor of a halt to the Lungmen plant. On 26 April 2013, the ruling party introduced a bill in the legislature to organize a national referendum over the future of the Lungmen project. What appears to be an exemplary exercise of democracy is seen by many as a manouver to get a silent majority for the project’s completion. The referendum legislation requires a quorum of at least 50 percent to make the outcome binding, a score difficult to achieve nationwide.

In November 2011, the Government presented a new energy strategy to “steadily reduce nuclear dependency, create a low-carbon green energy environment and gradually move towards a nuclear-

[467] 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&pager.offset=0&board_no=501, accessed 1 June 2013.

[468] Nucleonics Week, “Lungmen critic gives legislators plan for reinspection, oversight”, 2 May 2013.

[469] Asia Pulse, “Minister Casts Doubt on Viability of 4th Taiwan Nuclear Plant”, PennEnergy, 15 March 2012.

[470] Nucleonics Week, “Lungmen critic gives legislators plan for reinspection, oversight”, 2 May 2013.

[471] Focus Taiwan News Channel, “Start Date for Commercial Operation of Nuclear Power Plant Postponed,” 6 January 2011, at http://focustaiwan.tw/ShowNews/WebNews_Detail.aspx?ID=201101060017&Type=aECO.

[472] Le Monde, “Taïwan, l’apprenti sorcier du nucléaire”, 8 February 2012.

[473] Hsu Hwai-Chiung, “The Impacts on Taipower Nuclear Power Plants after Fukushima Accident”, Taipower, 27 July 2011.

free homeland".[474] The document released by the Ministry of Economic Affairs' Bureau of Energy also announced the shutdown of its oldest reactors at Chinshan (grid connection 1977 and 1978) as soon as the Lungmen reactors come online and the non-renewal of operating licenses beyond a 40-year lifetime. That would mean the shutdown of the operating units between 2016 and 2025.

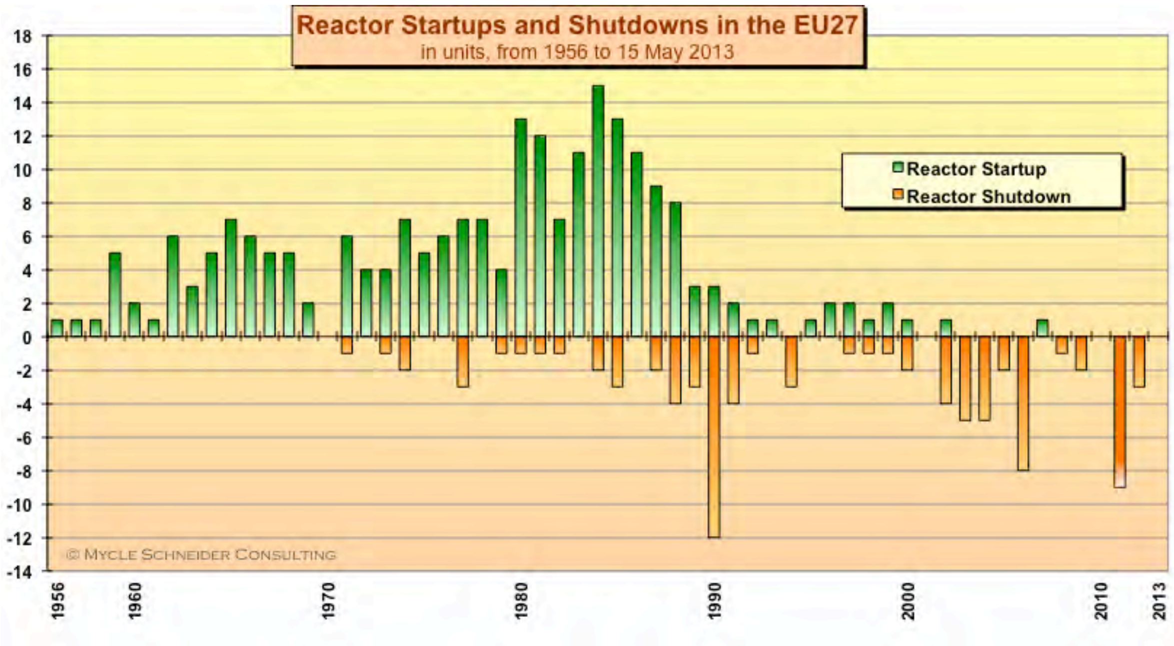
European Union (EU27) and Switzerland

The European Union 27 member states (EU27) have gone through three nuclear construction waves, two small ones in the 1960s and the 1970s plus a large one in the 1980s (mainly in France). The region has not had any significant building activity since the 1990s. (See Figure 26.)

In July 2013, 14 of the 27 countries in the enlarged EU operated 131 reactors—about one-third of the world total—12 fewer than before the Fukushima events and one-quarter below the historic maximum of 177 units in 1989. (See Figure 27.) The vast majority of the facilities, 112 or 85.5 percent, are located in eight of the western countries, and only 19 are in the six newer member states with nuclear power.

In 2012, nuclear power produced 27 percent of the commercial electricity in the EU, down from 31 percent in 2003.[475] Nearly half (48 percent) of the nuclear electricity in the EU27 was generated by one country, France.

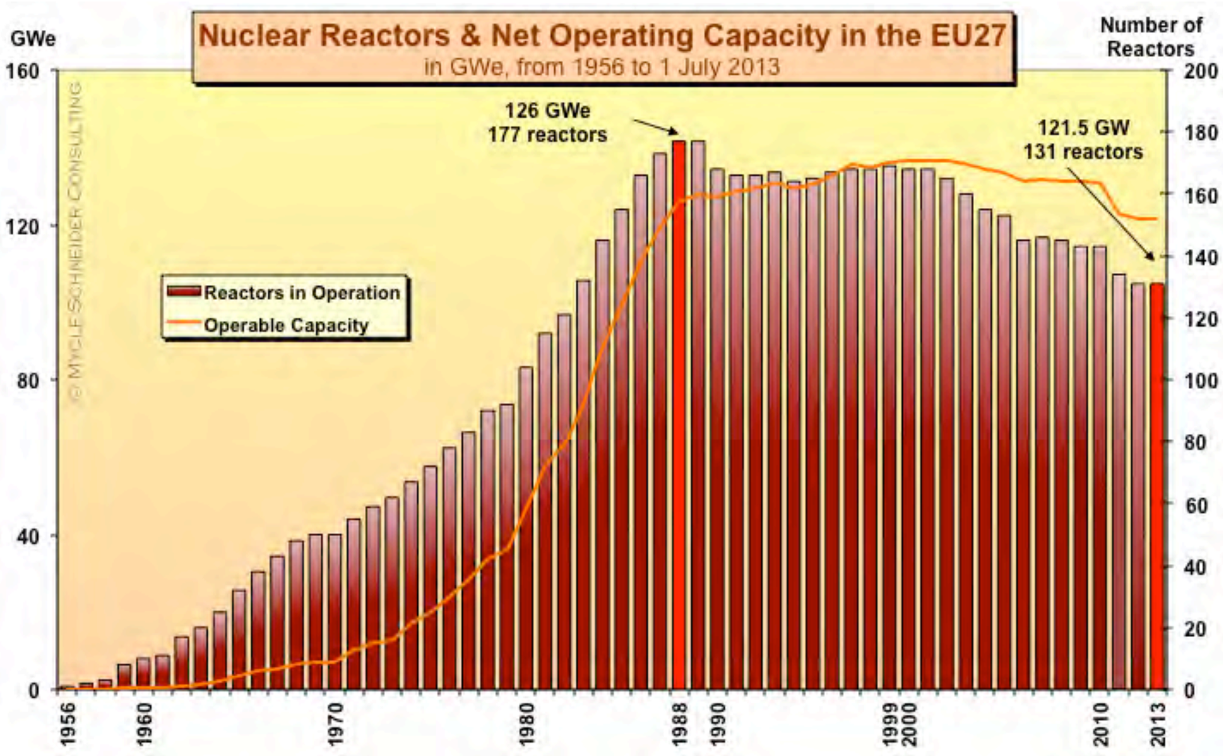
Figure 26: Nuclear Reactors Startups and Shutdowns in the EU27, 1956–2013



Source: IAEA-PRIS, MSC, June 2013

[474] Bureau of Energy, "Ensure Nuclear Security—Steadily Reduce Nuclear Dependency—Create a Low-carbon Green Energy Environment & Gradually Move Towards a Nuclear-free Homeland", Ministry of Economic Affairs, 3 November 2011.
[475] EURELECTRIC, "Key Statistics – Edition 2013", 7 June 2013.

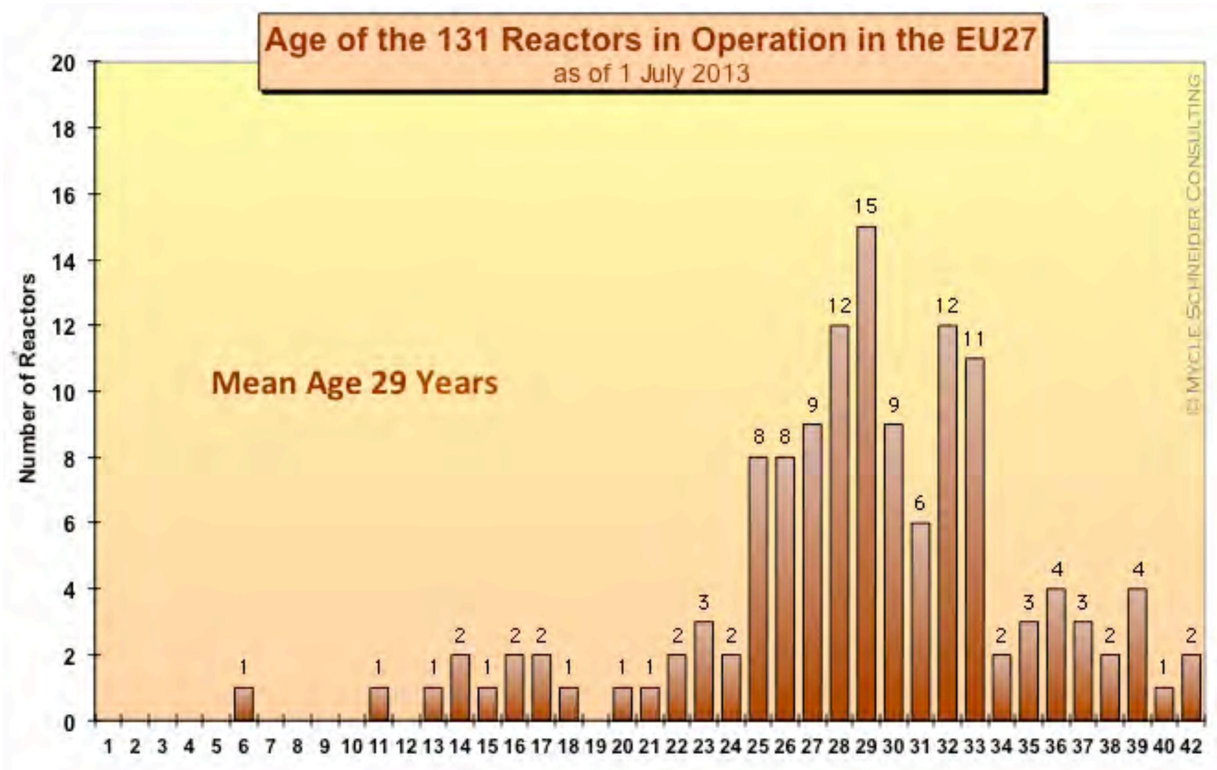
Figure 27: Nuclear Reactors and Net Operating Capacity in the EU27, 1956–2013



Source: IAEA-PRIS, MSC, June 2013

With the lack of new reactor construction, the average age of the EU's reactors now stands at 29 years (see Figure 28).

Figure 28: Age Pyramid of the 131 Nuclear Reactors Operated in the EU



Sources: IAEA-PRIS, MSC, July 2013

Western Europe

In Western Europe (EU15), as elsewhere, the public generally overestimates the significance of electricity in the overall energy picture, as well as the role of nuclear power. Electricity currently accounts for only about one-fifth of the EU15's commercial primary energy consumption.

As of July 2013, the EU15 was home to 112 operating nuclear power reactors, or 45 units fewer than in the peak years of 1988/89.

Two reactors are currently under construction in the older member states EU15, one in Finland and one in France. These are the first building sites in the region since construction began on the French Civaux-2 unit in 1991. Apart from the French exception 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 provides a short overview by country (in alphabetical order).

Belgium operates seven reactors and has the world's third highest share of nuclear in its power mix, at 51 percent in 2012 (down from a maximum of 67.2 percent in 1986). The nuclear plants achieved their best productivity level generating 46.7 TWh in 1999 compared to 38.5 TWh in 2012. In 2002, the country passed nuclear phase-out legislation that required the shutdown of nuclear plants after 40 years of operation, meaning that (based on their start-up dates) plants would be shut down between 2015 and 2025. On 13 October 2009, the Government issued a 10-page general policy statement that included one reference to nuclear power: "The government has decided to postpone by 10 years the first sequence of the phase-out of nuclear power."[476] However, that government was voted out in June 2010, just prior to voting on supporting legislation to delay the phaseout. Following Fukushima and the establishment of a new Government the still existing phase-out legislation was left in place and no legislative initiative has been taken to overturn it, even if the operator GDF-Suez is lobbying hard to postpone via an extension of "at least 10 years".[477]

In the summer of 2012, the operator identified unprecedented numbers of 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 including international experts, 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 Belgian safety authority, stated that "some uncertainty about the representativity of the test program for the actual reactor pressure vessel shells cannot be excluded".[478] The safety authority's own subsidiary BEL-V concluded at the same time[479]:

> Indeed there exists no validated procedure neither for evaluating flaws having the morphology and orientation of the hydrogen-induced flaws nor for evaluating thousands of those defects with interactions between themselves (clustered flaws) because such a situation has never been met (and, as a result, accepted) in an operating safety-related pressure component like the reactor pressure vessel for which break exclusion is assumed.

[476] Prime Minister of Belgium, "Déclaration du gouvernement relative à sa politique générale," 13 October 2009, at http://archive.vanrompuy.belgium.be/files/Statepremier.pdf.

[477] Gérard Mestrallet, et al., "Nuclear in Belgium: recent developments", GDF Suez, 4 November 2011.

[478] AIB-Vinçotte, "Synthesis Report Doel165", 28 January 2013.

[479] BEL-V, "Safety Evaluation Report – Flaw indications in the RPVs of Doel 3 and Tihange 2", 31 January 2013.

An independent assessment[480] equally concluded that "FANC should obtain—before authorizing the restart of the affected reactors—absolute certainty that the flaws will not lead to the failure of the reactor pressure vessel. This is obviously not the case at present and will not be the case even if the complementary tests should prove positive".

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".[481] The units restarted in spite of the serious concerns by independent scientists and reached full capacity respectively on 9 and 11 June 2013. The underlying issue has not gone away.

Finland currently operates four units that supplied 22.1 TWh or 32.6 percent of its electricity in 2012 (down from a maximum of 38.4 percent in 1986). Finland's load factor has been constantly amongst the top five nuclear countries. Although it dropped in 2012 by 3.3 percent, with an annual average of 90.7 percent, it is still number four in the world.

In December 2003, Finland became the first country to order a new nuclear reactor in Western Europe in 15 years. AREVA NP, then comprising 66 percent AREVA and 34 percent Siemens[482], is building a 1.6 GWe EPR under a fixed-price turn-key contract with the utility TVO—an arrangement that AREVA top managers have admitted in private talks they would "never do again". The project was financed essentially on the balance sheets of the country's leading firms and municipalities under a unique arrangement that makes these customers liable to pay the plant's indefinite capital costs for an indefinite period, whether or not they get the electricity—a Capex "fixed price" but "take-or-pay contract".

Construction started in August 2005 at Olkiluoto on the Finnish west coast. Close to eight years later, the project is about seven years behind schedule and now 280 percent over budget (see also Economics section). The plant is currently expected to start up in 2016 and the cost estimate has been raised to €8.5 billion. It remains unclear who will cover the additional cost: the vendors and TVO blame each other and are in litigation. "TVO is not pleased with the situation and repeating challenges with the project scheduling" and admits that "the plant completion may be further delayed".[483] According to TVO, about 75 percent of the installation work has been completed.

From the beginning, the Olkiluoto-3 (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 several dozen nationalities made communication and oversight extremely complex.

The Finnish regulator STUK has still not yet validated the EPR's Instrumentation and Control (I&C) system. TVO stated in February 2013 that "the I&C design has not proceeded as planned" and could cause further delays.

The repeated construction delays of OL3 are a blow not only to power planning by the utility and to the 60 large customers involved in the project consortium, but also for the Finnish Government.

In late February 2013, TVO's Board of Directors proposed a new shareholder loan commitment of €300 million to its shareholders in order to cope with financing costs and maintain a minimum

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480 Ilse Tweer, "Flawed Reactor Pressure Vessels in Belgian Nuclear Plants Doel-3 and Tihange-2", March 2013; see http://www.greens-efa.eu/fileadmin/dam/Documents/Studies/Flawed%20Reactor%20Pressure%20Vessels.pdf, accessed 1 June 2013.

481 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.

482 Siemens quit the consortium in March 2011 and announced in September 2011 that is was abandoning the nuclear sector entirely.

483 TVO, "Information about the start-up of Olkiluoto 3 nuclear power plant unit", press release, 11 February 2013, see http://www.tvo.fi/news/32, accessed 1 June 2013.

25 percent share of shareholders capital or loan.[484] Credit rating agency Fitch nevertheless downgraded TVO from BBB+ to BBB in late May 2013[485] - see Table 4 for more details.

OL3 was part of the government's strategy to achieve its target of a zero-percent increase of 1990 emissions under the Kyoto Protocol. The lack of an operational OL3 will force Finland to use emissions trading to compensate for the GHG's produced in the country.

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 1–1.8 GWe reactor to start construction in 2012 and enter operation "in the late 2010s".[486] The decision was ratified by the Finnish Parliament on 1 July 2010. But already significant delays have emerged. In late March 2012, TVO invited five reactor vendors—AREVA, GE Hitachi (GEH), Korea Hydro and Nuclear Power (KHNP), Mitsubishi and Toshiba—to submit bids, which were transmitted in January 2013. A license application is planned for mid-2015 and start-up "around 2020."[487]

In parallel, Fortum Power is planning a similar project, known as Loviisa-3. In addition, 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—which has first been 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.[488] 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 PWR AES-2006. Fennovoima stated that it will select the plant supplier "during 2013".[489] However, while Toshiba and AREVA were explicitly mentioned in government and parliament planning authorizations, this is not the case with Rosatom. Greenpeace has already announced it will challenge the decision in court, "if the government shows any signs of approving a Rosatom deal under the current criteria".[490]

France is the worldwide exception in the nuclear power sector. In 1974, the Government launched the world's largest public nuclear power program in response to the oil crisis in 1973. After four decades of unchanged support for nuclear power the new Government under President François Hollande has promised a significant shift in energy policy.

In 2012, France's 58 reactors[491] produced 407.4 TWh or 74.8 percent of the country's electricity, a drop of almost 3 percent. Nuclear generation and its share in France's power mix reached their maximum in 2005, with respectively 431.2 TWh and 78.5 percent. The annual load factor dropped another 2.3 percent to 73.6 percent, compared to countries that exceed 90 percent.

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[484] TVO, "TVO Board of Directors proposes new shareholder loan commitment to its shareholders", 27 February 2013, see http://www.tvo.fi/news/39, accessed 1 June 2013.

[485] FitchRatings, "Fitch Downgrades Teollisuuden Voima Oyj to 'BBB', Outlook Stable", 24 May 2013.

[486] TVO, "Construction of a Nuclear Power Plant Unit at Olkiluoto – General Description – OL4," www.tvo.fi/www/page/2840/, August 2008.

[487] WNN, "Bidding starts for Olkiluoto-4", 26 March 2012, see http://www.world-nuclear-news.org/NN-Bidding_starts_for_Olkiluoto_4-2603124.html, accessed 2 June 2012.

[488] Fennovoima, "Fennovoima received bids for nuclear power plant", press release, 31 January 2012.

[489] 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.

[490] Nucleonics Week, "Fennovoima, considering smaller reactor, opens negotiations with Rosatom", 11 April 2013.

[491] All pressurized water reactors, 34 x 900 MW, 20 x 1300 MW. and 4 x 1400 MW.

France has a significant base load overcapacity that has led to the "dumping" of electricity on neighboring countries and stimulated the development of highly inefficient thermal applications of electricity. A historical winter peak-load of 102 GW in February 2012, (up from 97 GW in December 2010) is to be compared with an installed capacity of 128.7 GW[492]. However, during the coldest days in February 2012, France imported up to 13 GW of power, of which Germany contributed about 3 GW (see also the following section on Germany).

France's seasonal peak electricity load has increased rapidly since the mid-1980s, due mainly to the widespread introduction of electric space and water heating in an effort to absorb the nuclear surplus – an issue anticipated by critics in the 1970s. Over 30 percent of French households now heat with electricity, the most wasteful form of heat generation because it results in the loss of most of the primary energy during transformation, transport, and distribution. The difference between the lowest load day in summer and the highest load day in winter is now over 70 GW. A drop of 1C° in outside temperature is equivalent to an increase in capacity of 2.3 GW. Short-term peak load cannot be met with nuclear power but rather by either fossil fuel plants or expensive peak-load power imports.

Considering its existing nuclear overcapacity's and the average age of its reactors (28.4 years in mid-2013), France should not need to build any new units for a long time. In addition, the nuclear share in the power mix is too high; lifetimes of operating units are planned to be extended; the shutdown of the gaseous diffusion uranium enrichment plant will save huge amounts of electricity[493], and several nuclear plants should be made redundant through efficiency.

If the French Government and EDF opt to proceed with construction of a new unit, then this is not to relief capacity constraints but because the nuclear industry faces a serious problem of maintaining competence in the field.

In December 2007, EDF started construction of Flamanville-3. The FL3 site encountered quality-control problems with basic concrete and welding similar to those at the Olkiluoto-3 (OL3) project in Finland, which had started two-and-a-half years earlier. As in Finland, the extensive employment of foreign workers exacerbated communication and social problems.[494] It took until April 2012 for the French safety authority to judge satisfactory the instrumentation and control (I&C) system solution proposed by EDF for FL3. The project is now at least four years late and not expected to start commercial operation before 2016. The price tag has more than doubled since construction start and has been increased to €8.5 billion in December 2012, €2 billion more than in 2011—a "terrible publicity", as trade journal *Usine Nouvelle* noted.[495] In addition, the Italian partner ENEL that held 12.5 percent of the project decided to quit the project. EDF is obliged to buy back ENEL's shares for an estimated €690 million.

Beyond the EPR building problems, the two state-owned companies EDF and AREVA continue to fight over several strategic issues: follow-up agreements on reprocessed uranium conversion, uranium enrichment, reprocessing and plutonium fuel fabrication, as well as the overall industrial strategy.

Even before the Fukushima accident, but especially after 3/11, there have been major difficulties with large investment projects—in Italy, the United Kingdom, and the United States—and all are taking a toll on the balance sheet and credit rating of France's major nuclear companies. While EDF

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[492] Capacity increased by 1,865 MW net in 2012, mainly from solar (+1,012 MW or +40 percent), wind (+757 MW) and natural gas (+981) additions, which largely compensated for the shutdown of just under 1,000 MW of oil and coal plants. Source: RTE, "Bilan électrique 2012", January 2013.

[493] The EURODIF plant at Tricastin consumed the production of up to three reactors and is scheduled for shut-down by the end of 2012.

[494] The French Nuclear Safety Authority (ASN) notes in an inspection report that a translator, one of only two French speaking individuals in a team of steel workers, "had difficulties to understand the questions" the inspectors asked, per ASN, "Letter to the Director of the FL3 Construction Project," 29 December 2010.

[495] Usine Nouvelle, "EDF a évité de pire sur l'EPR de Flamanville", 7 December 2013, see http://www.usinenouvelle.com/article/edf-a-evite-le-pire-sur-l-epr-de-flamanville.N187560, accessed 1 June 2013.

accumulated a huge debt burden that increased through 2012 by €8 billion to €41.5 billion net ($54 billion), AREVA lost €2.5 billion in 2011 and another €100 million in 2012. AREVA's debt increased by €400 million—equivalent to an additional provision for OL3—to almost €4 billion.[496] In December 2011, Standard & Poor's downgraded AREVA to 'BBB-' rating as well as its stand-alone credit profile of 'bb-'."[497] It has not changed since. AREVA's share price had plunged in 2012 by up to 88 percent of its peak 2007 value, while EDF shares had lost up to 85 percent of their value over the same period, hitting the bottom in January 2013. In December 2012, Moody's downgraded EDF's perspective from stable to negative.[498]

France also operates many other nuclear facilities, including uranium conversion and enrichment, fuel fabrication, and plutonium facilities. France and the United Kingdom are the only countries in the EU that engage in reprocessing, or separating plutonium from spent fuel. The U.K. has announced it will abandon reprocessing in the near future. France's two La Hague facilities are licensed to process 1,700 tonnes of fuel per year; however, all significant foreign clients have finished their contracts and have stopped plutonium separation. The La Hague operator AREVA NC therefore depends entirely on the domestic client EDF for future business, yet reprocessing's high cost burdens financially stressed EDF.

The current Government under President Hollande constitutes without any doubt a major rupture not only with his predecessor Nicolas Sarkozy, but also with previous administrations. For the first time since 1974, a French Government has announced plans for the closure of the oldest operating reactors (Fessenheim-1 and -2, connected to the grid in 1977), the abandoning of a new-build project (Penly-3) and the systematic reduction of the share of nuclear generated electricity (from about 75 to 50 percent by 2025). Currently a major national energy debate is ongoing that will lead to framework legislation to be submitted to the National Assembly before the end of 2013.[499]

Four days after 3/11, **Germany**'s conservative and pro-nuclear Government decided to shut down 8 of its fleet of 17 reactors. Originally for a three-month period, the closure of almost half of the German reactors turned out to be permanent. Nuclear power plants generated 94.1 TWh net in 2012—a drop of 29 percent compared to pre-3/11 year 2010—and provided 16.1 percent of the electricity (gross) in the country (1.5 percent less than in 2011 and down from the historic maximum of 30.8 percent in 1997)[500].

On 14 March 2011, Chancellor Angela Merkel abruptly announced putting plant life extension plans on hold and initiated a major re-shift of the country's nuclear policy. On 6 June 2011 the Government passed far-reaching energy transition legislation, including a revision (the 13th) of the Nuclear Law (Atomgesetz). The legislation passed the Bundestag on 31 July 2011 almost by consensus, and came into force on 6 August 2011. Key characteristics include:

- The operating licenses will expires once the production credit is used up and at the latest according to Table 5. 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.

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496 AREVA, "Résultats annuels 2012", 28 February 2013.

497 According to Standard & Poor's (S&P) credit rating categories, BBB- is the lowest S&P investment grade. If S&P did downgrade AREVA by one additional notch, it would slip into the junk bond category. S&P points out that AREVA's current rating incorporates three notches of uplift above the company's SACP [Stand-Alone Credit Profile] for "extraordinary state support". In other words, AREVA's SACP of bb- is already "junk" and just one notch off "highly speculative".

498 EDF, "Reference Document 2012", 5 April 2013.

499 For background see Mycle Schneider, "France's great energy debate", see http://bos.sagepub.com/content/69/1/27.abstract, 9 p. and Mycle Schneider, "Nuclear power and the French energy transition: It's the economics, stupid", see http://bos.sagepub.com/content/69/1/18.abstract, 9 p.; Bulletin of the Atomic Scientists, January-February 2013, the site has a paywall, accessed 2 June 2013.

500 These figures are from AGEB, "Bruttostromerzeugung in Deutschland von 1990 bis 2012 nach Energieträgern", February 2013.

• The production credit can be transferred from older to newer plants.

The legislative package included seven other laws ranging from energy efficiency (€3 billion per year for buildings) and increase in the use of renewable energy (with a new target of a 35 percent share of electricity by 2020) to natural gas as well as the large-scale extension of the grid system.

The German nuclear phase-out decision has generated widespread interest from other countries and has led to a number of unfounded claims, such as that 'Germany would have to replace nuclear electricity through increased coal consumption or nuclear power imports from France'. In fact, Germany made notable progress in energy efficiency, and gross electricity consumption decreased by 1.4 percent in 2011 and another 1.3 percent in 2012, while renewable energy generation increased by 32 percent over the same period and represented 22 percent in the power mix in 2012. However, cheap coal prices on the world market led to perverse effects: while production from natural gas plants dropped by almost 20 percent over the past two years, lignite plants boosted production by 9 percent over the same period and coal plants in 2012 reached the same production level as pre-3/11 year 2010. These effects, however, are expected to be brief and temporary.[501]

Table 5: Closure Dates for German Nuclear Reactors 2011-2022

Reactor Name (type, net capacity)	Owner/Operator	End of license (latest closure date)	First Grid Connection
Biblis-A (PWR, 1167 MW)	RWE	6 August 2011	1974
Biblis-B (PWR, 1240 MW)	RWE		1976
Brunsbüttel (BWR, 771 MW)	KKW Brunsbüttel[502]		1976
Isar-1 (BWR, 878 MW)	E.ON		1977
Krümmel (BWR, 1346 MW)	KKW Krümmel[503]		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	31 December 2015	1981
Gundremmingen-B (BWR, 1284 MW)	KKW Gundremmingen[504]	31 December 2017	1984
Philippsburg-2 (PWR, 1402 MW)	EnBW	31 December 2019	1984
Brokdorf (PWR, 1410 MW)	E.ON/Vattenfall[505]	31 December 2021	1986
Grohnde (PWR, 1360 MW)	E.ON		1984
Gundremmingen-C (BWR, 1288 MW)	KKW Gundremmingen		1984
Isar-2 (PWR, 1410 MW)	E.ON	31 December 2022	1988
Emsland (PWR, 1329 MW)	KKW Lippe-Ems[506]		1988
Neckarwestheim-2 (PWR, 1310 MW)	EnBW		1989

Notes: PWR=Pressurized Water Reactor; BWR=Boiling Water Reactor

Sources: Atomgesetz, 31 July 2011, Atomforum Kernenergie May 2011; IAEA-PRIS 2012

The key driver behind the increase in hard coal and lignite burning is the price signal on the European power exchange market, *not* the nuclear phase-out. Europe has a large structural overcapacity, so in the absence of a significant carbon price, there has been an increasing incentive to operate existing lignite and coal fired power plants – especially in 2012 when an unusually cold winter helped drive up competing natural-gas prices. Germany does not have any capacity problems, on the contrary, the country never exported more than in 2012 with 23 TWh *net,* a 3.7 fold increase over the previous year,

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[501] A.B. Lovins, "Germany's renewables revolution", 17 April 2013, http://blog.rmi.org/blog_2013_04_17_germanys_renewables_revolution, and blog on the disinformation campaign about Germany's *Energiewende*, http://blog.rmi.org, in press, July 2013

[502] Vattenfall 66,67%, E.ON 33,33%

[503] Vattenfall 50%, E.ON 50%

[504] RWE 75%, E.ON 25%

[505] E.ON 80%, Vattenfall 20%

[506] RWE 87,5%, E.ON 12,5%

and due to its highly competitive wholesale prices, (which renewable power has sharply reduced in the past few years), Germany is the only country that consistently exports electricity to France.

The Fukushima events and the political reaction accelerated industrial strategic shifts. Electronics giant Siemens, which built all of Germany's nuclear plants and exported more, announced in September 2011 that, after having left AREVA NP, the joint consortium with AREVA, it would quit the nuclear sector entirely. Siemens Chairman Peter Löscher declared that "we will not enter into the overall responsibility or the financing of the construction of nuclear power plants anymore. This chapter is closed for us. Siemens will be a motor for the German energy transition (Energiewende)".[507] In addition, Siemens entered into a "strategic alliance" with Boeing in the U.S. for the development and implementation of micro-grids. German utilities RWE and E.ON also pulled out of nuclear projects in various countries, including in the Bulgaria, Finland, the Netherlands and the U.K.

The **Netherlands** operates a single, 40-year-old 480 MW PWR that provided 3.7 TWh or 4.4 percent of the country's power in 2012 (down from a maximum of 6.2 percent in 1986). For comparison, renewables, mainly biomass and wind, accounted for over 10 percent in power generation in 2012.[508] In June 2006, the operator and the Government reached an agreement to allow operation of the reactor until 2033.[509]

On 23 January 2012, the utility DELTA announced it was putting off decision on nuclear new-build "for a few years" and that there would be "no second nuclear power at Borssele for the time being". The company provided the following reasons for its decision: "The financial crisis, combined with the substantial investment needed for a second nuclear power plant, current investment conditions, overcapacity in the electricity market and low energy prices."[510]

In early 2004, Borssele operator EPZ extended a reprocessing contract with AREVA NC. This is a curious decision considering that there are no possibilities in the Netherlands of using separated plutonium. Therefore, EPZ has paid the French utility EDF to get rid of the plutonium. However, more recently EPZ has applied for a license to load MOX fuel into the Borssele reactor, which was granted in June 2011.[511] The reasons for the change in plutonium management remain unknown. In France, the extracted plutonium has zero book value and negative market value.

Spain operates seven reactors, an eighth unit was shut down at the end of 2012. Nuclear plants provided 58.7 TWh or 20.5 percent of the country's electricity in 2012 (maximum of 38.4 percent in 1989). Beyond the de-facto moratorium that has been in place for many years, the previous Premier Jose Luis Zapatero announced at his swearing-in ceremony 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, "there will be no new nuclear plants."[512]

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507 Der Spiegel, "Kapitel abgeschlossen", 17 September 2011. One month earlier, Siemens had announced that it had entered a "strategic alliance" with the U.S. company Boeing to develop micro-grids to boost efficiency and the use of renewable energies. Source: Siemens, Press Release, 8 August 2011.

508 Statstics Netherlands, "More renewable electricity generated", 26 February 2013, see http://www.cbs.nl/en-GB/menu/themas/industrie-energie/publicaties/artikelen/archief/2013/2013-3785-wm.htm, accessed 2 June 2013.

509 WNA, "Nuclear Power in the Netherlands," www.world-nuclear.org/info/inf107.html, accessed 2 June 2013.

510 DELTA, "DELTA puts off decision for a few years, no second nuclear plant at Borssele for the time being", press release, 23 January 2012

511 Ministry of Economic Affairs, Ministry of Foreign Affairs, 4th National Report of the Netherlands, September 2011, prepared for the Fourth Review Conference of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, May 2012.

512 "Spain Insists on Energy Saving, Not Nuclear Plants," *Reuters*, 21 January 2009.

Spain has, however, been implementing both uprating and lifetime extensions for existing facilities. Licenses for the operating units would have run out between 2010 and 2018; however, in 2009 the Government extended the operating license of the then 40-year old Garoña plant to 2013, and in 2010 it granted the 30-year old Almaraz-1 plant a 10-year extension and a capacity increase of 7 percent. The 28-year old Almaraz-2 plant also will be uprated.[513] 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.[514]

Nevertheless, on 16 December 2012, Garoña was shut down definitively. The operator Nuclenor had calculated that further operation of the 446 MW plant would not be economic. Not only would Nuclenor have to invest about €120 million to upgrade the 42-year old plant, but it would also have to face a new tax of €153 million in 2013 following an energy tax reform that was overdue in Spain.

Spain is one of only three countries that increased opposition to nuclear energy since April 2011, according to a September 2012 update of a 24-country study by IPSOS: 63 percent of those polled oppose nuclear power, 6 percent more than in the previous study.[515]

The added capacity from Spain's nuclear uprating (64 MW at Almaraz so far) remains negligible compared to the country's surge in renewables. With an installed renewable electricity capacity of 34 GW (end of 2012), almost five times larger than its nuclear capacity, Spain is number four in the world.[516] Spain is also number four in the world in installed wind capacity, number six in installed PV capacity and a leader in concentrated solar power plants with over 2,500 MW installed, with over 800 MW added in 2012 alone.[517] Renewables have met over 30 percent of the Spanish electricity demand for the past three years and over half in spring 2013.

Sweden operates 10 reactors that provided 61.5 TWh or 38.1 percent of the country's electricity in 2012 (down from a maximum of 52.4 percent in 1996). Sweden's per capita power consumption is among the highest in the world, due primarily to the widespread and inefficient thermal use of electricity. In recent years, however, Sweden has had negative growth rates in residential electricity consumption.[518]

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; the other six were still 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) went off line in 2005.

On 5 February 2009, the parties of Sweden's conservative coalition government signed an agreement on energy and climate policy that defines ambitious renewable energy and energy efficiency targets and calls 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.[519] As a result, new plants could again be built—but only if an existing plant is shut down, meaning that the maximum number of operating units will not exceed the current ten. This puts Sweden many years away from potential new construction. Trade journal *Nuclear Intelligence Weekly* notes: "In 2012 Vattenfall asked the regulator

[513] "Spain Approves Increase in Nuclear Power Output, *Expansion* Says," Bloomberg.com, 4 January 2011.

[514] "No Limits for Spanish Reactors," WNN, 17 February 2011.

[515] IPSOS, op.cit.

[516] PEW, "Who is Winning the Clean Energy Race?", PEW Charitable Trust, April 2013.

[517] PEI, "What are the future prospects for utility-scale CSP?", May 2013.

[518] JRC, "Energy Efficiency Status Report 2012", 2012.

[519] "Swedish Government Overturns Nuclear Ban," www.neimagazine.com, 21 June 2010.

for more clarity regarding the newbuild process, but 2025 is the earliest date for any new units."[520] In the meantime utility Vattenfall envisages to extend lifetimes of five of its seven units at Forsmark and Ringhals to 60 years. The objective for Ringhals-1 and -2 is a 50-year lifetime.[521]

Operators have pushed uprating projects to over 30 percent: at Oskarshamn-2 a 38 percent capacity increase is under way while a 33 percent uprate has been implemented at Oskarshamn-3 with a two-year delay. Work at Oskarshamn-2 is also seriously delayed and not now expected to be completed before April 2014.[522]

Swedish public opinion remains split over general nuclear power acceptance. A 2012-update to a 24-country survey gives proponents a scant 52 percent majority.[523]

The **United Kingdom** operates 16 reactors as of 1 July 2013. Nuclear plants provided 64 TWh or 18.1 percent of the country's electricity in 2012 (down from a maximum of 26.9 percent in 1997). The first-generation Magnox reactors, with 11 stations, have all been retired, except for one at Wylfa, which is to close by the end of 2014.[524] The seven second-generation stations, the Advanced Gas-cooled Reactors (AGR), are also at or near the end of their design life, although the owners now plan to extend their life by seven years to 40 years with retirements only in 2016–29. The newest plant, Sizewell-B, is the United Kingdom's only PWR and was completed in 1995.

The industry has a long history of economic and technical problems. (See the chapter Economics of Nuclear Power), right up through the past decade: In 2004 the government prevented privately owned nuclear generator British Energy from going into liquidation. While the state-owned nuclear fuel and technology company BNFL was also effectively bankrupt because it could not meet its liabilities, the Government split up the company, passing the physical assets (and its costly decommissioning obligations) to a new agency, the Nuclear Decommissioning Authority (NDA), while the capabilities were privatized.

The NDA is now responsible for decommissioning all Britain's civil nuclear facilities except those owned by British Energy, a discounted liability[525] estimated in 2013 to be in excess of £58 billion ($90 billion)[526], up from less than £34 billion ($53 billion) in 2007. The NDA inherited negligible funds for this task, relying partly (and increasingly) on government grants and partly on income from the facilities still in operation, including one remaining Magnox reactor, the THORP reprocessing plant, and the Sellafield MOX Plant (SMP) a plutonium fuel manufacturing plant. Both of the latter facilities, however, have been plagued by very serious technical problems that have kept their operation significantly below expectations, if they were operating at all. An internal Government report on the SMP, released in June 2013, revealed that the plant had cost the taxpayer £2.2 billion (US3.4 billion) and that it was "not fit for purpose"[527]. Both plants are to be retired.

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520 NIW, "Potential and Existing Global Nuclear Newbuild Projects Open to International Vendors", 15 March 2013.

521 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.

522 OKG, "Early Indication of Delays in Modernisation of Oskarshamn 2", 23 April 2013, see http://www.okg.se/en/Media/News/Early-Indication-of-Delays-in-Modernisation-of-Oskarshamn-2/, accessed 2 June 2013.

523 IPSOS, op.cit.

524 Magnox, "Fact and figures", see http://www.magnoxsites.co.uk/our-sites/wylfa/facts-and-figures, viewed 5 June 2013.

525 The recent Nuclear Decommissioning Authority Annual Reports only give discounted figures. In the 2007/08 report the discounted £40.7 billion turn into an undiscounted £63 billion.

526 Nuclear Decommissioning Authority, "Annual Report and Accounts 2012/13", 2013.

527 Independent, "Revealed: £2bn cost of failed Sellafield plant". 9 June 2013.

In 2008, the Labour Government of Gordon Brown 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.[528] 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.[529] Northern Ireland and Scotland[530] are not included.

EDF Energy, wholly owned by French state utility EDF and currently the only remaining utility with a concrete investment plan, was given planning permission to build two reactors at Hinkley Point in April 2013. In February 2013 Centrica withdrew from the Hinkley project saying that "since our initial investment [in 2008], the anticipated project costs in new nuclear have increased and the construction timetable has extended by a number of years[531]." However, the Government remains in negotiation with EDF over the electricity price guarantee for the project which is estimated to cost £14 billion for two EPRs (see Economics of Nuclear Power)[532]. It is unclear when these negotiations will reach a conclusion and what impact EU State Aid approval will have. Recent reports suggest that final European Commission approval of the Government's Contract for Difference (CFD) scheme will take at least 18 months, if granted at all, and as of July 2013 the review process had not even begun[533]. Therefore, even if EDF and the U.K. Government reach an agreement on the strike price, construction would only begin before January 2015, if EDF had confidence in the final outcome of the State Aid review. Independent analysts suggest such confidence may not prove justified.

Two other consortia are considering investment in new nuclear in the U.K.. Horizon nuclear was bought by Hitachi from E.ON and RWE for an estimated price of £700 million (USD 1 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[534]. The remaining consortium, Nugen, is now a 50:50 partnership between Iberdrola and GDf-Suez after the British utility SSE pulled out in 2011. The consortium is planning to make an investment decision around 2015.

The only non-EU Western European country that operates nuclear power plants is **Switzerland**. It operates five reactors that generated 24.5 TWh and covered 35.9 percent of the country's electricity consumption in 2012 (down from a maximum of 44.4 percent in 1996). Until after 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. A local referendum on 13 February 2011 saw a slim 51/49 percent majority for future replacement of the 40-year old Mühleberg reactor that is expected to shut down by 2022. That same day, a cantonal referendum on a proposed geological repository in Nidwalden turned into a fiasco for its proponents, with 80 percent of voters refusing the nuclear waste disposal project.[535]

However, Fukushima had a 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

[528] DECC, "National Policy Statement for Nuclear Power Generation", July 2011.

[529] Bradwell, Hartlepool, Heysham, Hinkley Point, Oldbury, Sizewell, Sellfield, and Wylfa.

[530] The Scottish government is opposed to new build and said it would not allow replacement of the Torness and Hunterston plants once they will be shut down (likely in 2016 and 2023, respectively). Only 18 percent of the Scottish people supported new build in a pre-Fukushima poll, The Scotsman, "Only 18% of Scots Say 'Yes' to New Nuclear Power Stations", 27 September 2010.

[531] Guardian, "Centrica withdraws from new UK nuclear projects", 4 February 2013.

[532] See also numerous items in the Essential News section on the web www.WorldNuclearReport.org.

[533] ICIS, "European approval of UK's CFD subsidies may set-back launch – DECC", 21 June 2013.

[534] Telegraph, "Hitachi reluctant about UK nuclear reactor plan", 14 April 2013.

[535] "Bern Says Yes to Nuclear Power Plant," swissinfo.ch, 13 February 2011.

21 percent in two months.[536] 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 Strategy includes measures to reduce energy consumption and to boost renewable energies. The Government intends to articulate its Energy Strategy 2050 as "indirect counter proposal" to the "Nuclear Phase-out Initiative" (Sortir du nucléaire) launched in early 2013.[537] Various environmental, clean energy and anti-nuclear groups have initiated 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.[538]

Central and Eastern Europe

In **Bulgaria,** nuclear power provided 14.9 TWh or 31.6 percent of the country's electricity in 2012 (down from a maximum of 47.3 percent in 2002), with generation occurring at the remaining two units of the Kozloduy plant. Around 14 percent of the electricity produced in Bulgaria is exported. In reaction to an agreement during the 1992 G7 summit, implemented as part of Bulgaria's accession to the EU, the Bulgarian Government agreed to close the four VVER 440-230 designed units at Kozloduy, two of which were closed in 2002 and two in 2006, as they were deemed unsafe. Bulgaria has received €870 million ($1.14 billion) from the EU as compensation for the closure, for decommissioning, waste management and alternative energy sources. Despite this considerable grant, it is estimated that there remains a €579 million shortfall in the budget to decommission the units and the Government does not have a commitment to meet this shortfall. "The absence of sufficient funding arrangements puts the completion of the decommissioning processes at risk."[539]

Construction of a reactor at the Belene site began in 1985 but was suspended following the political changes in 1989 and formally stopped in 1992, due in part to concerns about the geological stability of the site. In 2004, a call for tender for completion of the 2 GW of nuclear capacity was made and seven firms initially expressed interest. In October 2006, Russia's ASE consortium, which involves the French nuclear constructor AREVA, Germany's Siemens, and Bulgarian firms, was awarded the contract, valued at the time at €4 billion ($5.8 billion). However, the deal failed to materialize as the Western partners pulled out. This led in November 2010 to a new memorandum of understanding (MoU) with the Russian state energy company Rosatom to re-establish the Belene Power Company with 51 percent initially being held by NEK. The most recent consortium proposed to start construction by October 2011. But in September 2011 the Russian company responsible for the export of reactors (AtomStroyExport) and the state utility (NEK) extended their pre-construction agreement until March 2012.

The Belene story took another twist in March 2012 when the project was officially cancelled by the Prime Minister. He stated "We just can't afford to pay the total cost of the project, which will reach

[536] AREVA, "Impact of Fukushima event on nuclear power sector – Preliminary assessment", 25 March 2011.

[537] Schweizerische Eidgenossenschaft, Bundesrat, "Bundesrat legt Energiestrategie 2050 als indirekten Gegenvorschlag zur Atomausstiegsinitiative vor", 15 March 2013, see http://www.news.admin.ch/message/index.html?lang=de&msg-id=48168, accessed 5 June 2013.

[538] Schweizerische Energiestiftung, "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.

[539] *European Court of Auditors,* "EU Financial Assistance For The Decommissioning Of Nuclear Plants In Bulgaria, Lithuania And Slovakia: Achievements And Future Challenges", Special report No 16, 2011 http://bookshop.europa.eu/en/eu-financial-assistance-for-the-decommissioning-of-nuclear-plants-in-bulgaria-lithuania-and-slovakia-pbQJAB11014/

some 10 billion euros. And there is no way we can make future generations pay."[540] Atomstroyexport announced on 11 September 2012 that it has increased its claim against NEK to €1 billion for losses connected with the cancelled Belene project.[541]

However, soon after the announcement, the Cabinet decided to allow construction of a 7th and potentially an 8th nuclear reactor at Kozloduy, although the Government made clear it will not participate in the project but will leave it to the private market. In January 2013 the CEO of the Kozloduy power plant said that negotiations were ongoing with a number of companies and that a new reactor could be in operation by 2022.[542]

A referendum was held in January 2013 in which a majority called for the continuation in the use of nuclear power, although the turnout at 21 percent was far under the 60 percent required to make the referendum binding, but rather required the Parliament to vote on the issue.[543] This vote took place in March 2013, permanently ending the Belene project. The options for new developments in Kozloduy was left open, but remain unlikely.

The **Czech Republic** has six Russian-designed reactors in operation at two sites, Dukovany and Temelín. The former houses four VVER 440-213 reactors, and the latter two VVER 1000-320 units. Between them, they produced a record 28.6 TWh, 35.3 percent of the country's electricity in 2012.

Temelín was the focus of considerable controversy since a decision was taken to restart construction in the mid-1990s after being halted in 1989. The two reactors were eventually started in 2000 and 2002, with financial assistance from the U.S. Export-Import Bank and I&C technology supplied by Westinghouse.

In July 2008, CEZ announced a plan to build two more reactors at Temelín, with construction to start in 2013 and commissioning of the first unit in 2020. In March 2010, CEZ announced that discussions had begun with three vendor groups prior to the bid submission: a consortium led by Westinghouse, a consortium of Škoda JS, Atomstroyexport, and OKB Gidropress; and France's AREVA.[544] In February 2011, the final delivery date was shifted to 2025.[545] In October 2011 CEZ asked for tenders from three companies (AREVA, Westinghouse and Atomstroyexport with Skoda) for a turnkey contract for the construction of two units plus nine years' worth of fuel. In October 2012, AREVA was excluded from taking any further part in the process as it was said to have failed to meet the commercial and technical requirements. AREVA is appealing the decision. However, the other bidders also have problems and CEZ requested that both the remaining consortium improve their bids in all areas.[546] In July 2013 CEZ announced that negotiations with the consortium would continue until at least October 2013.[547]

The financing of any future new-build in Czech Republic, as in the U.K. and other EU countries, is faced with the basic problem that the current market price for electricity falls below the break-even point for nuclear new-build. In this case, the Finance Minister has stated the electricity from new reactors at Temelin would cost €60-65/MWh, well above the current market price of €40.[548] Consequently, CEZ is looking for a Contract for Difference, along similar lines to the U.K., which

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[540] Reuters, "UPDATE 2-Bulgaria abandons Belene nuclear plant plans", 28 March 2012, http://www.reuters.com/article/2012/03/28/bulgaria-nuclear-idUSL6E8ES7A420120328, accessed 5 June 2013.

[541] NIW, "Russia Fires €1 Billion Claim for Belene Losses After Westinghouse Entry", 14 September 2012.

[542] Novinite.com, "CEO of Bulgaria's Kozloduy NPP: Unit 7 may be Functional by 2020-22", 28 January 2013.

[543] BBC, "Bulgaria nuclear vote 'invalidated by low turnout'", 27 January 2013.

[544] WNA, "Nuclear Power in Czech Republic," January 2013. http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Czech-Republic/#.UW_xnaI3vX4

[545] Reuters, "Czech CEZ Puts off Temelin Expansion Deadline to 2025," 18 February 2011.

[546] Bloomberg, "CEZ Says Temelin Atomic Plant Bidders Must Improve Offers", 25 March 2013

[547] Wall Street Journal Europe, "CEZ Postpones Deadline for Decision on Temelin Nuclear Tender", 2 July 2013.

[548] Prague Daily Monitor, "Kuba: Decision on Temelín can't be based solely on power prices", 17 April 2013

leads to a Government guaranteed electricity price for a fixed, multi-decade, period (see Economics section for more information).

The Dukovany plants have operated since the first half of the 1980s and have been the subject of engineering changes to extend the life of the reactors while simultaneously expanding their output by about 15 percent. The operators envisage that the units will continue operating until 2025.

Hungary has only one nuclear power plant at Paks, which houses four VVER 440-213 reactors that provided 14.8 TWh or 45.9 percent of the country's electricity in 2012 (down from a maximum of 51.4 percent in 1990). The reactors started commercial operation in the early 1980s and have been the subject of engineering works to enable their operation for up to 50 years accompanied by a 20 percent increase in capacity. In April 2003, the site's second reactor experienced the country's worst-ever nuclear accident, rated on the international scale as a "serious incident" (INES Level 3), which resulted in evacuation of the main reactor hall and the venting of radioactivity to the outside environment. The reactor was out of operation for 18 months. Despite this, in December 2012 the Hungarian Atomic Energy Authority completed a review, set to enable the first unit, which started operating in 1982, to operate until 2032. Similar approvals are expected for the other units.[549]

In March 2009, the Hungarian parliament approved a government decision-in-principle to build additional reactors at Paks.[550] The proposed additional units (5 and 6) "will not generate extra power but make up for the output of the phased-out blocks."[551] Russian assistance seems to be the preferred option, and Hungary's foreign minister has indicated that expansion of the Paks plant would be part of a "package deal" on outstanding economic issues with Russia.[552] Prime Minister Viktor Orban said in December 2011 that the goal is to have nuclear power provide 60 percent of the country's electricity needs, compared with around 40 percent now.[553] Nevertheless, Hungary has started preparations for a tender procedure that also should include other designs. It furthermore started a transboundary environmental impact assessment that notified all EU member states, Ukraine and Switzerland. In June 2012 it announced that it hoped that a reactor design would be chosen by 2014-15 with construction to start by 2017-18. A separate company has been set up to build the new units, which could enable an equity investor of up to 50 percent[554]. Meanwhile, according to a post-Fukushima survey, in April 2011, a 62 percent majority of Hungarians opposes new-build and a surprising 80 percent consider nuclear's viability "limited and soon obsolete".[555] In a September 2012 updated edition to the survey, opposition to nuclear power shrank but still held a 53 percent majority.[556]

Romania's Cernavoda nuclear power plant hosts Europe's only CANDU (Canadian-designed heavy water) reactors. The plant project was initiated under the regime of Nicolae Ceausescu in the 1970s and was initially proposed to house five units. Construction began in 1980 on all the reactors, in part using funding from the Canadian Export Development Corporation, but this was scaled back in the early 1990s to focus on unit 1. The unit was completed in 1996 at an estimated cost of around $USD 2.2 billion, nearly a decade late. The second unit, also completed with foreign financial assistance (a C$140 million [$USD 146 million] Canadian loan and a €223 million [$324 million] Euratom loan) was connected to the grid in August 2007. The two reactors generated 10.6 TWh or 19.4 percent of

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549 World Nuclear news, "New Lease of Life for Paks", 8 January 2013

550 John Shepherd, "Hungary's Parliament Paves Way to Build New Reactor Unit," NucNet, 31 March 2009.

551 Caboodle.hu "Hungary Mulls Plans to Build New Nuclear Blocks.", 14 January 2011.

552 Realdeal.hu "Hungary, Russia Seek to Resolve All Outstanding Issues in One Package, Says FM", 21 January 2011.

553 Bloomberg "Hungary Targets Expansion of Nuclear Energy Use", 15 December 2011 http://www.businessweek.com/ap/financialnews/D9RL10OO1.htm

554 Nuclear Intelligence Weekly, "Hungary: Newbuild Company Launched", 10 August 2012

555 IPSOS-2011, op.cit.

556 IPSOS-2012, op.cit.

Romania's electricity in 2012 (down from 20.6 percent in 2009). In 2012, Romania had the highest load factor in the world with 92.8 percent.

Plans are being actively developed to complete two additional units at the power plant. In November 2008, an investment agreement was signed between SNN and ENEL of Italy, CEZ of the Czech Republic, GDF Suez of France, and RWE Power of Germany (with each having 9.15 percent) as well as Iberdrola of Spain and ArcelorMittal Galati of Romania (with both having 6.2 percent). Commissioning of unit 3 was due initially in October 2014 and unit 4 in mid-2015; however, this has since been revised, with the first unit not expected to be completed until 2016 at the earliest. In January 2011, two months before Fukushima, CEZ sold its shares to Nuclearelectrica, and GDF Suez, RWE, and Iberdrola also withdrew from the project, explaining: "Economic and market uncertainties surrounding this project, related for the most part to the present financial crisis, are not reconcilable now with the capital requirements of a new nuclear power project."[557]

In late 2012, the Government sent letters to CEZ, GDF SUEZ, RWE and Iberdrola inviting them back into the project, but there has been no reported response to the request. Despite this the Government believes that it can still complete the project and has given the project until the end of 2013 to find financial partners. As Minister of Economy Varujan Vosganian stated, "We do not have enough funds to finance the construction of the reactors 3 and 4."[558] According to the *Curierul National*, the latest feasibility study conducted by Ernst & Young shows that the investment required to build reactors 3 and 4 is €7.67 billion - almost double the estimates of 2008 of €4 billion.[559] It has been suggested that China Guangdong Nuclear Power Group (CGN) is in talks to purchase 40 percent of an equity stake in the two new reactors.[560]

In **Slovakia**, the state utility Slovak Electric (SE) operates all four nuclear power plants at two sites: Bohunice, which houses two VVER 440 units, and Mochovce, which has two similar reactors. In 2012, these provided 14.4 TWh or 53.8 percent of the country's electricity production (down from a maximum of 57.4 percent in 2003). Of the three other reactors that once existed at Bohunice, the first, A1, was closed after two meltdown accidents in the late 1970s. Two older VVER 440-230 reactors were closed in 2006 and 2008 as part of the 1992 G7 agreement and the EU-accession partnership agreement. The two remaining operational units were the subject of both uprating (from 440 MW to 505 MW each) and upgrading (extending their operating lives to 40 years), which would enable the station to operate until 2025.[561]

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 ($2.9 billion) in new nuclear generating capacity, including completion of the third and fourth blocks of Mochovce. In February 2007, SE announced that it was proceeding with this initiative and that ENEL had agreed to invest the lower amount of €1.8 billion ($2.6 billion). In July 2008, the European Commission gave a conditioned opinion on the Mochovce 3 and 4 project, noting that the reactor did not have the "full containment" structure used in the most recent nuclear power plants planned or under way in Europe and requesting that the investor and national authorities implement additional features to withstand a potential impact from a small aircraft.[562]

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557 GDF-Suez, RWE, and Iberdrola, "GDF-Suez, RWE and Iberdrola Have Decided Not to Continue to Participate in the Cernavoda Nuclear Project in Romania," press release, 20 January 2011.

558 The Diplomat Bucharest, "Power play: the sorry saga of Romania's energy projects", February 2013

559 Curierul National, "Nuclearelectrica dry before listing", google translate of original article, 4 April 2013 see; http://www.curierulnational.ro/Eveniment/2013-04-04/Nuclearelectrica,+uscata+inainte+de+listare

560 Nuclear Intelligence Weekly, Briefs-Romania, 2 November 2012

561 TheDaily.sk, "SE Switches on Two Upgraded Nuclear Power Units," 11 October 2010.

562 European Commission, "Commission Issues Its Opinion on Units 3 and 4 of the Slovak Nuclear Power Plant of Mochovce," IP/08/1143 (Brussels: 5 July 2008).

Construction at Mochovce restarted on 3 December 2008. The units were expected to commence operation in 2012 and 2013. Initially €2.775 billion was allocated to the completion of the project.[563] It is now expected that unit three will be completed in 2014 and unit 4 in 2015, with a revised total budget of €3.8 billion.[564]

In **Slovenia**, the Krsko nuclear power plant was the world's first reactor to be owned jointly by two countries, **Croatia** and Slovenia. The reactor, a 688 MW Westinghouse PWR, was connected to the grid in 1981 and is due to operate until 2021. The output, 5.2 TWh in 2012, is shared between the two countries and covered 36 percent of Slovenia's power consumption that year (down from a maximum of 57.4 percent in 2003). Discussions remain ongoing for the construction of a second reactor at the site; a decision has been delayed several times in both countries.

In April 2013 the newly appointed Infrastructure Minister, Samo Omerzel, said that he wanted to focus on completing work on the thermal and hydro power stations and would reconsider the completion of a second reactor at Krsko.[565]

The Slovenian state-owned utility, GEN Energija, was reported to be in turmoil in March 2013 after a judge overturned the board's decision to dismiss its Director General, Martin Novsak. The reason for his dismissal was that he concealed a report from IRSN, the Technical Support Organization (TSO) of the French Nuclear Safety Authorities that advised against construction of a second unit on the grounds of seismic concerns. In a letter to GEN Energija, IRSN Director General Jacques Repussard states that "this new and serious finding does not allow concluding in a favorable manner as regards the suitability of the Krsko II sites for the implementation of a new nuclear power plant".[566] In addition, Repussard states: "IRSN considers that it is of utmost importance that the possible implications on the safety of the existing plant of this fault capability, as well as its potential structural relationship to nearby faults, be addressed without delay." In a response dated 26 February 2013, GEN Energija argues that IRSN's conclusions on site suitability "might be premature" and that GEN "is currently conducting a comprehensive field investigation to develop a greater understanding of features on Libna Hill", the incriminated fault line close to the Krsko site.[567]

Former Soviet Union

Armenia has one remaining reactor at the Medzamor (Armenia-2) nuclear power plant, which is situated within 30 kilometres of the capital Yerevan and provided 2.1 TWh or 26.6 percent (down from 45 percent in 2009) of the country's electricity in 2012. 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."[568]

In December 1988, Armenia suffered a major earthquake that killed some 25,000 people and led to the rapid closure of the 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, the younger of the two units.

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[563] WNA, "Nuclear Power in Slovakia", April 2013, http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Slovakia/#.UXeiuaI3vX4

[564] The Slovak Spectator, "Mochovce to be completed in 2014/15", 8 April 2013

[565] ANSA Med, "Slovenia: minister, Krsko nuclear plant plan to be reviewed", 3 April 2013

[566] IRSN, DG Jacques Repussard, letter to GEN Energija DG Martin Novsak, dated 9 January 2013.

[567] GEN Energija, DG Martin Novsak, letter to IRSN DG Jacques Repussard, dated 26 February 2013.

[568] DOE, Office on Energy Intelligence, *Most Dangerous Reactors: A Worldwide Compendium of Reactor Risk* (Washington, DC: May 1995).

The closure of Medzamor is linked, by the Government to the construction of a new nuclear power plant.[569] The EU is critical of this linkage stating: "In the EU's view it remains doubtful whether such action is needed in order to generate sufficient replacement capacity. The country has developed enough alternative energy sources to replace the 400 Megawatt currently stemming from Medzamor. Current Armenian ideas go however towards export of energy."[570] In October 2012, the Armenia Government announced that it would operate the Medzamor unit until 2026. This led to Turkish authorities calling for the immediate closure of the power station.[571]

The new reactor is planned to be a 1000 MW unit with negotiations continuing with the Russian authorities, including the signing of an inter-government agreement in August 2010. However, the Government has yet to attract funding for the project that was estimated by a U.S.-funded feasibility study to cost at as much as $5 billion[572] and commissioning is now not expected until 2020 at the earliest.

Russia has one of the most aggressive nuclear power construction programs in the world with 10 reactors under construction and suggestions of deals imminent for further projects all over the world. However, a more careful review shows an industry that has historically over-promised and has failed to meet its domestic targets and deliver on declared international sales.

In 2012, nuclear power provided 161.1 TWh or 17.8 percent of Russian electricity, the same level as the record year of 2009. However, across the country there is significant regional variation with for example nuclear power providing 30 percent in the European part of the country. Russia is one of the few countries in which nuclear power's contribution has been increasing, although slowly as twenty years ago it provided 12 percent. There are 33 reactors in operation, four first-generation VVER 440-230s and 11 RBMKs (the Chernobyl type), four are small (11 MW) BWRs used for cogeneration in Siberia, one is a fast breeder the BN-600, and 13 are second-generation light water reactors (two VVER 440-213s and 11 VVER 1000s).

The life extension of the RBMK reactors is an important issue as the regulator (Rostekhnadzor) issued the licenses for lifetime extension nuclear units without public hearing and without environmental impact assessment. However, there are on-going aging problems with the first unit at Leningrad which was mothballed in the first part of 2013, while it is decided how to address the swelling in the graphite moderator.[573]

During 2012 construction started on one reactor, the Baltic-1, a VVER 1200, near Kaliningrad, the first new construction start for nearly two years. The project is subject to international opposition as the Environmental Impact Assessment does not comply with Russian norms and has not been adequately discussed with neighboring countries.[574] In May 2013, construction of Baltic-1 was "reported halted"[575], "as the possibility to export its power appears less certain", due to lower-than-expected demand and thus lack of investments in transmission infrastructure.[576] It was later reported

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[569] Asbarez "IAEA Head Inspects Medzamor Nuclear Plant", 18 April 2012 http://asbarez.com/102433/iaea-head-inspects-medzamor-nuclear-plant/

[570] European Commission, "European Neighbourhood and Partnership Instrument, Armenia, Country Strategy Paper, 2007-2013." European Neighbourhood Policy

[571] USAID, "Turkey renews demands for 'immediate closure' of Armenian nuke plant", 5 November 2012, USAID web site, http://www.armesri.am/News.html

[572] USAID, "Government extends service life of Metsamor NPP for another ten years", 19 October 2012, USAID web site, http://www.armesri.am/News.html

[573] Nucleonics Week, "Russian regulator gives Smolensk-1 Operating Life Extension to 2022", 17 January 2013

[574] 15min.it, "Russian experts join criticism of Kaliningrad nuclear facility", 19 September 2012

[575] Bellona, "Baltic NPP debacle: Construction reported halted, possibly mothballed", 30 May 2013, see http://www.bellona.org/articles/articles_2013/baltic_npp_debacle, accessed 23 June 2013.

[576] WNN, "Grid concerns for Baltic project", 11 June 2013, see http://www.world-nuclear-news.org/NN_Grid_concerns_for_Baltic_project_1106131.html, accessed 11 June 2013.

that "construction was frozen for two years",[577] while the project remains "under construction" according to IAEA statistics.

The VVER 1200 is the most widely adopted reactor design in Russia, with four others under construction and a number of further units planned. However, to date, none are operational and they have been subject to construction delays. The two units at Novovoronezh, when commissioned in 2009 were expected to start up in 2012 and 2013[578], but are now expected in 2014 and 2016.[579] There are two more reactors at Leningrad II, where the first unit is expected to be commissioned in 2014 with the second unit is now only expected in 2016, two years late.[580] Controversy remains over the cooling for the reactors which will extract water from the Baltic Sea; a request to change the design was supported by the St. Petersburg and Leningrad Oblast Legislative Assemblies.

Included in the IAEA's list of new-builds are three units that were started in the 1980s. These include two earlier VVER reactors at Rostov (due for completion in 2014 and 2017) and an RBMK at Kursk, the latter of which Rosatom (the State nuclear energy corporation) abandoned in February 2012.

Also under-construction is the Beloyarsky-4 (BN-800) a fast breeder reactor. Construction of the reactor first started in 1985, but was stopped following Chernobyl. At the time of the restart of the construction, it was said that much of the infrastructure was already completed[581] and that it would be completed in 2012. It is now expected to be completed in 2014 or 2015. The project is said to have been delayed by lack of funds. Also included in the construction list are two 35 MWe so-called floating reactors, (KLT-40S), which will be housed on a single vessel. These were ordered in February 2009 and expected to be delivered to the customer at the end of 2012[582], but are now expected only in 2014. Critics of the project point out that the risk of accidents on a floating nuclear plant is greatly increased because it is even more susceptible to the elements, subject to threats of piracy and if deployed widely will increase the risks of nuclear material proliferation.[583]

More than most countries a key issue for Russia will be the aging of its nuclear fleet. Currently, the working life of a reactor is considered to be 30 years and 17 of Russia's nuclear reactors are 30 or more years old.[584] To counter this, plans were announced in 2010 for life extensions of the oldest reactors, which would include extending the life span and expanding the capacity of the VVER 440s and RBMK reactors by 15 years and the VVER-1000 for 25 years.

For decades, the nuclear sectors in Russia and the former Soviet Union have promised that it would increase its electricity production. In 1992, Minatom announced plans to double nuclear energy

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[577] 15 Min.lt, "Rosatom orders conservation of unfinished nuclear power plant at Kaliningrad", 4 June 2013, see http://www.15min.lt/en/article/world/rosatom-orders-conservation-of-of-unfinished-nuclear-power-plant-in-kaliningrad-529-341922, accessed 6 July 2013.

[578] WNN, "Construction starts at second Novovoronezh-II unit", 14 July 2009 http://www.world-nuclear-news.org/NN-Construction_starts_at_second_Novovoronezh_II_unit-1407094.html

[579] WNA, "Nuclear Power in Russia", February 2013 http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/#.UULxO6LwnX4

[580] WNN, "Construction starts at Leningrad II", 27 October 2009, http://www.world-nuclear-news.org/NN-Construction_starts_at_Leningrad_II-2710084.html

[581] NucNet, "Beloyarsky-4 Construction On Schedule, Says Russia", 15 December 2006 http://www.analys.se/lankar/Internat/NucNet/internatNucRew50_06.htm, accessed 7 June 2013.

[582] NEI "KLT-40S nuclear barge project still afloat", 9 March 2010, see http://www.neimagazine.com/features/featureklt-40s-nuclear-barge-project-still-afloat/, accessed 11 March 2013

[583] NTI, "Floating nuclear reactors could fall prey to terrorist, experts say", 13 August 2010, Global Security Newswire, see http://www.nti.org/gsn/article/floating-nuclear-reactors-could-fall-prey-to-terrorists-experts-say/, accessed 11 March 2013

[584] IEA, "Russia", US Energy Information Administration, 18 September 2012, http://www.eia.gov/countries/cab.cfm?fips=RS, accessed 7 June 2013.

capacity by 2010[585], but instead it increased by only 40 percent.[586] In June 2010 the Government revised its latest target which would see 43 GW of nuclear capacity by 2030, implying a near doubling of the existing capacity. Rosatom's long-term strategy for 2050 envisages nuclear providing 45-50 percent of electricity by 2050 and 70-80 percent by the end of the century.[587] Sergei Kiriyenko, the chief of Rosatom, said that by 2030 it wants to build 38 reactors in Russia and 28 abroad, mainly in Europe and Asia.[588]

Russia has exported reactors in the past, including to Iran (where Russian engineers completed the Bushehr plant), India and China. In addition, most of the plants in Central and Eastern Europe were built using Soviet designs. The most concrete plans for new-build are in similar areas, including in China, India and Ukraine, where six reactors are being built. Less defined plans are said to be for Argentina, Bangladesh, Belarus, Czech Republic, Jordan, Syria, Turkey, Vietnam, and Venezuela.[589,590] (For an assessment of these projects, see national country reports and the Newcomer section). However, with the majority of these proposed sales to countries that currently don't have any nuclear power programs, there are no prospects for rapid construction and a high probability that they won't go beyond paper proposals.

Ukraine has 15 reactors in operation with an installed capacity of 13 GW, which provided 84.8 TWh or 46.2 percent of the country's electricity in 2012 (down from a maximum of 51.1 percent in 2004). In addition to the operating reactors, the country has four closed reactors at Chernobyl and two reactors under-construction at Khmelnitski.

Chernobyl was the site of the world's worst nuclear accident, in 1986, when unit four suffered a massive explosion and fire which lead to radioactive contamination across the Eurasian continent. However, it did not result in the immediate closure of the stations. Instead the remaining units were restarted and unit 2 operated until it suffered a further fire in 1991. Unit 1 was then closed in 1996 and in December 2000 as part of an international agreement to finance measures to build a sarcophagus around unit 4 and undertake remedial work near the station. As of the end of 2010, a total of $990 million had been pledged by national governments and the European Commission to the Chernobyl Shelter Fund. This, along with a project build an interim spent fuel store, will require an additional €740 million.[591]

Since the Chernobyl accident, construction has not started on any new reactors, although a number of projects which were started before 1986 have been completed. The most recent was in 2004, the 2nd unit at Khmelnitsky. Consequently, the average age of reactors in Ukraine is now 25 years. As with Russia, in Ukraine many of the reactors are now approaching the end of their 30-year design life and they will either have to close or undergo life extension programs. In March 2013, the European Bank for Reconstruction and Development (EBRD) awarded the state-owned nuclear operator, Energoatom, a €300 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, with further funding, also of around €300 million, to come

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585 Federal Research Division, "Russia Country Studies", Library of the US Congress, http://countrystudies.us/, accessed March 2013

586 BP, "BP Statistical Review of World Energy" 2012

587 Nuclear News, "Russia speeds up nuclear investment", 22 November 2012, see http://www.world-nuclear-news.org/NP_Russia_speeds_up_nuclear_investment_2211121.html, accessed 7 June 2013.

588 Enformable, "Putin dubs 20 year construction of nuclear power plant 'renaissance' of atomic energy", 12 December 2011, see http://enformable.com/2011/12/putin-dubs-20-year-construction-of-nuclear-power-plant-renaissance-of-atomic-energy/, accessed 7 June 2013.

589 PowerMag, "Russia's Nuclear Mission", 1 August 2010, http://www.powermag.com/nuclear/Russias-Nuclear-Mission_2867_p4.html, accessed 7 June 2013.

590 WNA, "Nuclear Power in Russia", February 2013, http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/#.UUghJhfwnX4

591 EBRD, "Chernobyl 25 years on: New Safe Confinement and Spent Fuel Storage", European Bank for Reconstruction and Development, http://www.ebrd.com/downloads/research/factsheets/chernobyl25.pdf, 2011

from the EU through the Euratom loan facility[592]. 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"[593]. 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 October 2008, Atomstroyexport, of Russia, was said to have been awarded the contract from the completion of the 3rd and 4th units at Khmelnitsky, at a cost of $5-6 billion[594]. In February 2011, Russia and Ukraine signed an intergovernmental agreement to resume work on the third and fourth units. Russia is to finance the design, construction, and commissioning of the two reactors, as well as any services and goods the country supplies. In September 2012 the Verkhovaya Rada (Parliament) of Ukraine adopted in the first reading the draft laws on the construction of the third and fourth reactors, with 80 percent of the financing expected to come from Russia and the remainder coming from Energoatom. Critics of the project highlighted that Ukraine is already a net exporter of electricity.[595] Ukraine is rapidly increasing its electricity exports, with a 50 percent increase in 2011 over the previous year[596] and a similar increase in 2012. Electricity exports from Ukraine in 2012 in monetary terms were estimated at $574.8 million, with exports to Belarus totaling $231.4 million, to Moldova $52.7 million, Hungary $224.3 million, Poland $50.7 million, Romania $9.9 million, and Slovakia $5.8 million[597]. The EBRD claims that their nuclear project will enable Ukraine to increase its exports and that the project should "allow Ukraine greater flexibility to trade with the EU".[598]

[592] EBRD, "Nuclear Power Plant Safety Upgrade Programme", European Bank for Reconstruction and Development, accessed March 2013, http://www.ebrd.com/english/pages/project/psd/2011/42086.shtml
[593] Energoatom, "Ecological Assessment Report, main report", 31 January 2012 http://www.energoatom.kiev.ua/atachs/EARMR310112.pdf
[594] Moscow News, "Russia signs deal with Ukraine on finishing Khmelnitsky nuclear power plant", 9 June 2010
[595] Little Skylark, "Verkhovna Rada Decided To Finish The Khmelnitsky NPP", 6 September 2012, http://littleskylark.com/blog/verkhovna-rada-decided-to-finish-the-khmelnitsky-npp/, accessed 7 June 2013.
[596] WNU, "Ukraine Increases Electricity Export by 73%", 27 August 2012, see http://wnu-ukraine.com/news/economy-business/?id=2074, accessed 7 June 2013.
[597] Interfax, "Ukraine boosts electricity exports 39.3% in Jan and Feb", 13 March 2013, http://en.interfax.com.ua/news/economic/144358.html#.UUhfAxfwnX4, accessed 7 June 2013.
[598] EBRD, "Nuclear Power Plant Safety Upgrade Programme", European Bank for Reconstruction and Development, http://www.ebrd.com/english/pages/project/psd/2011/42086.shtml, accessed 7 June 2013.

Annex 2: Reactor Construction Times 2003-2013

Construction Times (in years) *Startups between 2003 and July 2013*				
Country	**Units**	**Mean Time**	**Min**	**Max**
China	11	5.9	4.4	11.2
India	6	6.7	5.1	8.8
S. Korea	5	4.4	4.0	5.3
Japan	4	4.4	3.8	5.1
Russia	3	23.8	19.2	26.8
Ukraine	2	18.8	18.2	19.5
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	**34**	**9.4**	**3.8**	**26.8**

Sources: IAEA-PRIS, MSC, 2013

Annex 3: Definition of Credit Rating by the Main Agencies

<table>
<tr><th colspan="2">Moody's</th><th colspan="2">S&P</th><th colspan="2">Fitch</th><th></th></tr>
<tr><th>Long-term</th><th>Short-term</th><th>Long-term</th><th>Short-term</th><th>Long-term</th><th>Short-term</th><th></th></tr>
<tr><td>Aaa</td><td rowspan="6">P-1</td><td>AAA</td><td rowspan="4">A-1+</td><td>AAA</td><td rowspan="4">F1+</td><td>Prime</td></tr>
<tr><td>Aa1</td><td>AA+</td><td>AA+</td><td rowspan="3">High grade</td></tr>
<tr><td>Aa2</td><td>AA</td><td>AA</td></tr>
<tr><td>Aa3</td><td>AA-</td><td>AA-</td></tr>
<tr><td>A1</td><td>A+</td><td rowspan="2">A-1</td><td>A+</td><td rowspan="2">F1</td><td rowspan="3">Upper medium grade</td></tr>
<tr><td>A2</td><td>A</td><td>A</td></tr>
<tr><td>A3</td><td rowspan="2">P-2</td><td>A-</td><td rowspan="2">A-2</td><td>A-</td><td rowspan="2">F2</td></tr>
<tr><td>Baa1</td><td>BBB+</td><td>BBB+</td><td rowspan="3">Lower medium grade</td></tr>
<tr><td>Baa2</td><td rowspan="2">P-3</td><td>BBB</td><td rowspan="2">A-3</td><td>BBB</td><td rowspan="2">F3</td></tr>
<tr><td>Baa3</td><td>BBB-</td><td>BBB-</td></tr>
<tr><td>Ba1</td><td rowspan="14">Not prime</td><td>BB+</td><td rowspan="6">B</td><td>BB+</td><td rowspan="6">B</td><td rowspan="3">Non-investment grade speculative</td></tr>
<tr><td>Ba2</td><td>BB</td><td>BB</td></tr>
<tr><td>Ba3</td><td>BB-</td><td>BB-</td></tr>
<tr><td>B1</td><td>B+</td><td>B+</td><td rowspan="3">Highly speculative</td></tr>
<tr><td>B2</td><td>B</td><td>B</td></tr>
<tr><td>B3</td><td>B-</td><td>B-</td></tr>
<tr><td>Caa1</td><td>CCC+</td><td rowspan="5">C</td><td rowspan="5">CCC</td><td rowspan="5">C</td><td>Substantial risks</td></tr>
<tr><td>Caa2</td><td>CCC</td><td>Extremely speculative</td></tr>
<tr><td>Caa3</td><td>CCC-</td><td rowspan="3">In default with little prospect for recovery</td></tr>
<tr><td rowspan="2">Ca</td><td>CC</td></tr>
<tr><td>C</td></tr>
<tr><td>C</td><td rowspan="3">D</td><td rowspan="3">/</td><td>DDD</td><td rowspan="3">/</td><td rowspan="3">In default</td></tr>
<tr><td>/</td><td>DD</td></tr>
<tr><td>/</td><td>D</td></tr>
</table>

Source: Wikipedia, 2012

Annex 4: About the Authors

Mycle Schneider is an independent international consultant on energy and nuclear policy based in Paris. He is a member of the International Panel on Fissile Materials (IPFM), based at Princeton University, U.S.. He has provided information and consulting services, amongst others, to the Belgian Energy Minister, the French and German Environment Ministries, the U.S. Agency for International Development, the International Atomic Energy Agency, Greenpeace, the International Physicians for the Prevention of Nuclear War, the Worldwide Fund for Nature, the European Commission, the European Parliament's Scientific and Technological Option Assessment Panel and its General Directorate for Research, the Oxford Research Group, and the French Institute for Radiation Protection and Nuclear Safety. Mycle has given evidence and held briefings at national Parliaments in thirteen 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 eighteen 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.

Peter A. Bradford, a former member of the United States Nuclear Regulatory Commission (NRC) and former chair of the New York and Maine utility regulatory commissions, has taught at the Yale School of Forestry and Environmental Studies and currently is an Adjunct Professor at Vermont Law School teaching "Nuclear Power and Public Policy." Mr. Bradford is also a commissioner on New York's Moreland Commission on Utility Storm Response and on the Texas/Vermont Low Level Radioactive Waste Commission. A member of the China Sustainable Energy Policy Council, he served on a recent panel evaluating the reliability of the Vermont Yankee nuclear power plant, on the European Bank for Reconstruction and Development (EBRD) Panel advising how best to replace the remaining Chernobyl nuclear plants in Ukraine, a panel on the opening of the Mochovce nuclear power plant in Slovakia, and the Keystone Center collaborative on nuclear power and climate change. He is the author of "Fragile Structures: A Story of Oil Refineries, National Securities and the Coast of Maine" and many articles. He is a graduate of Yale University and the Yale Law School and is Vice Chair of the board of The Union of Concerned Scientists (UCS).

Julie Hazemann 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 coop.

Komei Hosokawa, MA, PhD, teaches environmental sociology, development studies and energy policy issues at the School of Social and Environmental Research, Kyoto Seika University, Kyoto. He is co-chair of the Pacific-Asia Resource Center (PARC), Tokyo. He also serves as board director of the Takagi Fund for Citizen Science and of Greenpeace Japan. He is a social scientist by training, and has longtime field research experience in Indigenous communities and environment in Australia. In the late 1980s, Australia-Japan uranium issues led him to take an active part in the social movements concerning nuclear power questions in Japan and abroad. He is accredited member of the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS), Canberra. Recently he was appointed chief secretary of the Citizens' Commission on Nuclear Energy (CCNE), an independent think-tank launched by the Takagi Fund. CCNE aims to deliver alternative, sensible and comprehensive policy guidelines toward nuclear phaseout in Japan.

Steve Thomas is Professor of Energy Policy and Director of Research for the Business School, University of Greenwich. Mr. Thomas 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.

Yukio Yamaguchi, PhD in Engineering (University of Tokyo), studied condensed matter physics at the University of Tokyo Graduate School of Science. He has taught in Northwestern University, University of Tokyo, Hosei University and several other schools. He is deeply concerned about the relations between the problems of science education and the problems of nuclear energy; and published a number of books in these topics particularly targeted at middle and high school students. He is familiar with the history of grassroots resistance in Japan. Since 1998, he is co-director of the Citizen's Nuclear Information Center (CNIC), Tokyo. He is also an enthusiastic supporter and practitioner of organic farming.

Annex 5: Abbreviations

ABWR – Advanced Boiling Water Reactor

ADR – Alternative Dispute Resolution

AECL – Atomic Energy Canada Limited

AGEB – Artbeitsgemeinschaft Energiebilanz

AGR – Advanced Gas Reactor

APWR – Advanced Pressurized Water Reactor

ASN – French Nuclear Safety Authority

BERR – Department for Business, Enterprise and Regulatory Reform (U.K.)

BNEF – Bloomberg New Energy Finance

BOO – Build, Own and Operate

BOOT – Build-Own-Operate-Transfer

BWR – Boiling Water Reactor

CANDU – Canadian Deuterium Uranium

CCS – Carbon Capture and Storage

CEA – French Atomic Energy Commission

CEO – Chief Executive Officer

CFD – Contract for Difference

CGN or CGNPC – Chinese Guangdong Nuclear Power Company

CHP – Combined Heat and Power

CNEA – Comision Nacional de Energia Atomica – Argentina

CNSC – Canadian Nuclear Safety Commission

CNNC – Chinese National Nuclear Company

COL – Construction and Operation Licence

CSN – Consejo de Seguridad Nuclear – Spain Safety Authority

DAC – Design Acceptance Certificate

DECC – Department of Energy and Climate Change – U.K.

DGEC – Direction générale de l'énergie et du climat – France

DGEMP – Direction générale de l'énergie et des matières premières – France

DOE – US Department of Energy

EBITDA – Earnings before interest, taxes, depreciation and amortization

EC/EBIDTA – Enterprise Value Earnings before interest, taxes, depreciation and amortization

EDF - Électricité de France

EIA – Environmental Impact Assessment

EMR – Electricity Market Reform

ENEC – Emirates Nuclear Energy Corporation

EPR – European Pressurized Water Reactor or Evolutionary Pressurized Water Reactor#

ERÚ – Czech Energy Regulatory Office

ESBWR – Economic Simplified Boiling Water Reactor

ESP – Early Site Permit

EU – European Union

EU ETS – European Union Emissions Trading System

EVN – Electricity of Vietnam

EWEA – European Wind Energy Association

FANC – Belgian Nuclear Control Authority

FANR – Federal Authority for Nuclear Regulation - United Arab Emirates

FCF – Free Cash Flow

FL3 – Flamanville-3

FIT – Feed-in Tariff

GDA – Generic Design Assessment

GWEC – Global Wind Energy Council

I&C – Instrumentation and Control

IAEA – International Atomic Energy Agency

IDAC – Interim Design Acceptance Certificate

IEA – International Energy Agency

IEEJ – Institute for Energy and Economics of Japan

INES – International Nuclear Events Scale

INIG – Integrated Nuclear Infrastructure Group

IRSN – Institut de radioprotection et de sûreté nucléaire – France

IZES – Institut für Zukunfts Energie Systeme

JAEC – Jordon Atomic Energy Commission or Japan Atomic Energy Commission

JAIF – Japan Atomic Industrial Forum

JNES – Japan Nuclear Energy Safety Organisation

JSW – Japan Steel Works

KA-CARE – King Abdullah City for Atomic and Renewable Energy

KEPCO – Korea Electric Power Corporation or Kansai Electric Power Corporation – Japan

KHNP – Korea Hydro and Nuclear Power

KINS – Korean Institute of Nuclear Safety

K-POPONS – The Korean Professors' Organization for a Post-Nuclear Energy Society

LTS – Long Term Shutdown

METI – Ministry of Economics, Trade and Industry

MoU – Memorandum of Understanding

MOX – Mixed Oxide Fuel

mSv – millisievert

mSv/h – millisievert per hour

NAIIC – National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission

NDA – Nuclear Decommissioning Authority

NEI – Nuclear Engineering International

NEXI – Nippon Export and Investment Insurance

NINA – Nuclear Innovation North America

NIW – Nuclear Intelligence Weekly

NNB GenCo – Nuclear New Build Generation Company

NPS – National Policy Statement (U.K.)

NPV – net present value

NPCIL – Nuclear Power Corporation of India Ltd

NPI – Nuclear Power International

NPT – Non-Proliferation Treaty

NNC – National Nuclear Centre (Kazakhstan)

NPP – Nuclear Power Plant

NRA – Nuclear Regulation Authority – Japan

NRC – Nuclear Regulatory Commission – U.S.

NSG – Nuclear Suppliers Group

NSSC – Nuclear Safety and Security Commission – Korea

OECD – Organisation for Economic Development and Co-operation

OFGEM – Office for Gas and Electricity Markets – U.K.

OL3 – Olkiluoto-3

ONR – Office of Nuclear Regulation – U.K.

OPG – Ontario Power Generation

PAEC – Pakistan Atomic Energy Commission

PBMR – Pebble Bed Modular Reactor

PGE – Polska Grupa Energetyczna

PLEX – Plant Life Extension

PPA – Power Purchase Agreement

PRIS – Power Reactor Information System

PSC – Public Service Commission

PV – Photovoltaic

PwC – PricewaterhouseCoopers

PWR – Pressurized Water Reactor

RBMK – Light water cooled, graphite moderated

S&P – Standard and Poor's

SCRO – State Research Council Office – China

SCE(&G) – Southern California Electric (& Gas)
SE – Slovak Electric
SEA – Strategic Environmental Assessment
SNPTC – State Nuclear Power Technology Corp. – China
STP – South Texas Project
STUK – Finnish Radiation and Nuclear Safety Authority
Sv – Sievert
Sv/h – Sievert per hour
TANE – Toshiba American Energy Corporation
TEPCO – Tokyo Electric Power Company
TFEU – Treaty on the Functioning of the European Union
TVA – Tennessee Valley Authority
TVO – Teollisuuden Voima Tyj
UAE – United Arab Emirates
UBS – Union Bank of Switzerland
VEB – Vnesheconombank
VVER – Light Water Reactor – Russian design
WACC – Weighted Average Cost of Capital
WANO – World Association of Nuclear Operators
WNA – World Nuclear Association
WEC – World Energy Council
WNISR – World Nuclear Industry Status Report
WNN – World Nuclear News

Electrical Units

kW – kilowatt (unit of installed electric power)
kWh – kilowatt-hour (unit of electricity)
MW – megawatt (10^6)
MWe – megawatt electric
GW – gigawatt (10^9)
GWe – gigawatt electric
TWh – terawatt hour (10^{12})

Annex 6. Status of Nuclear Power in the World (1 July 2013)

Countries	Nuclear Reactors[1]				Power[2]	Energy[3]
	Operate (Reactors)	Capacity (MWe)	Average Age (Years)	Under Construction[4] (Reactors)	Share of Electricity[5]	Share of Commercial Primary Energy
Argentina	2	935	34	1	5%(=)	2%
Armenia	1	375	33		27%(−)	?%
Belgium	7	5 926	33		51%(−)	15%
Brazil	2	1 884	22	1	3%(=)	1%
Bulgaria	2	1 906	24		32%(=)	20%
Canada	19	13 532	30		15%(=)	7%
China	18	13 816	8	28	2%(=)	<1%
Czech Republic	6	3 766	22		35%(+)	16%
Finland	4	2 736	34	1	33%(=)	20%
France	58	63 130	28	1	75%(−)	39%
Germany	9	12 068	28		16%(−)	7%
Hungary	4	1 889	28		46%(+)	16%
India	20	4 388	19	7	4%(=)	1%
Iran	1	915	2		<1% (+)	<1%
Japan	44	38 009	26		2,1%(−)	<1%
Mexico	2	1 530	21		5%(=)	1%
Netherlands	1	482	40		4%(=)	1%
Pakistan	3	725	19	2	5%(+)	2%
Romania	2	1 300	11		19%(=)	8%
Russia	33	23 643	30	9	18%(=)	6%
Slovakia	4	1 816	21	2	54%(+)	21%
Slovenia	1	688	32		36%(−)	?%
South Africa	2	1 860	27		5%(=)	3%
South Korea	23	20 718	18	4	30%(−)	13%
Spain	7	7 112	29		21%(=)	10%
Sweden	10	9 395	34		38%(−)	28%
Switzerland	5	3 263	38		36%(−)	20%
Taiwan	6	5 018	32	2	18%(=)	8%
Ukraine	15	13 107	25	2	46%(=)	16%
United Kingdom	16	9 243	30		18%(=)	8%
USA	100	98 903	34	3	19%(=)	8%
EU27	**131**	**121 457**		**4**	**27%(=)**[6]	
World Total	**427**	**364 078**	**28**	**66**	**10%(–)**[3]	**4,5%**

Notes

[1] Mycle Schneider Consulting, based on IAEA, PRIS database, July 2013, and others.
[2] In 2012, based on IAEA, PRIS database, July 2013.
[3] BP, "Statistical Review of World Energy", June 2013.
[4] As of 1 July 2013.
[5] A +/-/= in brackets refer to change in 2012 versus the level in 2011; a change of less than 1% is considered =.
[6] Eurostat, "Electricity Statistics", 2011, http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=File:Electricity_Statistics,_2011_%28in_GWh%29.png &filetimestamp=20120507123319, accessed 7 June 2012.

Annex 7. Nuclear Reactors in the World Listed as "Under Construction" (1 July 2013)

Country	Units	MWe (net)	Construction Start	Planned Grid Connection
Argentina				
…Atucha-2	1	692	1981/07/14	Middle of 2013[1]
Brazil				
…Angra	1	1 245	2010/06/01	2016[2]
China[3]	28	27 790		
…Changjiang-1		*610*	2010/04/25	2014
…Changjiang-2		*610*	2010/11/21	2015
…Fangchenggang-1		*1000*	2010/07/30	2015
…Fangchenggang-2		*1000*	2010/12/23[4]	2016
…Fangjiashan-1		*1000*	2008/12/26	2013/12
…Fangjiashan-2		*1000*	2009/07/17	2014/10
…Fuqing-1		*1000*	2008/11/21	2013/11
…Fuqing-2		*1000*	2009/06/17	2014/09
…Fuqing-3		*1000*	2010/12/31	2015/07[5]
…Fuqing-4		*1000*	2012/11/17	2016/05[6]
…Haiyang-1		*1000*	2009/09/24	2014/06
…Haiyang-2		*1000*	2010/06/21	2015/03
…Hongyanhe-2		*1000*	2008/03/28	2013
…Hongyanhe-3		*1000*	2009/03/07	2014
…Hongyanhe-4		*1000*	2009/08/15	2014
…Ningde-2		*1000*	2008/11/12	2013
…Ningde-3		*1000*	2010/01/08	2014
…Ningde-4		*1000*	2010/09/29	2015
…Sanmen-1		*1000*	2009/04/19	2014/03[7]
…Sanmen-2		*1000*	2009/12/17	2015/09
…Shidao Bay-1		*200*	2012/12/09	2016
…Taishan-1		*1660*	2009/10/28	2014[8]
…Taishan-2		*1660*	2010/04/15	2015
…Tianwan-3		*1050*	2012/11/17	2017
…Yangjiang-1		*1000*	2008/12/16	2013/08
…Yangjiang-2		*1000*	2009/06/04	2014
…Yangjiang-3		*1000*	2010/11/15	2015
…Yangjiang-4		*1000*	2012/11/17	2017
Finland				
…Olkiluoto-3	1	1 600	2005/08/12	2016 [9]
France				
…Flamanville-3	1	1 600	2007/12/03	2016[10]
India	7	4 824		
…Kakrapar-3		*630*	2010/11/22	2015/03/31
…Kakrapar-4		*630*	2010/11/22	2015/09/30
…Kudankulam-1		*917*	2002/03/31	2013/07 (commercial operation)[12]
…Kudankulam-2		*917*	2002/07/04	2014/03 (commercial operation)[13]
…PFBR		*470*	2004/10/23	2014 (commercial operation)[14]
…Rajasthan-7		*630*	2011/07/18	2016/03/31
…Rajasthan-8		*630*	2011/09/30[11]	2016/09/30
Pakistan	2	630		
…Chasnupp-3		*315*	2011/05/28	2016/09/01
…Chasnupp-4		*315*	2011/12/18	2017/07/01

Country	Units	MWe (net)	Construction Start	Planned Grid Connection
Russia[15]	9	7 273		
…BN-800		*789*[16]	1985[17]	2014[20]

...*Leningrad-2-1*		*1085*	2008/10/25	2016 (commercial operation)[21]
...*Leningrad-2-2*		*1085*	2010/04/15	2016? (commercial operation)[22]
...*Novovoronezh-2-1*		*1114*	2008/06/24	2014 (commercial operation)[23]
...*Novovoronezh-2-2*		*1114*	2008/07/12	2016 (commercial operation)[24]
...*Lomonosov-1*		*32*	2007/04/15	2019/12 (commercial operation)[25]
...*Lomonosov-2*		*32*	2007/04/15	2019/12 (commercial operation)[26]
...*Rostov-3*		*1011*	1983[18]	2014 (commercial operation)[27]
...*Rostov-4*		*1011*	1983[19]	2017/06 (commercial operation)[28]
Slovakia	2	880		
...*Mochovce-3*		*440*	1985/01/01[29]	2014/10[31]
...*Mochovce-4*		*440*	1985/01/01[30]	2015/10[32]
South Korea	5	6 320		
...*Shin-Kori-3*		*1340*	2008/10/31	2013/09 (commercial operation)[33]
...*Shin-Kori-4*		*1340*	2009/09/15	2014/12 (commercial operation)[34]
...*Shin-Wolsong-2*		*960*	2008/09/23	2014 (commercial operation)[35]
...*Shin Hanul-1*		*1340*	2012/7/12	2017/04 (commercial operation)[36]
...*Shin Hanul-2*		*1340*	2013/6/19	2018/04 (commercial operation)[37]
Taiwan	2	2 600		
...*Lungmen-1*		*1300*	1999/03/31	2014-15 (commercial operation)[38]
...*Lungmen-2*		*1300*	1999/08/30	2015 (commercial operation)[39]
Ukraine	2	1 900		
...*Khmelnitski-3*		*950*	1986/03/01	2015/01/01[40]
...*Khmelnitski-4*		*950*	1987/02/01	2016/01/01[41]
United Arab Emirates	2	2 690		
...*Barakah-1*		*1 345*	2012/07/18	2017[42]
...*Barakah-2*		*1 345*	2013/05/30	2018[43]
USA	3	3 399		
...*Virgil C. Summer-2*		*1 117*	2013/03/09	2017/03/15[44]
...*Vogtle-3*		*1 117*	2013/03/12	mid-2017[45]
...*Watts Bar*		*1 165*	1972/12/01	2015/09-12[46]
Total	66	63 443	1972-2013	2013-2019

Sources: IAEA-PRIS, 2013, unless otherwise noted.

Notes

[1] Delayed multiple times. This date from Nucleoeléctrica Argentina S.A., "El hombre que logró terminar Atucha II", accessed 22 June 2012. IAEA-PRIS indicates 1 July 2013.

[2] Delayed multiple times. IAEA commercial startup 1 January 2016 reintroduced in 2013, http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=26, accessed 22 June 2013.

[3] No IAEA startup date for any Chinese reactor (except Fuqing-3 and Changjiang-2). The estimate for all reactors are drawn or derived from www.world-nuclear.com/info/inf63.html, accessed 15 June 2013.

[4] This date was introduced by IAEA-PRIS at a much later date. The WNA gives 2011 as construction start, see http://www.world-nuclear.com/info/inf63.html, accessed on 22 June 2013.

[5] IAEA gives 31 July 2015 as commercial operation date, see http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=935, accessed 22 June 2013.

[6] Operation previously announced for 2017 by WNA (December 2012). Last estimate May 2016 from www.world-nuclear.com/info/inf63.html, WNA, Nuclear Power in China, updated 7 June 2013, accessed 15 June 2013.

[7] WNA says Sanmen -1 "is expected to load fuel in 2013 and begin operation in 2014 with the second about one year later", WNA, "Chinese Nuclear Energy", Updated 30 April 2013, see http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/#.UYEjs4UgpGw, accessed 1 May 2013.

[8] Commercial operation for Taishan reactors 2014 & 2015, WNA, "Chinese Nuclear Energy", Updated 30 April 2013 - http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/#.UYEjs4UgpGw, accessed 1 May 2013.

[9] After numerous revisions of the original planned commissioning in 2009, the date refers to "commercial operation". Teollisuuden Voima (TVO) is preparing for the possibility that the start of the regular electricity production of Olkiluoto 3 nuclear

power plant unit may be postponed until year 2016" TVO, Information About the Start-up of Olkiluoto 3 Nuclear Power Plant Unit, 11 February 2013, http://www.tvo.fi/news/32, accessed February 11, 2013.

[10] Delay of at least four years from original planning. EDF maintains this target date for first "commercialization of electricity" in spite of persisting major building issues (concreting, maintenance bridge…), see EDF, "Remplacement des consoles du pont de manutention du bâtiment réacteur", Note d'information, 16 mars 2012.

[11] Announced only in February 2012.

[12] Delayed numerous times. No IAEA or WNA startup date. The latest IAEA date (2011/02/28) was simply dropped without being replaced. Construction at least 5 years behind schedule. Commercial operation 2013/07 according to NPCIL, Plants Under Construction, Kudankulam, http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=77, accessed 15 June 2013

[13] Delayed numerous times.. Construction at least 5 years behind schedule. No IAEA start-up date. Commercial operation 2014/03 according to NPCIL, Plants Under Construction, Kudankulam, http://www.npcil.nic.in/main/ConstructionDetail.aspx?ReactorID=77, accessed 15 June 2013

[14] Delayed numerous times. No IAEA start-up date. This estimate for commercial operation from www.world-nuclear.org/info/inf53.html, delayed from 2012 to 2013 a year ago, and to 2014 in latest versions. According to update from 1 May 2012, reactor was 86 percent complete, M.V. Ramana, personal communication, 14 June 2012.

[15] Note on the Kursk-5 project: We decided to pull it from the list. No IAEA startup date is given and it was deleted from the WNA construction list. WNA states on its website: "In February 2012 Rosatom confirmed that the project was terminated." Kursk-5 is based on an upgraded RBMK design.

Note on Baltiisk (Baltic nuclear plant): We have withdrawn the project from the list after reports that construction was halted and the reactor replaced by a smaller design, see http://www.bellona.org/articles/articles_2013/baltic_npp_debacle, accessed 23 June 2013.

[16] Capacity increased from 750 MW to 789 MW since July 2012.

[17] The IAEA Power Reactor Information System (PRIS) database curiously provides a construction start date as 2006/07/18. Until 2003, the French Atomic Energy Commission (CEA) listed the BN-800 as "under construction" with a construction startup date of "1985." In subsequent editions of the CEA's annual publication ELECNUC, Nuclear Power Plants in the World, the BN-800 had disappeared.

[18] Originally construction started in 1983 and it resumed after interruptions in September 2009, from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/, accessed 4 May 2012.

[19] Originally construction started in 1983 and, after interruptions, "first new concrete" was poured in June 2010, from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/, accessed 4 May 2012.

[20] Delayed numerous times; no IAEA startup date. This estimate from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/, accessed 4 May 2012.

[21] No IAEA startup date. This estimate from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/, accessed 16 June 2013 (previous estimate 10/2013 in December 2012).

[22] No IAEA startup date. This estimate from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/, accessed 16 June 2013.

[23] [No IAEA startup date.] Delayed from 2012/12/31. 31/12/2014 from PRIS, Novovoronezh-2-1 Reactor Details

http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=898, accessed 15 June, 2013.

[24] No IAEA startup date. This estimate from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/, accessed 16 June 2013.

[25] IAEA commercial operation date. Commercial operation originally planned for 2010 at Severod. Since moved to Lomonosov and delayed by two years.

[26] IAEA commercial operation date. Commercial operation originally planned for 2010 at Severod. Since moved to Lomonosov and delayed by two years. Then delayed by another two years to 2014.

[27] No IAEA startup date. This estimate from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/, accessed 15 June 2013.

[28] Delayed from 2016. No IAEA startup date. This estimate from http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/, accessed 15 June 2013.

[29] On 11 June 2009 construction officially resumed.

[30] On 11 June 2009 construction officially resumed.

[31] Delayed numerous times. This date from PRIS, Mochovce-3 Reactor Details, Updated 14 June 2013 - http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=544, accessed June 15, 2013.

and The Slovak Spectator, "Mochovce to be completed in 2014/15", 8 April 2013

[32] Delayed numerous times. This date from PRIS, Mochovce-3 Reactor Details, Updated 14 June 2013 - http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=544, accessed June 15, 2013.

and The Slovak Spectator, "Mochovce to be completed in 2014/15", 8 April 2013.

[33] No IAEA startup date. Delayed. This date from www.world-nuclear.org/info/inf81.html, accessed 16 June 2013.

[34] No IAEA startup date. Delayed. This date from www.world-nuclear.org/info/inf81.html, accessed 16 June 2013.

[35] No IAEA startup date. Delayed. Startup date of 2012/05/28 withdrawn from IAEA-PRIS. This date from www.world-nuclear.org/info/inf81.html, accessed 16 June 2013.

[36] New name for Shin Ulchin. Commercial operation date of 2017/04 from www.world-nuclear.org/info/inf81.html, accessed 15 June 2013, whereas Commercial date introduced by IAEA in late May (Shin Hanul-1 Reactor Details, Updated 30 May 2013) is 06/2016 http://www.iaea.org/pris/CountryStatistics/ReactorDetails.aspx?current=887 accessed 31 May 2013;

[37] No IAEA mentioning as of 29 June 2013; Commercial operation date of 2017/04 from www.world-nuclear.org/info/inf81.html, accessed 29 June 2013.

[38] No IAEA startup date. Delayed many times from original start-up date of mid-2006. This date according to media reports, including http://mobile.globalpost.com/dispatch/news/regions/asia-pacific/120305/taiwan-nuclear-power-plant-longmen-lungmen, accessed 5 May 2012 and Nucleonics Week, "Lungmen critic gives legislators plan for reinspection, oversight", 2 May 2013.

[39] No IAEA startup date. Delayed many times from original start-up date of mid-2006. This date according to media reports, including http://mobile.globalpost.com/dispatch/news/regions/asia-pacific/120305/taiwan-nuclear-power-plant-longmen-lungmen, accessed 5 May 2012 and Nucleonics Week, "Lungmen critic gives legislators plan for reinspection, oversight", 2 May 2013.

[40] Delayed numerous times.

[41] Delayed numerous times.

[42] No IAEA startup date. This estimate from WNA, Nuclear Power United Arab Emirates, Updated May 2013 - http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Arab-Emirates/#.Ubx_sIUgojo, accessed 15 June, 2013.

[43] No IAEA startup date. This estimate from WNA, WNA, Nuclear Power United Arab Emirates, Updated May 2013 - http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Arab-Emirates/#.Ubx_sIUgojo, accessed 29 June, 2013.

[44] No IAEA startup date. "Substantial completion", according to SCE, "Quarterly Report to the South Carolina Office of Regulatory Staff", Quarter Ending 31 March 2013.

[45] No IAEA startup date. This estimation from WNA, Nuclear Power in the USA, Updated April 2013 - http://www.world-nuclear.com/info/Country-Profiles/Countries-T-Z/USA--Nuclear-Power/#.UYFBUoUgqiY, accessed 1 May, 2013.

[46] Delayed again. Now scheduled for startup by December 2015, see TVA press release, "Watts Bar 2 Progress Remains on Track", 11 April 2013, see http://www.tva.com/news/releases/aprjun13/wbn2.html, accessed 22 June 2013.