Probabilistic Assessment of Global Nuclear Power Plant Construction Through 2030

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ABOUT WORTHINGTON SAWTELLE

Worthington Sawtelle LLC is a consulting and research firm which provides a full portfolio of business planning and strategy services to both new and existing participants in these emerging markets, including: market assessments, policy analysis and development; business strategy; go-to-market planning and launch; product commercialization strategies; feasibility studies; and due diligence on behalf of investors.

Global and national energy systems are evolving at a record pace. New technologies enter the market daily – many deployed with networking architecture and capabilities unheard of until now. Alternative (we think of them as "preferred") sources of energy that have been peripheral or thought of as inconsequential in the past have gained significant market share. Maneuvering and succeeding in this new landscape – and seascape – requires sophisticated navigation.

ABOUT THE AUTHOR

Gerry Runte began his career as Nuclear Fuel Manager with General Public Utilities Corporation (GPU). At the time GPU was one of the few utilities contracting for all stages of the nuclear fuel cycle and was acquiring fuel for the systems four nuclear units: Three Mile Island Units 1 and 2; Oyster Creek and Forked River. After the accident at TMI-1, Runte was a member of a small team that successfully raised the additional $750 million necessary to complete cleanup. He was the owner's representative on behalf of Cajun Electric G&T's 30% share of the River Bend Nuclear Station. In the late 80s and early 90s, Runte was Manager of Rate Affairs for GPU Nuclear Corporation, where he implemented a program to assure the corporation's preparedness to withstand operational and management prudence reviews. In the early 90s, Runte was Director of Strategic Planning for the GPU System.

After GPU, Runte served in executive leadership roles at the Gas Technology Institute (GTI) and two of its fuel cell development companies, Mosaic Energy and M-C Power Corporation.

In his current position as Principal at Worthington Sawtelle LLC, a consultancy specializing in emerging energy technologies, and previously as General Manager of Clean Energy at ARES Corporation, Runte has played a central role in developing partnerships, structuring joint ventures, and guiding product commercialization in the clean energy and alternative fuels sectors.

Runte holds a Bachelor's degree in Math and Chemistry and a Masters in Nuclear Engineering, both from Pennsylvania State University.

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1 EXECUTIVE SUMMARY

1.1 Research Objectives

The nuclear power industry has begun to receive serious attention once again with the promise of new reactor designs and has increasingly been named among the portfolios of national governments as long-term sources of electricity. Unfortunately, this industry has a long history of over optimism in terms of both the readiness of technology and its economics. Those parties interested in determining the kinds of growth opportunities in nuclear power business sector might offer them need a realistic appraisal of what is likely to emerge in the next eight years.

This report answers several questions regarding commercial nuclear power: Is the perceived resurgence of this industry plausible and if so, how much of a market does it constitute? Are nuclear capacity addition forecasts accurate? Are cost estimates for plant construction and operation reasonable? How does the cost of electricity from these new designs compare with alternative sources of electricity?

This report also attempts to provide some context to the business of nuclear power, insight as to why it declined in the 80s and then remained dormant over much of the 90's; what issues have been resolved since then and what barriers remain.

The objectives of the report are to equip the reader with realistic and objective insight into:

- The nature of the nuclear power "renaissance" and whether or not it is a short term or sustainable change in the industry; and
- Cost assessments and comparisons of nuclear technologies among themselves and other electricity generation sources

By providing

- A synthesis forecast of all available official information regarding new nuclear plant capacity plans and capital investment; and a
- Probabilistic forecast of new nuclear plant capacity and investments through 2030.

1.2 Scope

This report examines the global nuclear power industry and its prospects between 2014 and 2030. The report scope includes:

- Brief history of nuclear power commercial development;
- Basics of nuclear generation; descriptions of the primary technologies deployed as well as the new generations of reactor designs currently in development;
- Impact of the Fukushima-Daichi incident on the commercial industry;
- Market drivers and barriers;
- Assessment of the economics of the new generation technologies and how they compare with other generation sources; and
- Forecasts of capacity additions as well as capital investments in nuclear power from 2014-2030.

In addition to providing a business context to commercial nuclear power, this report provides:

- Insight into the relative economics of comparable sources of electricity generation;
- A discussion of the economics of the large scale NPPs now in construction and the small modular reactor (SMR) designs that are in development; and
- A more meaningful way to look at the growth projections of this industry.

1.3 Methodology

Worthington Sawtelle reviewed the most recent primary forecasts for nuclear power plant construction (capacity, scheduled commercial operation, construction status, cost) produced by the World Nuclear Association, the International Atomic Energy Agency, the U.S. Energy Information Administration, the Nuclear Energy Institute and the International Energy Agency. These forecasts were further refined and supplemented by:

- Reports and presentations by the staff of all relevant government agencies and state owned entities, including those of the U.S. Nuclear Regulatory Commission, the Russian State Nuclear Organizations, the China National Nuclear Corporation and the Indian Department of Atomic Energy;
- Direct testimony in rate regulatory proceedings regarding the timing and costs of nuclear plants currently under construction in several U.S. states, and;
- Private sector company financials and plans from investor and conference presentations.

In addition, we consulted secondary sources for the report, including industry journals and publications, product literature, white papers and technical journals, and financial reports for industry suppliers.

All Key Participants cited in the report were given the opportunity to be interviewed or provide input and most complied.

The base year for analysis and projection is 2014. With 2014 as a baseline, we developed market projections for 2014 to 2020 and then to 2030. These projections begin with a database that synthesizes the above sources. We then combined its unique understanding of the key market drivers, and their impact from a historical and analytical perspective, with scenario and probability based forecasting techniques to capture the uncertainties in the forecast. Each of the market forecast sections in this report give detailed descriptions of the analytical methodologies used. All dollar projections presented in this report are in 2013 constant dollars unless otherwise cited.

1.4 Observations

Commercial nuclear power generation has had an unsettled role among the world's choices for electricity generation. There have been periods when it was hailed as the single best option for long term, large-scale economical electricity generation. There have also been periods where, at least in certain countries, nuclear power generation was regarded as anathema. Indeed, during the 80's and 90's, very few nuclear power plants (NPPs) were constructed. Beginning in the early 2000's nuclear power seemed to be making a comeback with the promise of safe, environmentally sound and economic power generation delivered by a new generation of reactor designs. A few environmental groups even accepted it as having a place among low carbon energy source portfolios.

In this decade, most countries are planning for a future where sources of electricity are environmentally benign, but sufficiently robust and economic to fuel strong economic growth. Developing nations view energy and electricity as a potential constraint on their economic growth; their available energy needs to stay ahead of their economy's leaps and bounds. Nuclear power is a strong consideration in these countries but less so in developed nations where capital is limited and energy demand is flat. In 2011 it accounted for about 12.3% of electricity supply worldwide; in 2012 about 13.5%.

Much of the enthusiasm for nuclear comes from the promises of several new reactor designs including advanced pressurized water and boiling water reactors (PWR and BWR), as well as gas cooled reactors and fast neutron reactors (GCR and FNR). These new designs have passive safety measures that allow for safe shutdown without operator intervention. In addition, another group of small modular reactors (SMR) are in development that are scalable to meet specific energy demands of several hundred megawatts (MW).

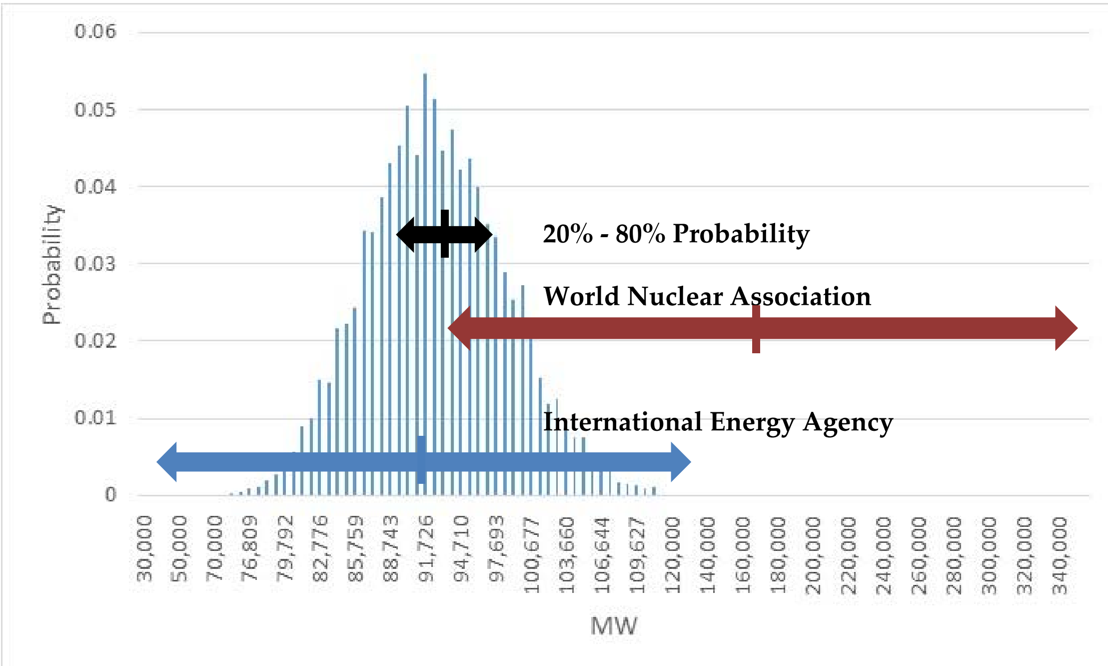
Many of the same issues that plagued nuclear power in the past remain unresolved: cost; waste management; decommissioning expense and perceived risk. The Fukushima-Daichi incident in Japan in 2011 heightened awareness to these issues and caused reductions in many nuclear power construction plans.

Assessing business opportunities in nuclear power is no simple task because of its hybrid nature. Governments developed the technology as an adjunct to nuclear weapons and nuclear submarine programs. Construction and operation of NPPs remains a government role in most countries. In fact, it is fair to say that nuclear power fits best in the context of large centrally planned economies where substantial financial resources are available and where the government bears the economic and technological risk. Nuclear power is nonetheless a commercial venture in some free market economies with varying degrees of autonomy from government control with a very large network of fully commercial suppliers for components. Governments and the supplier sector, both of whom need to market the viability of the technology and influence public opinion for continued support, heavily influence most forecasts of nuclear power growth. Some governments chose to be rather opaque regarding details, especially regarding costs and the extent to which reported costs are subsidized. These circumstances have resulted in consistently overstated forecasts and overly optimistic anticipated costs, traditions that continue today.

We believe a reasonable approach to assessing this industry incorporates a probabilistic forecast of new capacity and investment.

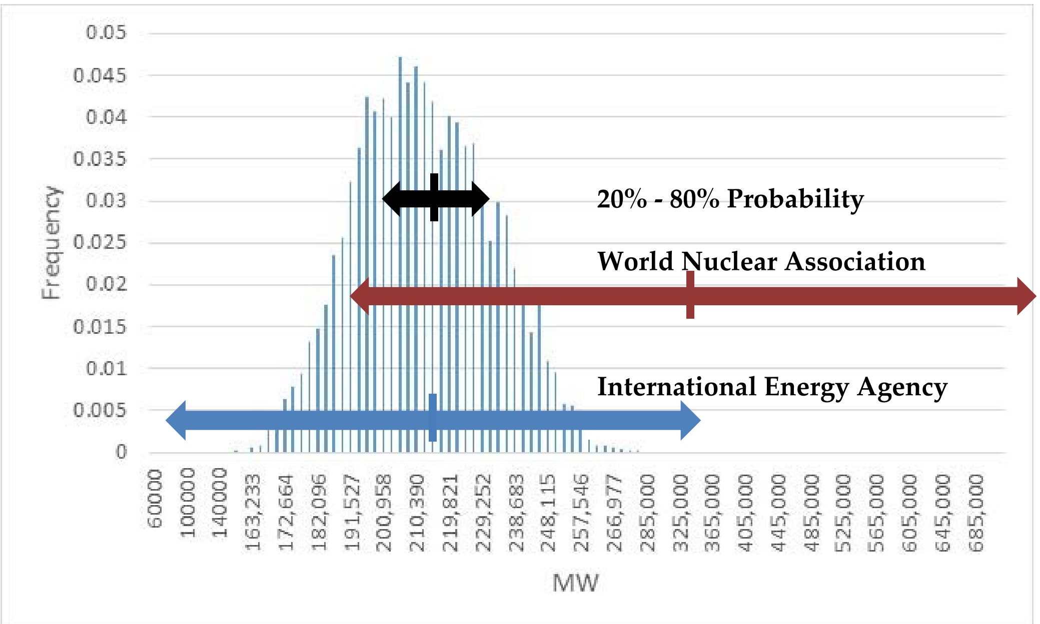
Figure 1 and Figure 2 present our forecast of cumulative new global nuclear capacity and the corresponding investment required. The figures indicate that the likely range of either metric are significantly less than that of the World Nuclear Association (WNA), but within the (rather broad) range of the International Energy Agency (IEA) forecast.

Figure 1 Probable Range of Cumulative Capacity Additions 2014 – 2020, MW



Source: Worthington Sawtelle LLC

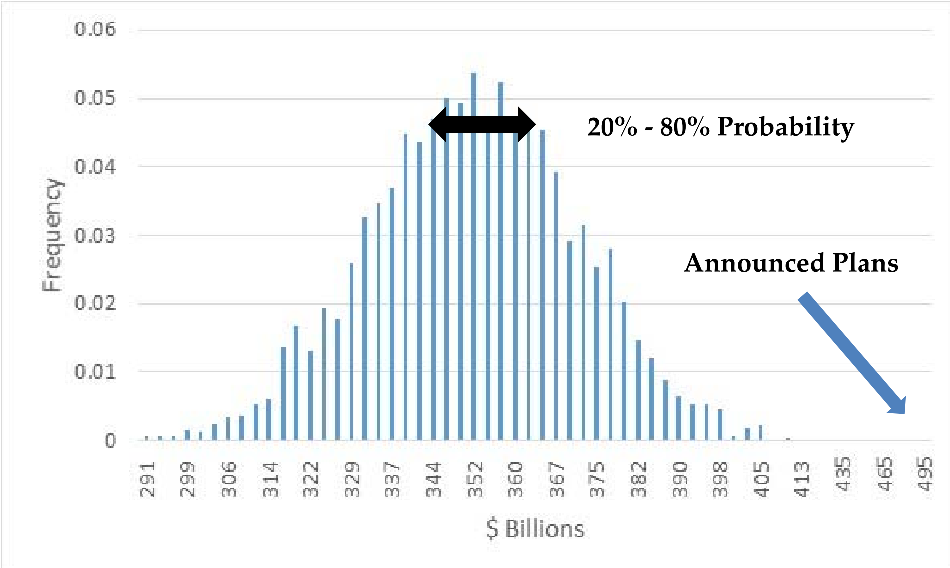
Figure 2 Probable Range of Cumulative Capacity Additions 2014 – 2030, MW



Source: Worthington Sawtelle LLC

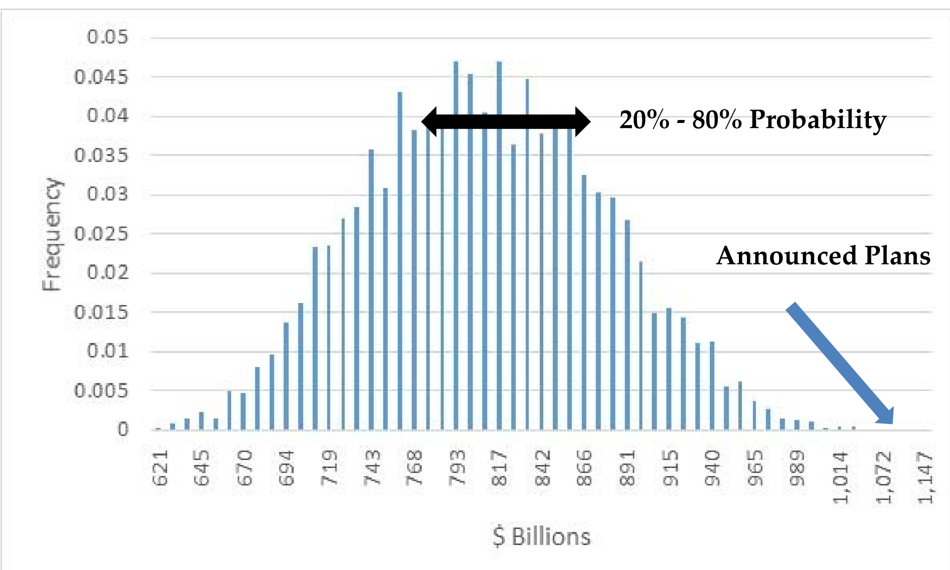
Figure 3 and Figure 4 present these capacity addition forecasts in terms of the necessary investment required (on an overnight cost of capital basis. $2013). Note the disparity between the probable range of investment and the amount that would be required if all announced plans were realized.

Figure 3 Probable Range of Overnight Capital Expenditures 2014 – 2020, $ Billions



Source: Worthington Sawtelle LLC

Figure 4 Probable Range of Overnight Capital Expenditures, 2014 – 2030, $ Billions



Worthington Sawtelle LLC believes these probabalistic forecast are likely to be far more accurate than the announced plans of the various industries.

1.5 Findings

Worthington Sawtelle LLC has assessed all of these factors and concludes:

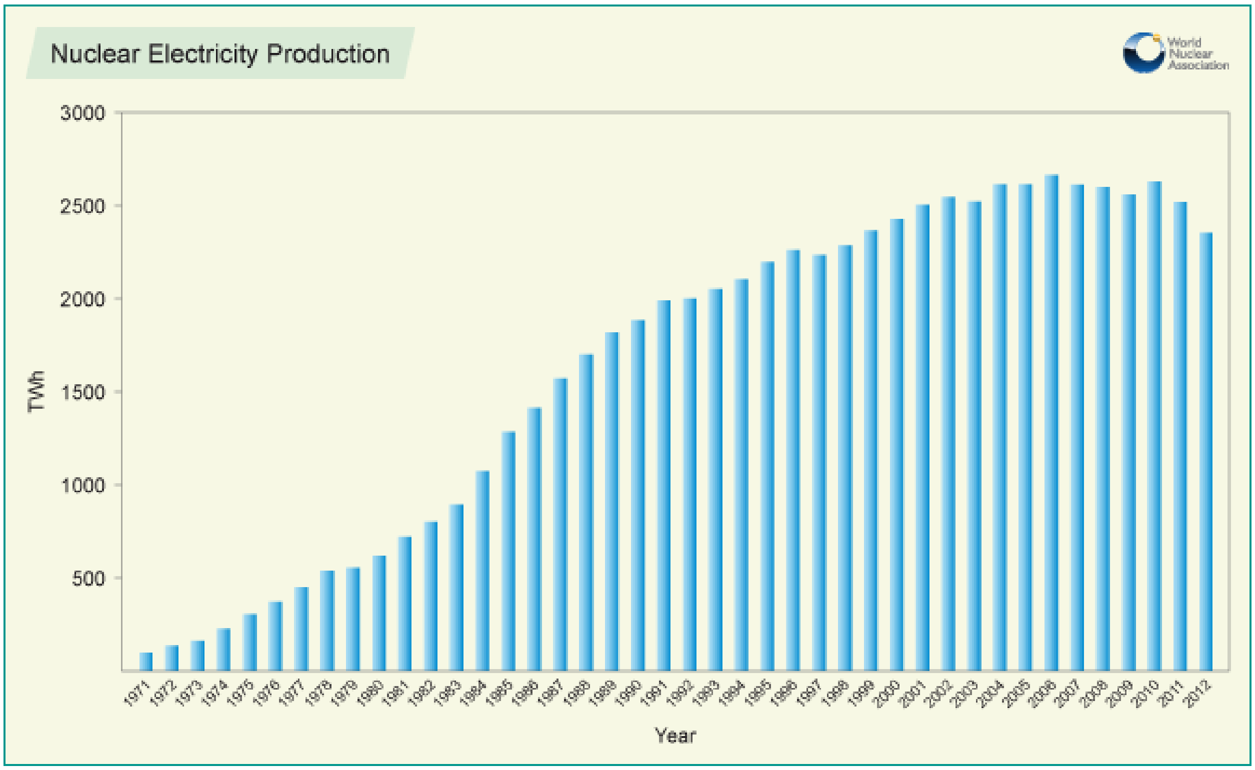
- International agencies have adopted a “high/low” forecasting basis that is so broad as to be meaningless; nuclear industry associations project capital additions about double what this probabilistic based forecast suggests.
- Likewise, the “as announced” forecasts likely overstate cumulative nuclear investments between 2014 and 2030 by about $300 billion but understate costs on a per unit basis
- A “nuclear renaissance” of sorts is happening, although not in the West, but in China, Russia, Korea and India.
- The cost of electricity from new generation large NPPs is likely to be less expensive than smaller scale SMRs;
- The state of development in SMRs is such that they do not factor in a forecast of new capacity through 2020; and,
- Growth in decommissioning services will build with capital expenditures for decommissioning potentially rivaling or even surpassing new builds.

2 OVERVIEW

2.1 Global Commercial Nuclear Power and the Nuclear "Renaissance"

At the end of 2012, nuclear power plants (NPP) generated a little over 7 % of the world's electricity. Because of Fukushima and other plant retirements, global nuclear generation in 2012 declined 7 % from 2011 and 11% from 2010. See Figure 5.

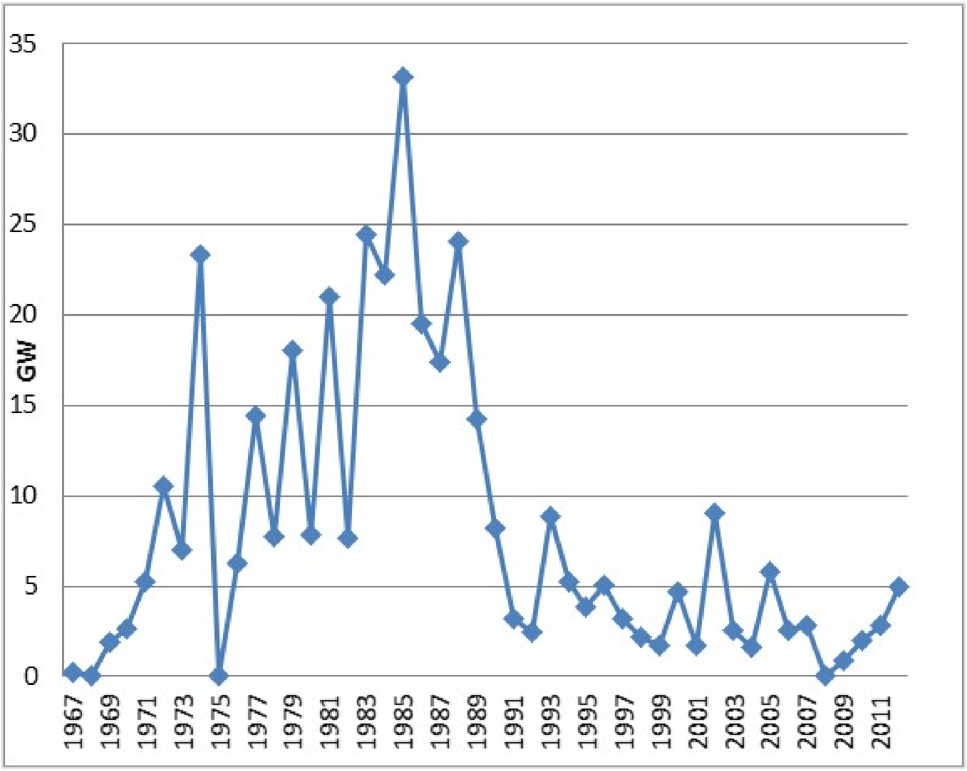
Figure 5 Global Nuclear Energy Production, 1971 - 2012



Source: World Nuclear Association

Nearly 80% of those NPPs entered service more than 20 years ago. After a period of significant growth in the 1970s and 1980s new NPPs stalled at a few plants per year, starting in the early 1990s, as shown in Figure 6 Since 2005, a number of countries either have started new construction programs or are seriously considering them. These new programs intend to deploy a new generation of nuclear reactor designs that are inherently safer than the designs of most reactors currently in service. This most recent period is referred to by the nuclear industry as the "Nuclear Renaissance." Figure 6 portrays the annual nuclear capacity that came on line between 1967 and 2012.

Figure 6 Annual Capacity of NPPs Entering Commercial Operation, 1967 - 2012 (GW)



Source: Worthington Sawtelle LLC

There are a number of reasons why commercial NPP installations fell off sharply 20 years ago, some well understood and others less so. Some of the issues involved have been resolved and others have not. The trajectory of new NPP capacity forecasts has been very volatile over the last several years, trending to fewer additions rather than more. Despite the lowering of forecasts, though, the market is, indeed, growing over the forecast period of this report. Before that discussion can take place, context and a new vocabulary need to be established regarding the technology and its history.

2.2 Historical Perspective

At the end of the Second World War the U.S. and the Soviet Union continued development of nuclear weapons but also began to consider technologies that could use nuclear power for peaceful purposes. In the U.S., a number of demonstrations were conducted through the 50s and early 60s of small versions of nuclear reactors that generated electricity. Some of these prototypes had a dual purpose: stationary reactors for power generation and naval propulsion. A very similar evolution of nuclear technology was occurring in the Soviet Union.

Most of the early nuclear power plant demonstration units were FNRs. In the Soviet Union, small lead cooled FNRs were in service on submarines. In addition, the long-term goal for nuclear power was a fleet of breeder reactors. Breeders are initially fueled with isotopes that are created in LWRs, either as pure plutonium or as MOX.

The LMFBR was a far less developed technology than LWRs. The engineering challenges seemed to be resolvable, but at very high cost. In addition, the technology required a reprocessing industry that could economically extract the useful portions of spent fuel and then return that fuel to the LMFBR in the form of MOX. In the mid-1970s, reprocessing plants were identified as a potential nuclear weapons proliferation risk. At various stages during reprocessing isotopes necessary for nuclear weapons could be diverted. In 1976, President Ford banned commercial reprocessing in the U.S., although reprocessing of naval reactors and for weapons purposes continued. Reprocessing continues today in France, the U.K. and the Soviet Union but not as a commercial venture.

By the late 1970s, however, nuclear plant costs became increasingly uneconomic. The accident at Three Mile Island Unit 2 in March 1979 and the Chernobyl accident in 1984, as well as costs, led to the global decline in nuclear plant construction and a near moratorium on new construction until the early 2000s.

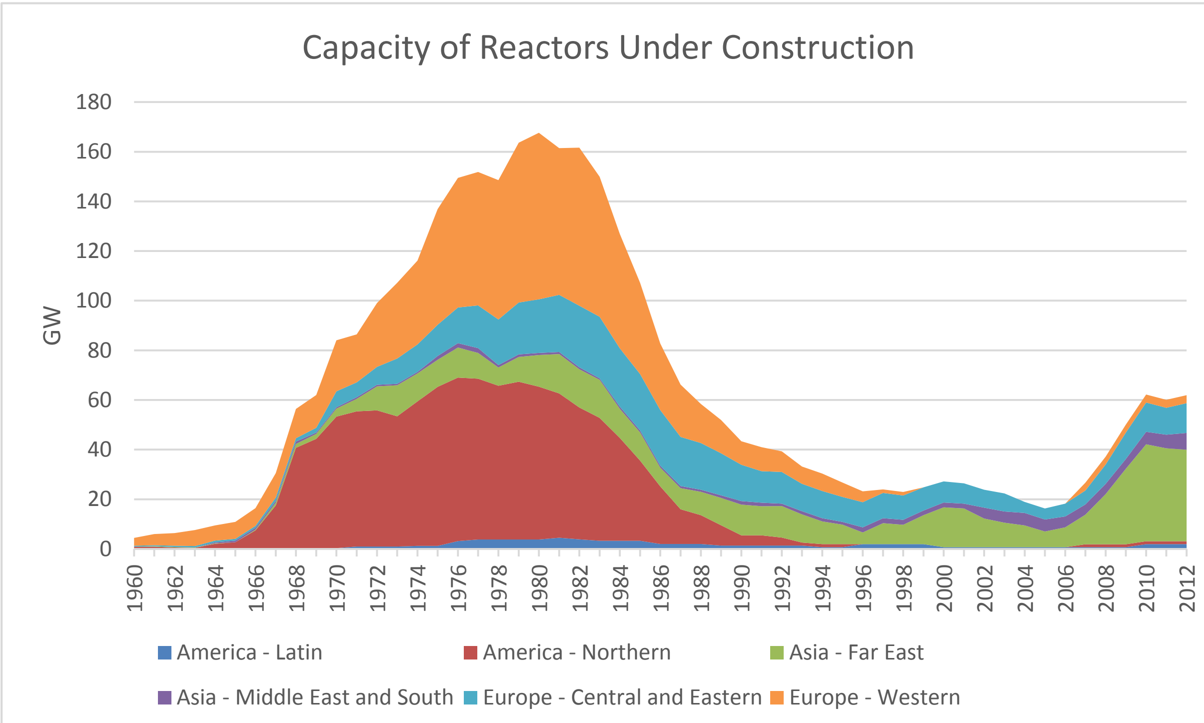
As with any other generation technology, fuel supply, availability and economics have a direct impact on future growth. Nuclear generation is no exception. The fuel for nuclear plants varies considerably and its production involves not just a mining industry, but also industrial chemical processing and ultimately high technology manufacturing.

The steps necessary to build fuel for nuclear reactors are commonly referred to as the “Nuclear Fuel Cycle” and are discussed in detail in Appendix A; Appendix B discusses the Nuclear Supply Chain.

2.3 Reasons for Collapse of U.S. and International Markets

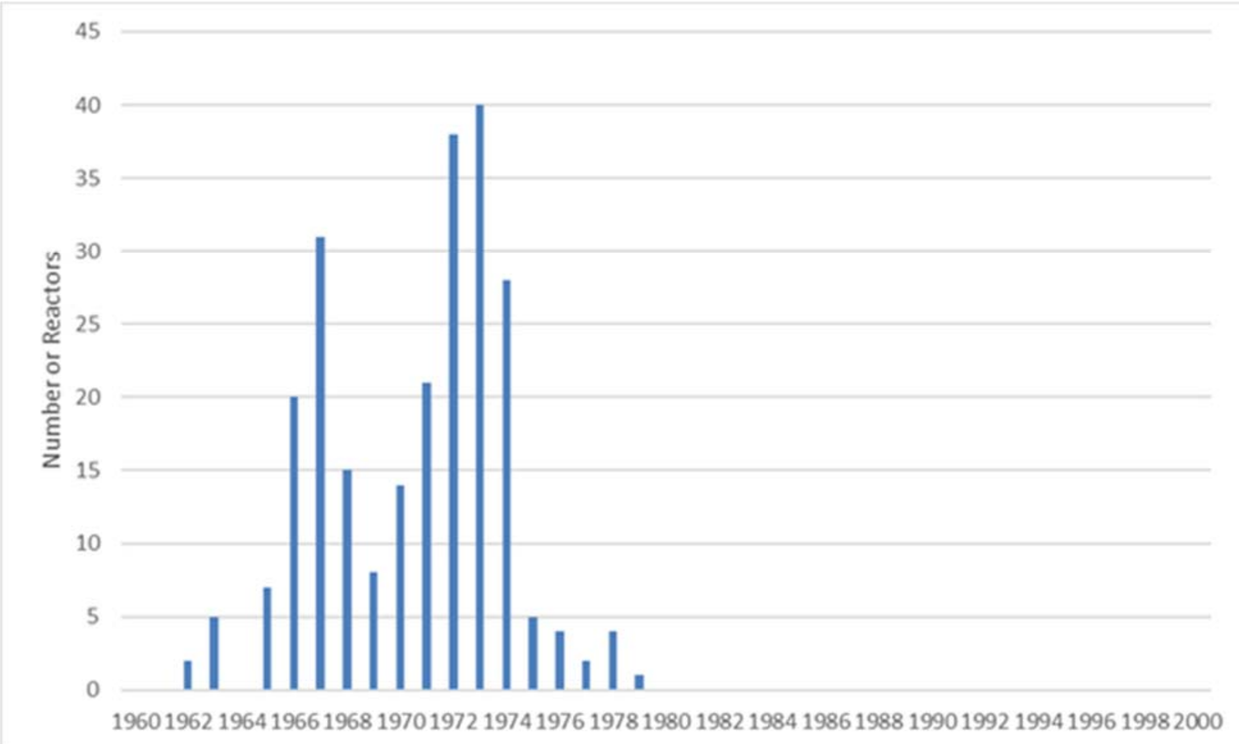
After a period of significant growth in the 1970s and 1980s new NPP installations stalled at a few plants per year, starting in the early 1990s, as shown in Figure 7. Figure 8 shows the impact of this decline in terms of new orders for NPPs in the U.S., where orders fell off sharply in 1973 and ended in 1979.

Figure 7 Global Nuclear Power Plant Construction 1960 - 2012



Sources: IAEA; PRIS

Figure 8 US Annual NPP Orders, 1960-2000



Sources: National Bureau for Economic Research; Worthington Sawtelle LLC

Furthermore, only about half of the reactors on order in the U.S. in 1974 were ever constructed.

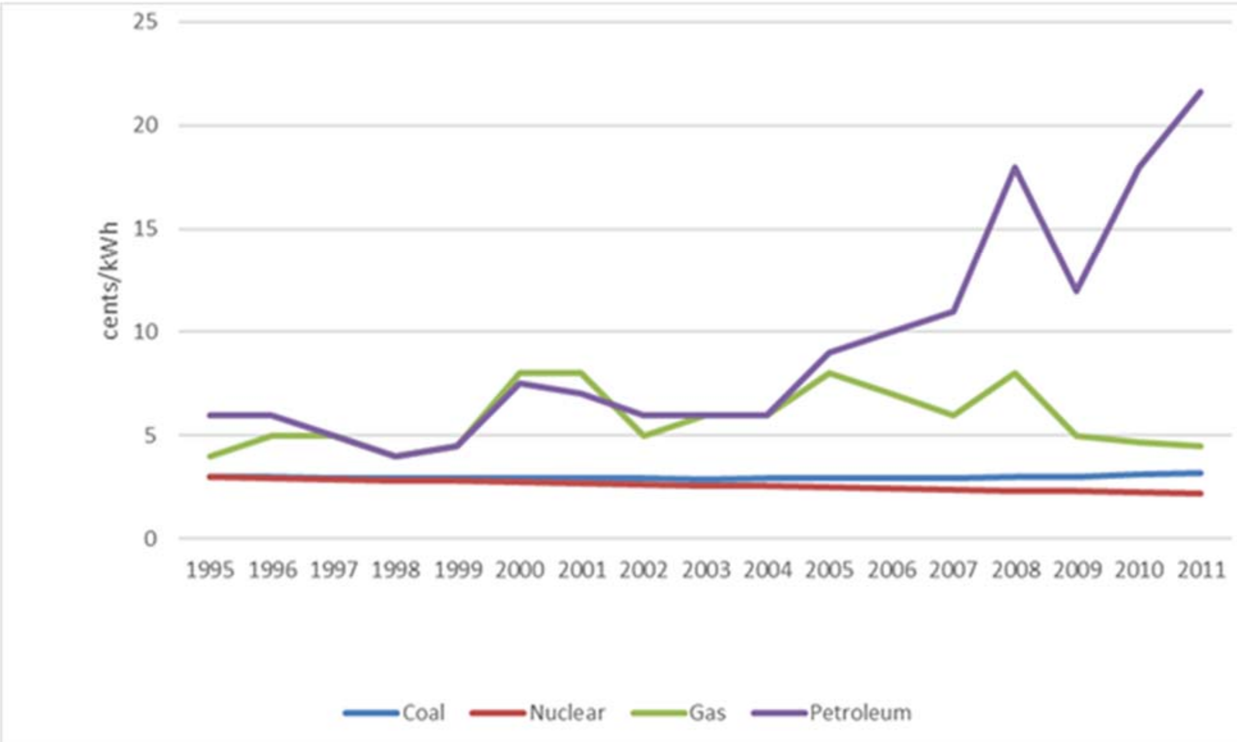
There are a number of reasons why commercial NPP installations fell off sharply 20 years ago, some well understood and others less so. In addition, some misconceptions persist. The chief causes, in order of importance, include:

1) High electricity cost;
2) In those countries where this applies, risk of incomplete allowance of costs by rate regulators;
3) Multiple vendors, designs, and the nuclear regulatory approval process; and
4) Public perception.

2.3.1 High Electricity Cost

The phrase "nuclear power is too cheap to meter" has haunted the nuclear industry ever since the chairman of the U.S. Atomic Energy Commission (AEC) coined it in 1954. In terms of the cost of fuel consumed and variable maintenance and operational costs, nuclear is among the least expensive fossil fuel consuming power generators. In most grids, where the next highest marginal cost of power is the next increment called upon to meet new load, nuclear units are always running because the metric used is the combined fuel and variable operations and maintenance cost of a unit. **Error! Reference source not found.** presents operating costs (fuel and variable operations and maintenance expenses) for the major electricity generation fuels.

Figure 9 U.S. Operating Costs, Coal, Nuclear, Natural Gas and Petroleum, 1995–2011, c/kWh



Source: NEI

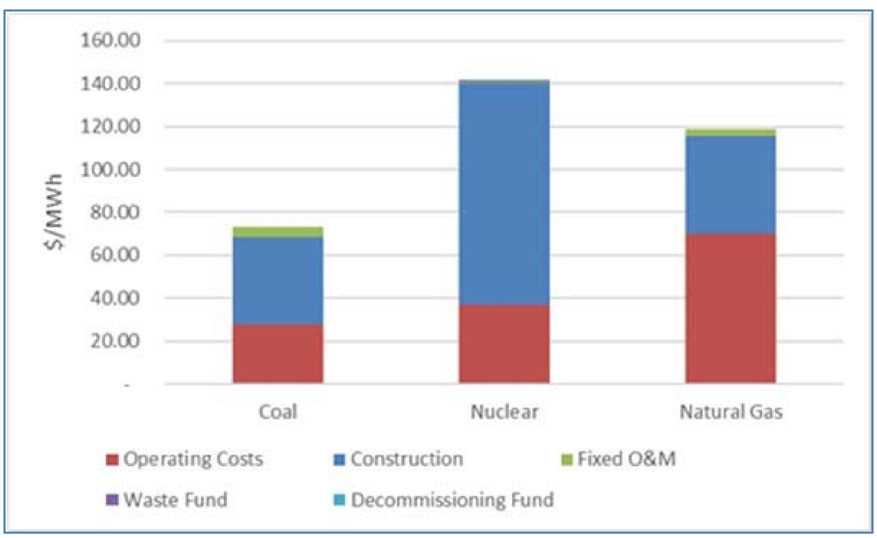
Operating costs are only one facet of overall plant economics and in the case of nuclear, only a very small fraction of the costs necessary for the owner to recover all costs including a return. Section 2.5 covers this topic in detail, however a good illustration of the differences among coal, natural gas and nuclear is found by comparing the components of their respective levelized cost of energy (LCOE). LCOE is the cost, in cents per kWh (c/kWh) that if applied to every kilowatt-hour produced over the life of the plant would assure complete recovery. These include construction capital; capital additions (equipment upgrades and replacements); fixed operations and maintenance costs (costs that occur whether the unit is operating or not); nuclear payments to the federal waste fund; and nuclear payments to its decommissioning fund. **Error! Reference source not found.**Table 1 and Figure 10 illustrate this relationship. It should be noted that the values shown are from a high construction cost case in one scenario of one analysis to highlight more clearly differences.

Table 1 Hypothetical Levelized Cost of Energy ($/MWh), Coal, Natural Gas and Nuclear

	Natural Gas	Coal	Nuclear
Construction	45.77	40.60	103.33
Operating Costs	69.94	27.63	36.66
Fixed O&M	3.30	5.14	0.97
Waste Fund	-	-	0.07
Decommissioning Fund	-	-	0.03
Total	119.01	73.37	141.06

Source: Worthington Sawtelle LLC

Figure 10 Hypothetical Levelized Cost of Energy (c/kWh), Coal, Natural Gas and Nuclear



Source: Worthington Sawtelle LLC

Under this scenario, the overall costs of electricity generated by nuclear would not be competitive with its fossil equivalents. A number of nuclear plants in the U.S. do show competitive costs that include capital recovery; however, in those cases the capital being recovered is the purchase price of the plant from their original owner, purchases that were typically cents on the dollar. Table 2 presents the purchases of U.S. NPPs by third parties from the original owners since 1998, as well as price paid.

Table 2 U.S. NPP Purchases by Third Parties Since 1998

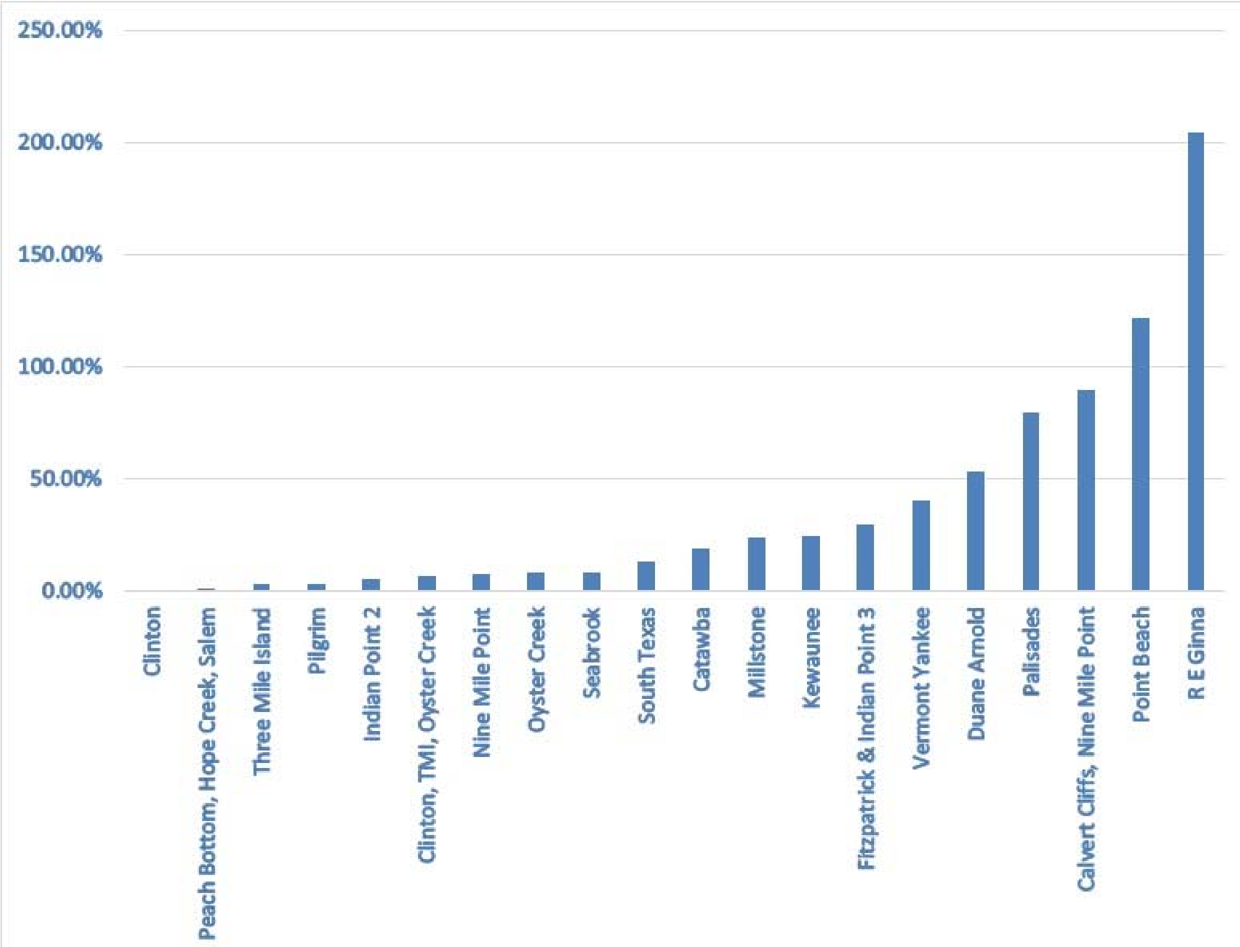
Buyer	Reactor	Net MWe sold	Year of Sale	Installed Cost, $/kW	Installed Cost, Year of Sale Dollars, $ /kW	Sale Price, $/kW
Entergy	Pilgrim	670	1999	202	588	21
AmerGen	Three Mile Island	786	1999	310	835	29
AmerGen	Clinton	924	1999	3,024	4,864	22
AmerGen	Oyster Creek	619	2000	58	197	16
PECO (Exelon) et al	Peach Bottom, Hope Creek, Salem	714	2001	2,497	2,497	28
Entergy	Fitzpatrick & Indian Point 3	1,743	2000	350	941	280
Entergy	Indian Point 2	939	2001	325	874	49
Dominion	Millstone	1,947	2001	1,652	2,554	613
Constellation	Nine Mile Point	1,536	2001	2,681	5,691	439
Entergy	Vermont Yankee	510	2002	216	710	288
FPL Energy	Seabrook	1,024	2002	5,390	8,670	731

Buyer	Reactor	Net MWe sold	Year of Sale	Installed Cost, $/kW	Installed Cost, Year of Sale Dollars, $ /kW	Sale Price, $/kW
Constellation	R E Ginna	495	2004	103	396	810
Genco & CPS	South Texas	630	2005	1,742	3,283	443
Dominion	Kewaunee	540	2005	1,437	1,437	355
FPL Energy	Duane Arnold	419	2006	380	1,349	716
Entergy	Palisades	798	2007	92	381	303
FPL Energy	Point Beach	1,012	2007	582	582	710
Duke, NCEMC	Catawba	229	2008	1,913	4,571	874
EDF	Calvert Cliffs, Nine Mile Point	1,997	2008	2,504	2,504	2,253

Sources: WNA; Worthington Sawtelle LLC

Figure 11 shows the sales price as a percentage of the original installed cost of the unit, escalated to the year of the sale. Of the 20 reported sales, two were greater than the installed cost; 75% were less than half and 50% were less than 10%.

Figure 11 U.S. NPP Sales Prices as Percentage of Original Installed Cost



Source: Worthington Sawtelle LLC

2.3.2 Regulatory Risk and Utility System Planning

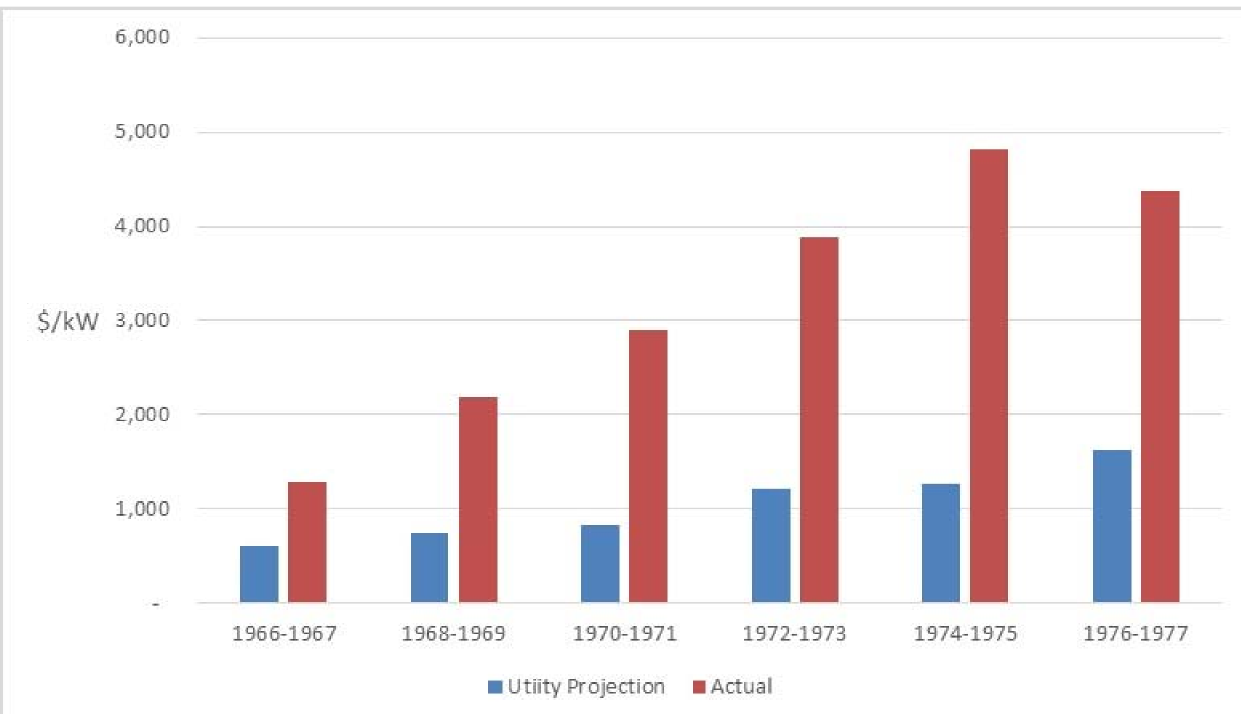
Regulators became increasingly concerned about the overall costs of nuclear plants as utilities filed for cost recovery for plants that cost far more than originally estimated. Table 3 and Figure 12 illustrate the disparity that grew between the original cost estimates for all U.S. nuclear plants in operation by the end of 1986 and their actual final costs (the data include 85 of the 104 U.S. operating units).

Table 3 Actual and Estimated Total Costs of U.S. NPPs in Operation in 1986, $/kW

	Total Cost		Interest and Inflation Component	
	Estimate	Actual	Estimate	Actual
1966-1967	128	313	20	100
1968-1969	169	815	40	500
1970-1971	236	1,404	60	1,000
1972-1973	652	2,075	400	1,200
1974-1975	556	2,777	300	1,800
1976-1977	1,059	2,235	600	1,300

Sources: U.S. D.O.E.; Worthington Sawtelle LLC

Figure 12 Actual and Estimated Total Costs of U.S. NPPs in Operation in 1986, $/kW



Sources: U.S. D.O.E.; Worthington Sawtelle LLC

Regulators began to question these investments and in some jurisdictions began what became referred to as "prudence reviews." In addition to "sticker shock", many of these new plants were built to meet electricity demand forecasts that, in retrospect, seemed overstated. These reviews became protracted adversarial proceedings where the utility's ability to get full recovery of its costs was at risk. The table and figure also illustrate the time component of these costs. By the early 80's, interest rates approached 20%, right at the time when many of these plants were under construction. This, and construction delays, added time and cost. In fact, the time related actual costs exceeded the total costs of the original estimates. Utilities therefore began to adopt a strategy that avoided regulatory risk by building new generation as demand increased and using technology with the shortest construction time for completion. Nuclear units did not fit in that new strategy.

2.3.3 Proliferation of Designs and the Nuclear Regulatory Review Process

Between 1965 and 1975 there were 13 designs submitted to the AEC/NRC by five different vendors: six BWRs, six PWRs and a HTGR. Also in 1974, the AEC was split into the Energy Research and Development Authority (ERDA) and the NRC. Table 4 presents the 13 different designs that were in review by the NRC.

Table 4 Diversity of U.S. Reactor Designs, 1965-1975

Vendors				
Babcock & Wilcox	**Combustion Engineering**	**General Electric**	**Westinghouse**	**General Atomics**
L Loop, 1968	2 loop, 1968	BWR2 Mark I- 1965	2 loop, 1966	HTGR
	System 80, 1976	BWR3 Mark I- 1966	3 loop, 1971	
		BWR4 Mark I - 1967	4 loop, 1975	
		BWR4 Mark II- 1973		
		BWR5 Mark II- 1973		
		BWR6 Mark III- 1975		

Source: Worthington Sawtelle LLC

The AEC and then the NRC quickly became overwhelmed, both from sheer volume and from the variety of designs to operate. Therefore, expectations for when any particular unit would receive its operating license were never met, and just got continually worse. Table 5 shows the impact of this licensing backlog. By 1974, new units were averaging 11 to 12 years from time of order to commercial operation.

Table 5 Licensing Backlogs, U.S. NPPs

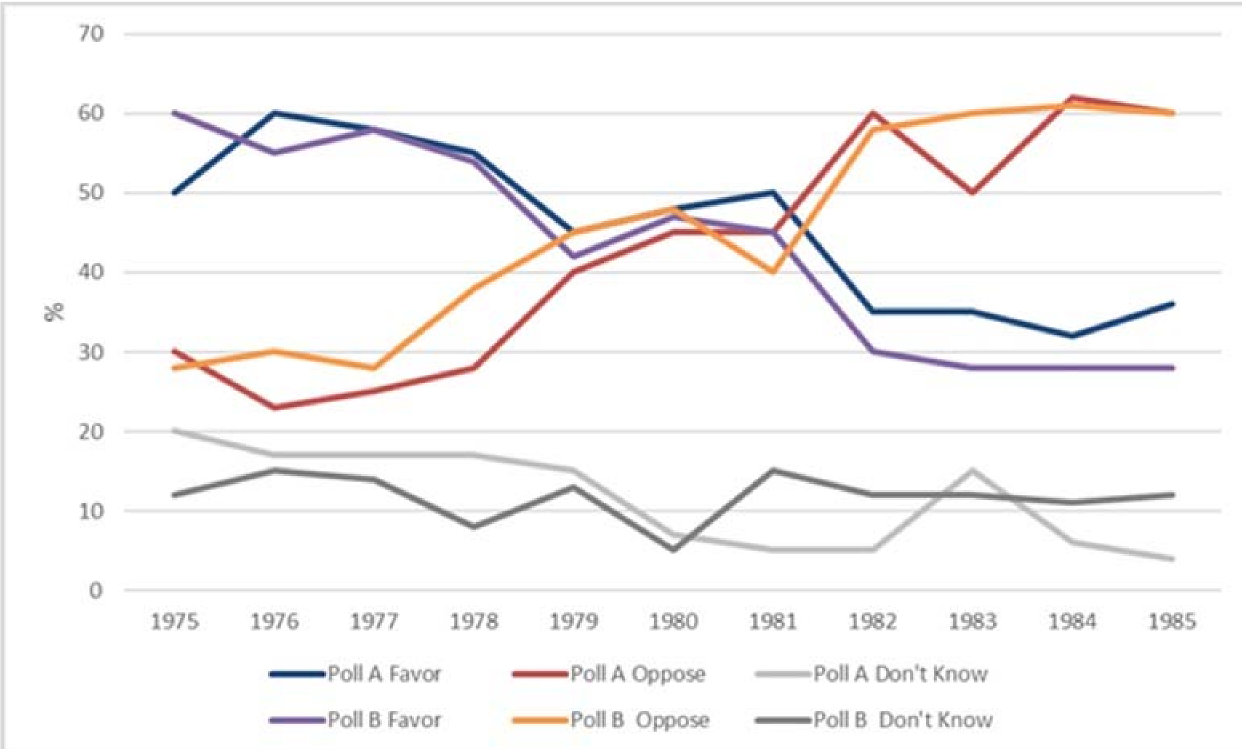
Year of Order	NPPs Ordered	Expected Years to Operations	Delay	Years from Order to Operation	NPPs Cancelled
1965	7	5.7	1.4	7.1	0
1966	21	5.3	1.8	7.1	1
1967	31	6.1	3.2	9.3	1
1968	16	6.5	3.7	10.2	2
1969	8	6.9	4.8	11.6	1
1970	15	6.1	3.6	9.6	2
1971	21	7.1	5.6	12.7	9
1972	38	8.1	3.5	11.6	13
1973	37	8.9	3.5	12.4	4
1974	33	8.8	2.4	11.3	11

Sources: Worthington Sawtelle LLC; California Institute of Technology

2.3.4 Public Perception

Widely considered the primary reason behind the collapse of the industry in the U.S., negative public perceptions about nuclear power only came in earnest after the Three Mile Island (TMI) accident and were, in fact a tossup for several years after that. Figure 13 shows the results of two polls during the period 1975–1985.

Figure 13 U.S. Public Attitudes About Nuclear Power, 1975–1985



Source: Adopted from Public Opinion Quarterly data by Worthington Sawtelle LLC

In 1982, the Soviet Union experienced a major nuclear accident at Chernobyl, in the Ukraine. Contamination from the accident spread over much of Europe as well as the surrounding countryside. It was only until this event that U.S. public opinion shifted to opposition of nuclear power.

Elsewhere, however, public perception has proved to be quite significant, as evidenced in Europe and the many protests against new NPPs in Asia.

2.4 The Fukushima Daichi Incident and its Impact

2.4.1 The Incident

On March 11, 2011, Japan suffered a catastrophic earthquake and tsunami. The tsunami, in addition to killing thousands of people, flooded emergency generators at the Fukushima Daichi Nuclear Power Plant in the northeast. These generators were in full operation maintaining electricity to cooling water pumps to three of six BWRs which had shut down automatically when the earthquake struck (three of the reactors were offline). When an emergency shutdown occurs from full power operation, even though the chain reaction has ceased, the radioactive elements in the core continue to generate heat, which diminishes slowly through decay; cooling water must continue to be pumped for several days until the core reaches an acceptable temperature. When the pumps stopped, cooling water in the cores boiled away, exposing the fuel rods, which began to melt. In addition, fuel rod metal casings (cladding) interacted with water releasing hydrogen gas that caused three explosions in secondary containment buildings. Ultimately, seawater was used to flood the reactors and electric power was restored after several days. A wide land area was contaminated from radioactive elements that were released on melting through airborne releases. Seawater was also contaminated and fishing around the plant is still banned.

2.4.2 Environmental Effects

The incident resulted in the relocation of nearly 160,000 people and the creation of an exclusion zone of about 800 square kilometers (300 square miles). Fifteen months after the incident a survey of fish catches found a little over 9% contaminated with cesium 137 in amounts that exceed regulatory limits.

2.4.3 National Responses to Fukushima

In the aftermath of the Fukushima events, nuclear programs in all countries reassessed their safety measures and regulatory processes. Many countries halted the licensing and construction process altogether: some have resumed and others have not.

2.4.3.1 Japan

Japan immediately halted construction of all reactors and suspended the 54 units that were operating shortly after the Fukushima incident. Subsequently, two governments have supported a phase out of nuclear by decommissioning all reactors at the end of their licensed lives. Two reactors, Oi Units 3 and 4, resumed operation July 2012. Restart of the other previously operating reactors is under review. Draft measures are expected to be completed in July 2013 that may ultimately allow the restart of existing units. Whether or not a complete phase out will occur is not clear now. The new government, which was elected in November 2012, is expected to have a more pro-nuclear stance and may assure the continued operation of some units.

Figure 14 presents the current status of the Japanese NPP fleet.

Figure 14 Status of Japanese NPPs post Fukushima

Source: Stratfor

2.4.3.2 Europe

Germany

Immediately after the incident, Germany shut down seven reactors that had entered service before 1980. In May 2011, the government reversed an earlier commitment to build new nuclear plants and extend the lives of existing ones and announced the phase out of nuclear by 2022. Opposition political parties have labeled the phase out unrealistic; however, the Merkel government is likely to prevail.

Switzerland

In May 2011, Switzerland decided to phase out its five nuclear units by 2034.

Italy

Italy held a referendum in July 2011 to reverse a 1987 decision to resume nuclear plant construction, which was defeated.

Belgium

Belgium had rejected a phase out plan for its nine reactors in 2009. In December 2011, it announced it would close three reactors by 2015 and the other four by 2025.

2.4.3.3 China

China's State Council halted new reactor licensing shortly after the accident and suspended all new construction. It resumed review of new plant applications and construction in October 2012; however, no new inland plants will be approved during the current Five Year plan that ends at the end of 2015. Inland plants with all actions deferred until at least 2015 amount to between 65 and 67 GW of capacity and are shown in Table 6.

Table 6 China Nuclear Plants with Suspended Actions Until 2015

Plant Name	Number of Units	Reactor Model	Total MWe
Taohuajiang	4	AP1000	1,000
Xianning	4	AP1000	4,000
Pengze	4	AP1000	4,000

Plant Name	Number of Units	Reactor Model	Total MWe
Xiaomoshan	6	AP1000	6,000
Yanjiashan/Wanan/Ji'an	2	AP1000	2,000
Haixing	6	AP1000	6,000
Hengyang	4	AP1000	4,000
Wuhu	4	CPR-1000	4,000
Jiyang	4	AP1000	4,000
Nanchun/Nanchong/Sanba, Yibin	4-6	CPR-1000	4,000 – 6,000
Shaoguan	4	AP1000	4,000
Xiangtan	4	AP1000	5,000
Longyou/ Zhexi	4	AP1000	4,000
Jingyu	4	AP1000	4,000
Jiutai - Liangjiashan	4	AP1000	4,000
Nanyang	6	CNNC	3,600
Totals	**71-73**		**65,600-67,600**

Source: Worthington Sawtelle LLC

There is some probability that Taohuajiang, Xianning and Pengze may never be completed.

2.4.3.4 France

The French government announced a reduction in the share of nuclear capacity in the nation's energy mix from 75% to 50% by 2025.

2.4.3.5 South Korea

While moving forward with a robust program, the Seoul Municipal Government has initiated a plan called "One Less Nuclear Power Plant." This initiative promotes a number of energy efficiency and demand reduction programs that would eliminate the need for one large power plant.

2.4.3.6 U.S.

The NRC created a task force to define any lessons learned and recommend any regulatory steps necessary. The result of the effort was the publication of three orders that answered to the need for:

- Mitigation strategies to respond to extreme natural events resulting in the loss of power at plants;
- Ensuring reliable hardened containment vents; and
- Enhancing spent fuel pool instrumentation.

In addition, an advanced notice of rulemaking was issued for station blackout regulatory actions. The NRC staff also plans to issue guidance to enable U.S. nuclear power plants to perform seismic and flooding reevaluations. Fukushima also prompted the need to review materials degradation likely after 60 years of service. New "Ageing Management Programs" should be expected for existing NPPs. A number of plants that were part of the DOE "Nuclear Power 2010" program have been suspended, terminated or indefinitely delayed since the incident although none officially cites Fukushima as a reason. Table 7 shows the units that were announced as part of the DOE program and their status. Projects that were suspended, indefinitely delayed, or terminated are shaded.

Table 7 Current NPP Status, DOE Nuclear Power 2010 Program

NPP	Owner	NRC Status	Loan Guarantee	Design	Expected Start Up
Calvert Cliffs 3	Unistar	Denied	n/a	EPR	Project terminated
South Texas 3,4	NRG	n/a		ABWR	Project terminated
Bellefonte 3,4	TVA	n/a	n/a	AP1000	Suspended
North Anna 3	Dominion	Early Site Permit Issued	n/a	ESBWR	Construction start indefinitely delayed
Lee 1,2	Duke	COL Application Submitted 12/07	n/a	AP1000	2021-23
Harris 2,3	Progress	COL Application Submitted 2/08	No application	AP1000	2019-20
Grand Gulf 3	Entergy	COL Application Submitted 2/08	Applied	ESBWR	Suspended

Vogtle 3,4	Southern	COL Issued 1/13	Awaiting final approval	AP1000	2016
Summer 2,3	SCANA	COL Approved	No application	AP1000	2017-18
Callaway 2	AmerenUE	COL Application Submitted 7/08	Applied	EPR	Cancelled
Levy 1,2	Progress	COL Application Submitted 9/08	Applied	AP1000	2019-20
Victoria 1,2	Exelon	COL Application Submitted 9/08	Applied	ESBWR	Suspended
NPP	**Owner**	**NRC Status**	**Loan Guarantee**	**Design**	**Expected Start Up**
Fermi 3	DTE Energy	COL Application Submitted 9/08	Not applied	ESBWR	?
Comanche Peak 3,4	TXU	COL Application Submitted 9/08	First reserve	APWR	?
Nine Mile Point 3	Unistar	COL Application Submitted 10/08	Applied	EPR	Suspended
Bell Bend	PPL	COL Application Submitted 10/08	Applied	EPR	2018
Amarillo 1,2	Amarillo	No COL application submitted	n/a	EPR	?
River Bend	Entergy	COL Application Submitted 9/08	Applied	ESBWR	Suspended
Elmore	Unistar	?		EPR	Suspended
Turkey Point 6,7	FPL	COL Application Planned 3/08	?	AP1000	2018–20

Source: Worthington Sawtelle LLC

2.4.3.7 Unaffected Programs

The Fukushima incident has not seemed to have had any major effect on the nuclear programs of India, Russia, Belarus, Korea, UAE, Lithuania, Romania, Czech Republic, Sweden, Spain, Bulgaria, and Britain, although there is clearly no public consensus in some of these countries as to the viability of new NPPs.

In May 2012, the newly elected French government announced a phase out of 50% of nuclear capacity by 2025 but reversed that decision shortly thereafter.

2.5 NPP Economics

The cost of new NPPs on a per unit cost basis vary considerably by region; however there does not appear to be much difference at all among the various technologies, whether large or small scale. Table 8 provides the forecasted installed cost (on an overnight basis) for units to be installed between 2013 and 2020.

Table 8 Overnight Cost Forecast, Nuclear Plants, $/kW ($2012)

Year of Announced Operation	Country	$/kW
2014	China	$ 3,200
	Russia	$ 2,340
	South Korea	$ 2,630
	Slovakia	$ 6,250
	Taiwan	$ 6,000
2015	China	$ 3,200
	Russia	$ 2,340
2016	Brazil	$ 5,460
	China	$ 3,200
	Finland	$ 6,600
	France	$ 6,800
	Ukraine	$ 5,660
	USA	$ 6,266

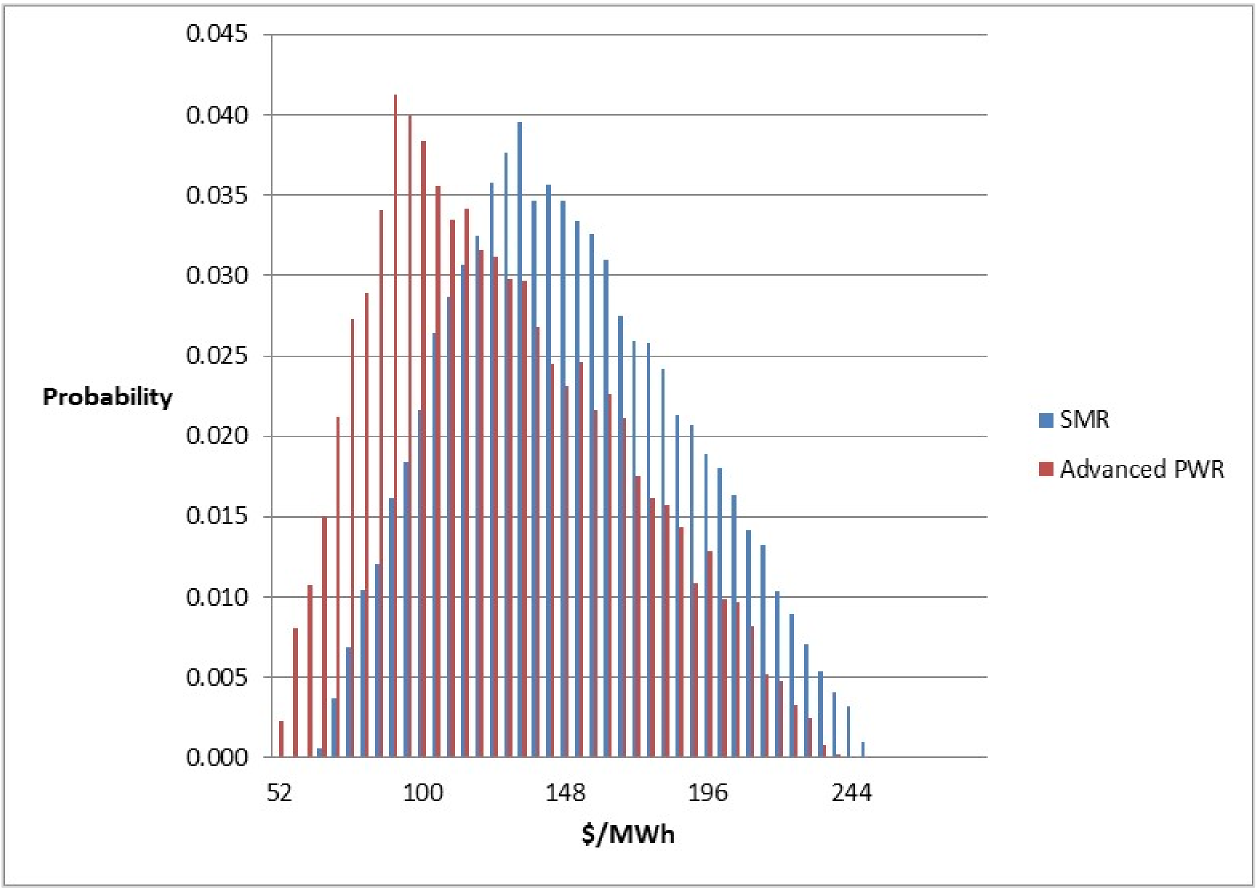
Year of Announced Operation	Country	$/kW
2017	UAE	$ 2,630
	China	$ 3,200
2018	UAE	$ 2,630
	China	$ 3,200
	UAE	$ 2,630
	USA	$ 6,800
2019	UAE	$ 2,630
	Turkey	$ 4,500
	UAE	$ 2,630
	USA	$ 7,000
2020	Armenia	$ 5,000
	UAE	$ 2,630
	UK	$ 7,815
	USA	$ 7,597

Source: Worthington Sawtelle LLC

It should be emphasized that these costs are the official estimates. In the case of the Chinese and Russian units, costs of about $3,000/kW seem achievable. In many other countries, the cost jumps over $4,000/kW. In the US, and Europe, however, costs are significantly higher, even in the official estimates. The US estimates for 2018 and 2019 seem unreasonably low when compared with units currently under construction and those that come later. All of these units are PWRs: AP1000, AP1400, EPR, CPR 1000, or VVER 1000.

Cost estimates for NPPs made prior to actual operation have historically been much lower than actual. Further, given the regional differences prices are quite volatile. Traditional cost forecasting is more likely ratify the already optimistic official estimates than provide any new insight. To counter this, costs of a generic next generation PWR and SMR were compared on a probabilistic basis. Figure 15 presents these results.

Figure 15 Probabilistic Ranges of Levelized Cost of Electricity (life time) for Advanced PWR and SMR, $/MWh



Source: Worthington Sawtelle LLC

These distributions were generated from the G4-ECONS nuclear cost model used by Oak Ridge National Laboratory (ORNL) and the International Atomic Energy Agency. The Advanced PWR was a generic 1,100 MW AP-1000 with a capital cost of $6,370/kW; the SMR was a generic 360 MW B&W mPower unit at $5,000/kW. ORNL estimates for fixed and variable costs were assumed, as well as $50/lb. U_3O_8 processed according to ORNL fuel cycle cost estimates. No escalation was assumed; a 5% discount rate was assumed for the PWR and a 7% rate applied to the SMR.

While the SMR has the greatest probability of cost at about $20/MWh higher than the PWR, the potential range of either technology's overall cost of electricity is quite similar. In the context of all the other uncertainties among cost components, for all practical purposes the two units are likely to cost the same.

3 GLOBAL NUCLEAR POWER MARKET FORECAST 2013-2030

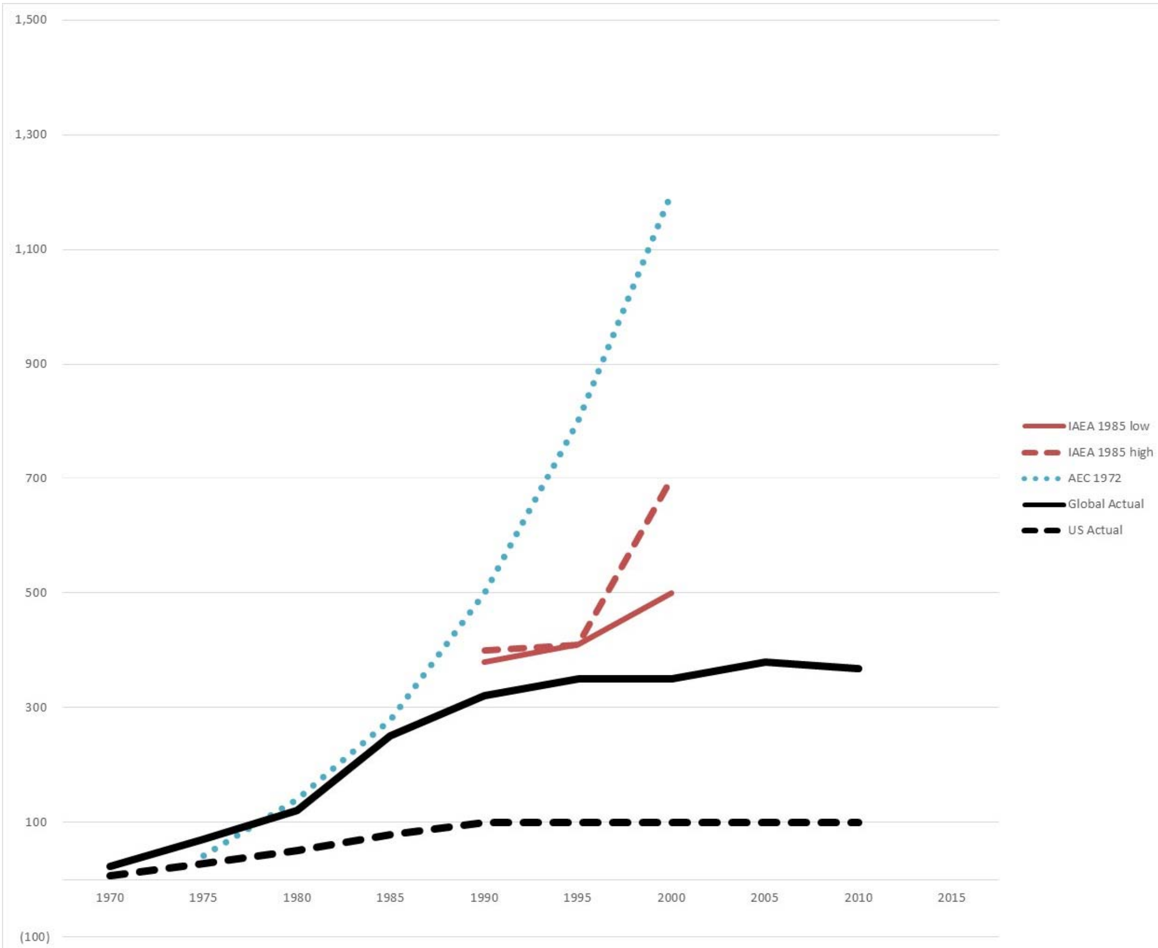
3.1 Global Nuclear Power Market Forecast Basis

This report provides three different forecasts of the nuclear power market through 2020 and 2030 in terms of new capacity, overnight capital investments and capital investments over the course of simulated construction schedules. Section 3.3 provides a forecast of these three metrics based upon announced or "official" costs and schedule. Section 3.4 provides forecasts that moderate the announced programs based on Worthington Sawtelle LLC judgments and organizes them into low, high and base case growth scenarios. Finally, Section 3.5 provides probability distributions of the three metrics, expressing Worthington Sawtelle LLC's best judgment of the most probable range of costs and schedule.

This variety of forecast methods is important because of the fact that many nuclear power programs are highly visible and, for some countries, a matter of national pride. Official estimates therefore tend to be quite optimistic. It can safely be said that no one has ever underestimated the cost of a NPP pre-construction. It does not matter whether the estimate is public or private.

Figure 16 shows several prominent forecasts from the 70's and 80's expressed in gigawatt hours electric (GWe): a 1972 forecast for U.S. nuclear capacity growth by the U.S. Atomic Energy Commission (AEC); the actual U.S. capacity additions; high and low forecasts for the International Atomic Energy Agency (IAEA) from 1985; and the actual global capacity installed.

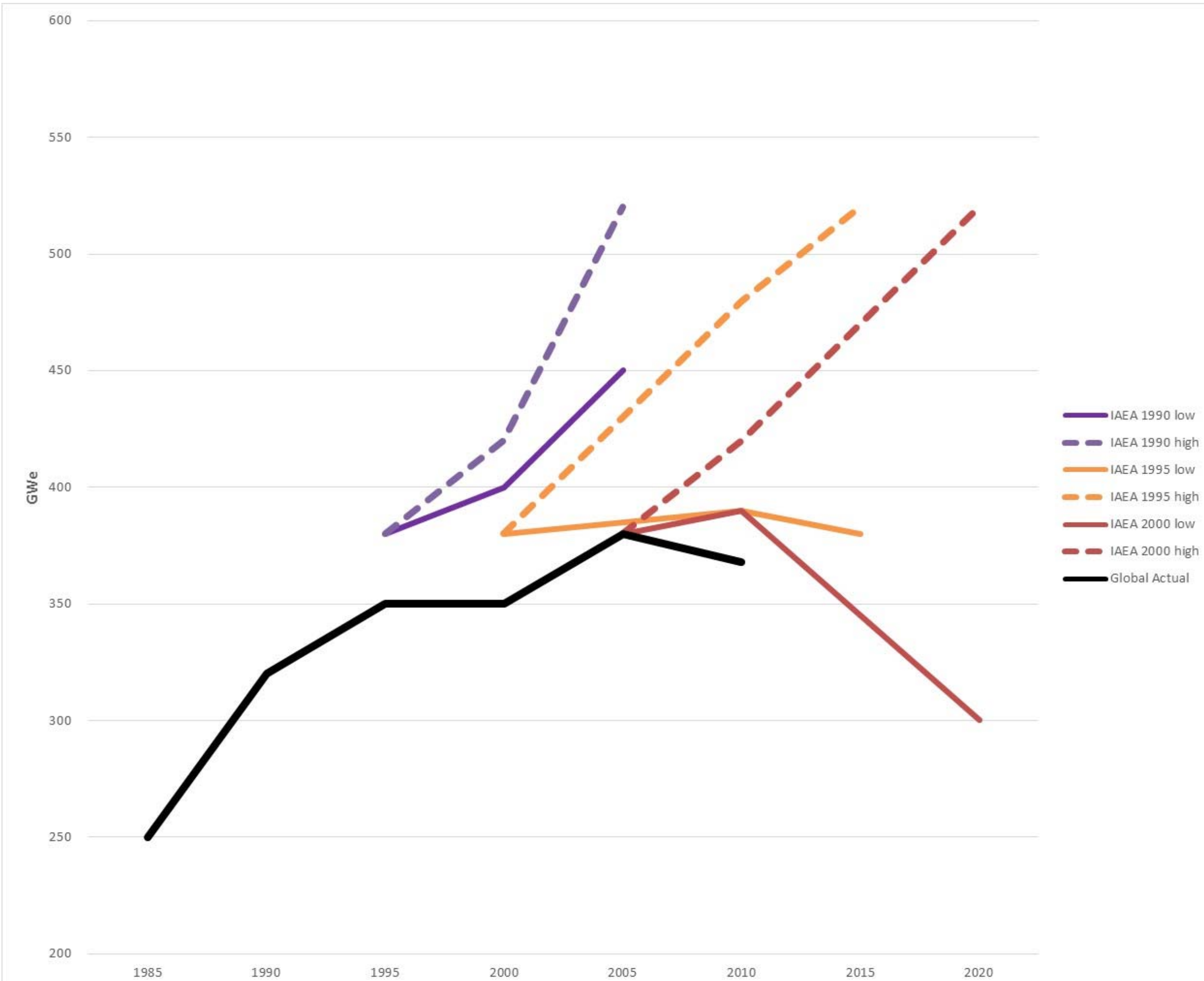
Figure 16 Nuclear Power Capacity Forecasts, 1972 – 1985, GWe



Source: Worthington Sawtelle LLC

In the late 80's and 90's the forecasts were tempered when compared with their predecessors but still overstated actual installations, as shown in Figure 17. This chart includes the IAEA 1990. 1995 and 2000 low and high cases as well as the global actual installations.

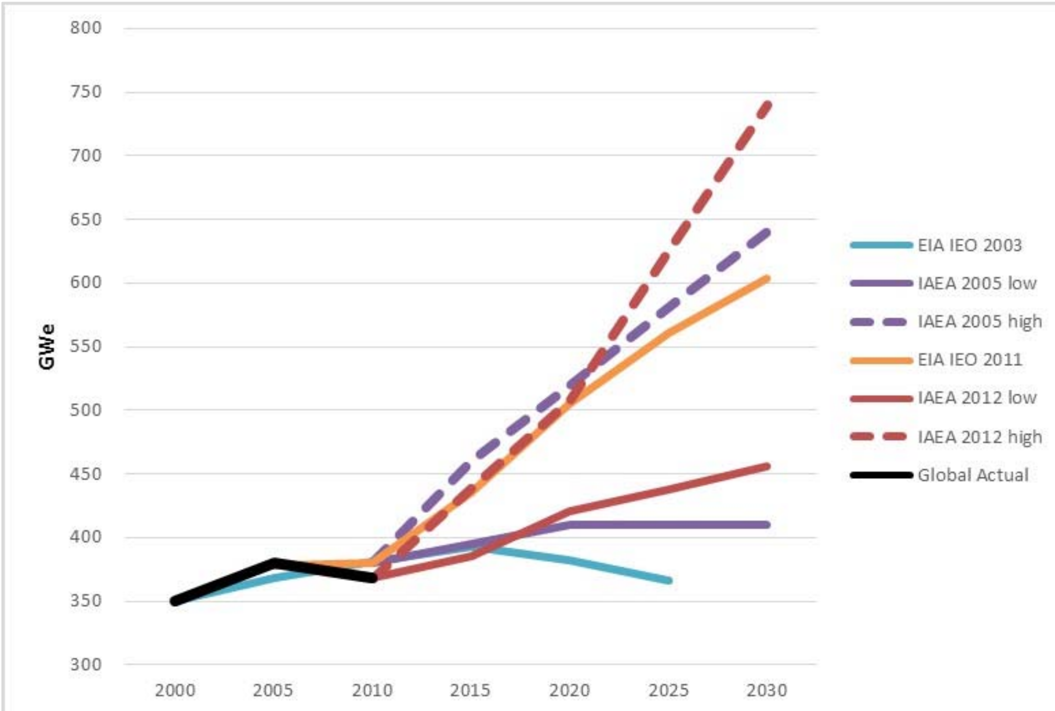
Figure 17 Nuclear Power Capacity Forecasts, 1995–2000, GWe



Source: Worthington Sawtelle LLC

Figure 18 presents the most recent forecasts: U.S. Energy Information Administration (EIA) International Energy Outlook (IEO) reference cases from 2003 and 2011; the IAEA 2005 and 2012 low and high cases; and actual global installations.

Figure 18 Nuclear Power Capacity Forecasts, 2003–2012, GWe



Source: Worthington Sawtelle LLC

In addition to overstatements of capacity additions, cost forecasts were similarly afflicted. Table 9 summarizes an analysis made by the U.S. DOE in 1986 that compared forecasts with actual costs. On average, forecasts underestimated costs by over 200%. This persistent optimism continues to this day and is not confined to the U.S. See Table 10.

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Table 9 Cost Estimates Compared with Actual Costs 1966-1977, $/kW

	Utility Projection	**Actual**	**Overrun (%)**
1966-1967	612	1,279	109
1968-1969	741	2,180	194
1970-1971	829	2,889	248
1972-1973	1,220	3,882	218
1974-1975	1,263	4,817	281
1976-1977	1,630	4,377	169
Average	**938**	**2,959**	**207**

Source: Congressional Budget Office

Table 10 Cost Estimate Revisions, 2002–2012, $/kW

Forecaster	Date of Forecast	Forecasted Cost
U.S. Forecasts		
MIT	2002	$2,000
Moody's Investment Services	2007	$5,000 - $6,000
Keystone	2007	$3,600 - $4,000
MIT	2007	$4,000
Georgia Power: Vogtle 3 & 4	2009	$6,500
	2012	$7,400
France		
EDF: Flamanville NPP	2007	$3,200
	2012	$6,700
Finland		
TVO: Olkiluoto NPP	2005	$3,200
	2012	$8,500

Source: Worthington Sawtelle LLC

On the other hand, some countries have provided more realistic appraisals, such as China and Korea. A realistic market forecast must therefore take a critical look at each national program and determine the degree of optimism built into the official forecasts. Given the scope and time horizon of these forecasts, a probability distribution is likely to be the most accurate representation of what is known about the market today.

3.2 Global Nuclear Power Market Forecasts Based on Announced Plans

3.2.1 Announced and Likely NPP Capacity Additions by Country

3.2.1.1 Armenia

Ajerbian has protested Metsamor's construction.

Table 11 Armenia Nuclear Generation Plant Construction and Operation, 2012–2020

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation Date	Likely Operation Date
Metsamor	PWR	VVER V-491	1,085	ROSATOM	2014	2020	>2030

Source: Worthington Sawtelle LLC

3.2.1.2 Bangladesh

Table 12 Bangladesh Nuclear Generation Plant Construction and Operation, 2014 – 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation Date	Likely Operation Date
Roopor 1	PWR	VVER	1,087	Rosatom	2015	2020	2021
Roopor 2	PWR	VVER	1,087	Rosatom	2015	2020	2021

Source: Worthington Sawtelle LLC

3.2.1.3 Belarus

Table 13 Belarus Nuclear Generation Plant Construction and Operation, 2014 – 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation Date	Likely Operation Date
Ostrovets 1	PWR	AES-2006	1,200	Rosatom	2013	2018	2020
Ostrovets 2	PWR	AES-2006	1,200	Rosatom	2013	2020	2021

Source: Worthington Sawtelle LLC

3.2.1.4 Brazil

The Angra 3 unit actually began construction as a KWU reactor in 1984 and was halted in 1986. It resumed in 2010 as an AREVA plant. At present, its German export credits have been withdrawn and its financing is questionable.

Table 14 Brazil Nuclear Generation Plant Construction and Operation, 2014 – 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation Date	Likely Operation Date
Angra 3	PWR	ATMEA	1,405	AREVA	2010	2016	2017

Source: Worthington Sawtelle LLC

3.2.1.5 Bulgaria

Table 15 Bulgaria Nuclear Generation Plant Construction and Operation, 2014 – 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation Date	Likely Operation Date
Kozluduy 7	PWR	AP1000	1,000	W	2014	2022	>2030

3.2.1.6 China

China has about 12.5 GW nuclear capacity in service as of 3Q12; its goal is to install another 40 GW by 2015 and another 30 to 40 GW between 2015 and 2020. The 2015 and 2020 goals represent reductions in earlier plans by 10 GW in 2015 and 20 GW in 2020, but nonetheless represent enormous investments for the country.

At present, it appears that the maximum new capacity China might add by the end of 2015 is about 25 GW, which is the amount of capacity already in construction with operation dates forecasted by that date. Although Chinese construction times are quite fast by western standards, new nuclear plants require about five years to complete. Achieving all of these operations date targets would result in a total installed nuclear capacity of 37.5 GW by 2015.

Accomplishing the 2020 goal of 60 GW to 70 GW total nuclear capacity is unlikely. New plants with official construction start and operational dates total about 19 GW between 2015 and 2020, which brings total installed capacity in 2020 to about 57.5 GW. This presumes the post Fukushima plants that are currently in suspension until 2015 will be allowed to resume construction then. If they are kept in suspension, the number for 2020 drops to 51 GW.

There are another 40 GW of NPPs planned that are to be installed after 2020, but no official dates are available for their construction. **Error! Reference source not found.** provides a list of nuclear generating stations either in construction or planned for operation through 2020. The four NPPs in post Fukushima suspension are highlighted.

Table 16 China Nuclear Generation Plant Construction and Operation, 2014 – 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Fangjiashan 1	PWR	CNP-1000	1,000	DFEC	2008	2014	2014
Fuqing 2	PWR	CPR-1000	1,000	DFEC	2009	2014	2014
Hongyanhe 2	PWR	CPR-1000	1,000	DFEC	2008	2014	2014
Ningde 2	PWR	CPR-1000	1,000	DFEC	2008	2014	2014
Ningde 3	PWR	CPR-1000	1,000	DFEC	2010	2014	2014
Sanmen 1	PWR	AP-1000	1,000	WH/MHI	2009	2014	2014
Taishan 1	PWR	EPR-1700	1,700	AREVA	2009	2014	2014
Yangjiang 2	PWR	CPR-1000	1,000	DFEC	2009	2014	2014
Changjiang 1	PWR	CNP-600	610	DFEC	2009	2015	2015
Fangchenggang 1	PWR	CPR-1000	1,000	DFEC	2010	2015	2015
Fangjiashan 2	PWR	CNP-1000	1,000	DFEC	2009	2015	2015
Fuqing 3	PWR	CPR-1000	1,000	DFEC	2010	2015	2015
Haiyang 1	PWR	AP-1000	1,000	WH	2009	2015	2015
Haiyang 3	PWR	AP-1000	1,000	WH	2009	2015	2015
Hongyanhe 3	PWR	CPR-1000	1,000	DFEC	2009	2015	2015

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Ningde 4	PWR	CPR-1000	1,000	DFEC	2010	2015	2015
Sanmen 2	PWR	AP-1000	1,000	WH/MHI	2009	2015	2015
Taishan 2	PWR	EPR-1700	1,700	AREVA	2010	2015	2015
Xianning 1	PWR	CPR-1000	1,000		2010	2015	2015
Yangjiang 3	PWR	CPR-1000	1,000	DFEC	2010	2015	2015
Changjiang 2	PWR	CNP-600	610	DFEC	2009	2016	2016
Fangchenggang 2	PWR	CPR-1000	1,000	DFEC	2010	2016	2016
Haiyang 2	PWR	AP-1000	1,000	WH	2010	2016	2016
Hongshiding 1	PWR	CPR-1000	1,000	WH	0	2016	2016
Hongyanhe 4	PWR	CPR-1000	1,000	DFEC	2009	2016	2016
Jiyang 1	PWR	AP-1000	1,000	WH	2010	2016	2016
Xianning 2			1,000		2011	2016	2016
Yangjiang 4	PWR	CPR-1000	1,000	DFEC	2011	2016	2016
Changjiang 3	PWR	CNP-600	650	DFEC		2017	2017
Haiyang 4	PWR	AP-1000	1,000	WH	2011	2017	2017
Jiyang 2	PWR	AP-1000	1,000	WH	2011	2017	2017

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Changing 4	PWR	CNP-600	650	DFEC		2018	2018
Fuqing 4	PWR	CPR-1000	1,000	DFEC	2013	2018	2018
Hongshiding 2	PWR	CPR-1000	1,000	DFEC		2018	2020
Pengze 1	PWR	AP1000	1,250		2012	2018	2018
Qinshan 4-1	FBR	PHWR	650	WH/MHI		2018	2018
Shandong shidowan	HTGCR	GEN IV	400	TSINGHUA UNIV	2013	2018	2018
Tianwan 7	PWR	VVER-1200	1,200	DFEC	2012	2018	2018
Fuqing 5	PWR	CPR-1000	1,000	DFEC	2014	2019	2019
Pengze 2	PWR	AP1001	1,250		2012	2019	2019
Qinshan 4-2	FBR	PHWR	650	WH/MHI		2019	2019
Sanming-1	FBR	BN-800	800	—	2013	2019	2019
Tianwan 8	PWR	VVER-1200	1,200	DFEC	2012	2019	2019
Fuqing 6	PWR	CPR-1000	1,000	DFEC	2015	2020	2020
Lufeng 1	PWR	CPR-1000	1,250		2014	2020	2020
Qinshan 5-1	FBR	PHWR	650	WH/MHI		2020	2020
Sanming-2	FBR	BN-800	800	—	2014	2020	2020

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Yangjiang 5	PWR	CPR-1000	1,000	DFEC		2020	>2030
Yangjiang 6	PWR	CPR-1000	1,000	DFEC		2020	2020
Fangchenggang 3	PWR	CPR-1000	1,000	DFEC		2021	2021
Huizhou 1	PWR	CPR-1000	1,250		2015	2021	2021
Lufeng 2	PWR	CPR-1000	1,250		2015	2021	2021
Qinshan 5-2	FBR	PHWR	650	WH/MHI		2021	2021
Taohuajiang 1	PWR	AP-1001	1,000		2016	2021	>2030
Taohuajiang 3	PWR	AP-1001	1,000		2016	2021	>2030
Wuhu unit 1	PWR	CPR-1000	1,250	DFEC	2015	2021	>2030
Wuhu unit 2	PWR	CPR-1000	1,250	DFEC	2015	2021	>2030
Bailong 1	PWR	CPR-1000	1250	AP1000		2022	>2030
Fangchenggang 4	PWR	CPR-1000	1,000	DFEC		2022	2022
Haiyang 5	PWR	CNP-1000	1,250			2022	2028
Lufeng 3	PWR	CNP-1000	1,250			2022	>2030
Pengze 3	PWR	AP1002	1,250		2017	2022	>2030
Taohuajiang 2	PWR	AP-1002	1,000		2017	2022	>2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Taohuajiang 4	PWR	AP-1002	1,000		2017	2022	>2030
Tianwan 5	PWR	CNP-1000	1,000	DFEC	2016	2022	2022
Wuhu unit 3	PWR	CPR-1000	1,250	DFEC	2016	2022	>2030
Wuhu unit 4	PWR	CPR-1000	1,250	DFEC	2016	2022	>2030
Bailong 2	PWR	CNP-1000	1250			2023	>2030
Fangchenggang 5	PWR	CNP-1000	1,000	DFEC		2023	2023
Haiyang 6	PWR	CNP-1000	1,250			2023	2029
Lufeng 4	PWR	CNP-1000	1,250			2023	>2030
Pengze 4	PWR	AP1003	1,250		2017	2023	>2030
Tianwan 6	PWR	CNP-1000	1,000	DFEC	2017	2023	2023
Xudabao 3	PWR	CNP-1000	1,000		2017	2023	2023
Fangchenggang 6	PWR	CNP-1000	1,000	DFEC		2024	2024
Haiyang 7	PWR	CNP-1000	1,250			2024	2030
Hebaodao	PWR	CNP-1000	1,000			2024	2024
Huizhou 2	PWR	CNP-1000	1,250		2018	2024	2024
Lufeng 5	PWR	CNP-1000	1,250			2024	>2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Xianning 3	PWR	AP-1000	1,000	DFEC	2018	2024	>2030
Xudabao 4	PWR	CNP-1000	1,000		2018	2024	2024
Donggang-1	PWR	CNP-1000	1000			2025	2025
Haiyang 8	PWR	CNP-1000	1,250			2025	>2030
Hengfeng	PWR	CNP-1000	2,000			2025	>2030
Jiyang 3	PWR	AP-1000	1,000	WH		2025	2025
Jiyang 4	PWR	AP-1000	1,000	WH		2025	2025
Lufeng 6	PWR	CNP-1000	1,250			2025	2031
Sanmen 3	PWR	AP-1000	1,000			2025	2025
Xianning 4	PWR	AP-1000	1,000	DFEC	2019	2025	>2030
Xudabao 1	PWR	CPR-1000	1,000	DFEC	2020	2025	2025
Xudabao 5	PWR	CNP-1000	1,000		2019	2025	>2030
Zhangzhou	PWR	CNP-1000	7,500			2025	>2030
Changde-1	PWR	CNP-1000	1000		2020	2026	>2030
Changde-2	PWR	CNP-1000	1000		2020	2026	>2030
Changde-3	PWR	CNP-1000	1000		2020	2026	>2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Changde-4	PWR	CNP-1000	1000		2020	2026	>2030
Donggang-2	PWR	CNP-1000	1000			2026	>2030
Haiyang 9	PWR	CNP-1000	1,250			2026	>2030
Hengren	PWR	CNP-1000	5,000			2026	>2030
Hongyanhe 5	PWR	CPR-1000	1,000	DFEC		2026	>2030
Longyou-1	PWR	CNP-1000	1,250			2026	>2030
Sanmen 4	PWR	AP-1000	1,000			2026	2026
Xudabao 2	PWR	CPR-1000	1,000	DFEC	2021	2026	2026
Xudabao 6	PWR	CNP-1000	1,000		2020	2026	2031
Donggang-3	PWR	CNP-1000	1000			2027	2031
Haiyang 10	PWR	CNP-1000	1,250			2027	2031
Heyuan	PWR	CNP-1000	4,000			2027	2031
Hongyanhe 6	PWR	CPR-1000	1,000	DFEC		2027	2028
Longyou-2	PWR	CNP-1000	1,250			2027	2031
Donggang-4	PWR	CNP-1000	1000			2028	2028
Longyou-3	PWR	CNP-1000	1,250			2028	2031

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Longyou-4	PWR	CNP-1000	1,250			2029	2031
Cangan-1	PWR	CNP-1000	1000		2025	2030	2031
Cangan-2	PWR	CNP-1000	1000		2025	2030	2031
Cangan-3	PWR	CNP-1000	1000		2025	2030	2031
Cangan-4	PWR	CNP-1000	1000		2025	2030	2031
Cangan-5	PWR	CNP-1000	1000		2025	2030	2031
Cangan-6	PWR	CNP-1000	1000		2025	2030	2031
Changchun jiutai 1	PWR	CNP-1000	1250		2025	2030	2031
Changchun jiutai 2	PWR	CNP-1000	1250		2025	2030	2031
Fuling	PWR	CNP-1000	1,250			2030	2031
Fuling	PWR	CNP-1000	1,250			2030	2031
Fuling	PWR	CNP-1000	1,250			2030	2031
Fuling 1	PWR	CNP-1000	1,250			2030	2031
Guangshui 1	PWR	CNP-1000	1,250			2030	2031
Guangshui 2	PWR	CNP-1000	1,250			2030	2031
Guangshui 3	PWR	CNP-1000	1,250			2030	2031

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Guangshui 4	PWR	CNP-1000	1,250			2030	2031
Shaoguan	PWR	CNP-1000	5,000			2030	2031

Source: Worthington Sawtelle LLC

3.2.1.7 Czech Republic

The Temelin units are currently the only new units seeking bids for construction. AREVA was recently excluded from bidding.

Table 17 Czech Republic Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Temelin-2	PWR	MIR-1200	1,200			2025	2029
Temelin-3	PWR		1,200			2025	>2030

Source: Worthington Sawtelle LLC

3.2.1.8 Finland

Finland's sole unit under construction is at Olkiluoto and has been plagued with cost and schedule overruns.

Table 18 Finland Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Olkiluoto-3	PWR	EPR	1,600	AREVA	2005	2016	2017

Source: Worthington Sawtelle LLC

3.2.1.9 France

France's Flamanville unit has experience similar delays and cost overruns as its Finnish counterpart.

Table 19 France Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Flamanville 3	PWR	EPR	1,600	AREVA	2007	2016	2017

Source: Worthington Sawtelle LLC

3.2.1.10 India

Indian plans call for 20,000 MWe of nuclear capacity to be on line by 2020 and 63,000 MWe by 2032, with nuclear supplying 25% of the country's electricity by 2050.

Table 20 India Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Kalpakkam	FBR		500	BHAVINI	2004	2014	2014
Kudankulam-2	PWR	VVER V-412	917	MAEP	2002	2014	2014
Kakrapar-3	PHWR	PHWR-700	630	NPCIL	2010	2015	2015
Kakrapar-4	PHWR	PHWR-700	630	NPCIL	2010	2016	2017
Rajasthan-7	PHWR	Horizontal	630	NPCIL	2011	2016	2017
Rajasthan-8	PHWR	Horizontal	630	NPCIL	2011	2016	2018
Jaitapur-1	PWR	EPR	1,650	AREVA		2021	2022
Jaitapur-2	PWR	EPR	1,650	AREVA		2022	2023
Jaitapur-3	PWR	EPR	1,650	AREVA		2023	>2030

Source: Worthington Sawtelle LLC

3.2.1.11 Iran

Iran ultimately commissioned Bushehr 1 in 2012 and continues to assert its plan to build a second unit on the site with Russian assistance.

Table 21 Iran Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Bushehr 2	PWR	VVER V-446	915	n/a		2020	>2030
Bushehr 3	PWR	VVER V-446	915	n/a		2020	>2030

Source: Worthington Sawtelle LLC

3.2.1.12 Japan

The prospects for nuclear plants in Japan remain in a considerable state of flux post-Fukushima. Table 22 shows the units that remain in the "official" queue for construction; however, the decision to commence construction of any units not under construction by 2011 is officially on hold, and one, the Namie-okada plant, was cancelled in April 2013.

Table 22 Japan Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Shimane-3	BWR	ABWR	1,325	HITACHI	2007	2016	2016
Higashi dori 1 (TEPCO)	BWR	ABWR	1,343	—	2011	2017	2031
Higashi dori 2 (TEPCO)	BWR	ABWR	1,343	—	2011	2019	2031
Ohma	BWR	ABWR	1,325	H/G	2010	2019	2021
Kaminoseki 1	BWR	ABWR	1,325			2020	2031
Kaminoseki 2	BWR	ABWR	1,325	—		2021	2031
Tsuruga-3	PWR	APWR	1,538	MHI		2021	2031
Higashi dori 2 (Tohuku)	BWR	ABWR	1,067		2010	2022	2031
Tsuruga-4	PWR	APWR	1,538	MHI		2022	2031

Source: Worthington Sawtelle LLC

3.2.1.13 Pakistan

Pakistan began construction of two smaller reactors from China National Nuclear Corporation in 2011.

Table 23 Pakistan Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Chasnupp 3	PWR		1,100	DFEC	2011	2016	2019
Chasnupp 4	PWR		1,100	DFEC	2011	2017	2020

Source: Worthington Sawtelle LLC

3.2.1.14 Russia

In 2012 Russia cut back its build program and indefinitely postponed any reactor that was not already in construction. Nine large units will be completed by 2020.

Table 24 Russia Nuclear Generation Plant Construction and Operation, 2014–2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Beloyarsky-4	(BN-800)	FBR	864	Rosatom		2014	2015
Leningrad 2-1	PWR	VVER V-491	1,085	Rosatom	2008	2014	2015
Novovoronezh 2-1	PWR	VVER V392M	1,114	Rosatom	2008	2014	2015
Rostov-3	PWR	VVER V-320	1,011	Rosatom	1983	2014	2014
South Urals 1	PWR		1,115	Rosatom		2015	2022
Leningrad 2-2	PWR	VVER V 491	1,085	Rosatom	2010	2016	2017
Novovoronezh 2-2	PWR	VVER V392M	1,114	Rosatom	2009	2016	2017
Leningrad 2-3	PWR	VVER v-491	1,085	Rosatom	2013	2017	2021
Rostov-4	PWR	VVER V-320	1,011	Rosatom	2010	2017	2017
Tversk-1	PWR		1,115	Rosatom	2012	2017	2019
Tversk-2	PWR		1,115	Rosatom	2013	2017	2019
Tsentral-1	PWR	-	1,115	Rosatom	2013	2018	2019

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Leningrad 2-4	PWR	VVER v-491	1,085	Rosatom	2014	2019	2022
Nizhegorodsk-1	PWR		1,115	Rosatom	2014	2019	2019
Primorsk-1	PWR		1,115	Rosatom		2019	2021
South Urals 2	PWR		1,115	Rosatom		2019	2028
Tsentral-2	PWR	-	1,115	Rosatom	2014	2019	2020
Kursk 2-1	PWR	-	1,115	Rosatom	2015	2020	2021
Primorsk-2	PWR		1,115	Rosatom		2020	2022
Seversk-1	PWR		1,115	Rosatom	2013	2020	2022
Smolensk 2-1	PWR		1,115	Rosatom	2016	2020	2023
South Urals 3	PWR		1,115	Rosatom		2020	2030
Tversk-3	PWR		1,115	Rosatom		2020	2026
Nizhegorodsk-2	PWR		1,115	Rosatom	2015	2022	2022
Kursk 2-2	PWR		1,115	Rosatom	2016	2023	2024
Kola 2-1	PWR	-	1,115	Rosatom	2015	2025	2025
Seversk-2	PWR		1,115	Rosatom	2014	2025	2028
Tversk-4	PWR		1,115	Rosatom		2025	>2030
Kursk 2-3	PWR		1,115	Rosatom	2022	2029	2030
Tsentral-3	PWR		1,115	Rosatom	2023	2029	>2030
Kursk 2-4	PWR		1,115	Rosatom	2023	2030	>2030
Tsentral-4	PWR		1,115	Rosatom	2024	2030	>2030
Kola 2-2	PWR	-	1,115	Rosatom	2020	2031	>2030

Source: Worthington Sawtelle LLC

3.2.1.15 Saudi Arabia

The Saudi's have announced plans to build 16 NPPs over the next 20 years. Several large vendors have decided to team on proposals as solicited for construction of these plants. Bids have not yet been solicited, however it appears that GE-Hitachi and Toshiba Westinghouse are likely to propose their respective reactor designs.

Table 25 Saudi Arabia Nuclear Generation Plant Construction and Operation, 2014 – 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Unit 1			1,000			2020	2023
Unit 2			1,000			2021	2024
Unit 3			1,000			2022	2025
Unit 4			1,000			2023	2026
Unit 5			1,000			2024	>2030
Unit 6			1,000			2025	>2030
Unit 7			1,000			2026	>2030
Unit 8			1,000			2027	>2030
Unit 9			1,000			2028	>2030
Unit 10			1,000			2029	>2030
Unit 11			1,000			2030	>2030
Unit 12			1,000			>2030	>2030
Unit 13			1,000			>2030	>2030
Unit 14			1,000			>2030	>2030
Unit 15			1,000			>2030	>2030
Unit 16			1000			2031	2031

Source: Worthington Sawtelle LLC

3.2.1.16 Slovakia

Construction continues on the Slovakian units however its Supreme Court has revoked their licenses, which was then overturned by the Slovak Nuclear Regulatory Authority, which allowed continued construction. These legal maneuvers are likely to delay operation of both units.

Table 26 Slovakia Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Mochovce 3	PWR	VVER V-213	391	SKODA	1987	2014	2016
Mochovce 4	PWR	VVER V-213	391	SKODA	1987	2015	2017

Source: Worthington Sawtelle LLC

3.2.1.17 South Korea

South Korea's Korean Electric Power Company was unfazed by Fukushima and continued forward with its build program without interruption. In the interim, however, KEPCO and others were charged with corruption over fake safety inspections and certifications. Several units are currently not operational while their uncertified cabling is replaced. The scandal is expected to delay operation of a few of the units under construction.

Table 27 South Korea Nuclear Generation Plant Construction and Operation, 2014–2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Shin-Kori-3	PWR	APR-1400	1,340	KEPCO	2008	2014	2015
Shin- Kori -4	PWR	APR-1400	1,340	KEPCO	2009	2014	2015
Shin Ulchin 1	PWR	APR-1401	1,341	KEPCO		2017	2017
Shin-Hanul-1	PWR	APR-1400	1,340	KEPCO	2012	2017	2017
Shin Ulchin 2	PWR	APR-1402	1,342	KEPCO		2018	2018
Shin-Hanul-2	PWR	APR-1400	1,340	KEPCO	2013	2018	2018
Shin- Kori 5	PWR	APR-1400	1,340	KEPCO	2014	2019	2020
Shin- Kori 6	PWR	APR-1400	960	KEPCO	2015	2020	2021
Shin- Wolsong 4	PWR	APR-1400	1,340	KEPCO		2020	2020
Shin Ulchin 3	PWR	APR-1401	1,341	KEPCO		2021	2021
Shin-Wolsong 5	PWR	APR-1400	1,340	KEPCO		2021	2021
Shin Ulchin 4	PWR	APR-1402	1,342	KEPCO		2022	2022

Source: Worthington Sawtelle LLC

3.2.1.18 Taiwan

Taiwan operates six reactors at present. The two Lungmen units are about 90% constructed but are the targets of frequent protests and have been started and stopped by different governments over the last 10 years. A public referendum on whether they should be completed was scheduled for late summer 2013 but was withdrawn in September. Such a referendum may reappear Spring 2014.

Table 28 Taiwan Nuclear Generation Plant Construction and Operation, 2014 - 2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Lungmen 1	BWR	ABWR	1,300	GE	1999	2015	2017
Lungmen 2	BWR	ABWR	1,300	GE	1999	2016	2018

Source: Worthington Sawtelle LLC

3.2.1.19 Turkey

Bidding between Rosatom and AREVA for the supply of this unit will be completed 1Q13.

Table 29 Turkey Nuclear Generation Plant Construction and Operation, 2014–2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Mersin Akkuyu 1	PWR	VVVER-1200	2,400	Rosatom	2015	2023	2027
Mersin Akkuyu 2	PWR	VVVER-1200	2,400	Rosatom	2015	2014	2028
Sinop 1	PWR	ATMEA	2,400	Mitsubishi/AREVA	2017	2023	2025
Sinop 2	PWR	ATMEA	2,400	Mitsubishi/AREVA	2015	2019	2026

Source: Worthington Sawtelle LLC

3.2.1.20 U.A.E.

The U.A.E. has begun construction of 4 KEPCO designed units near Abu Dhabi, assisted by a direct loan from the Ex-Im Bank.

Table 30 UAE Nuclear Generation Plant Construction and Operation, 2014–2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Barakah 1	PWR	APR1400	1,340	KEPCO	2012	2017	2017
Barakah 2	PWR	APR1400	1,340	KEPCO	2013	2018	2018
Barakah 3	PWR	APR1400	1,340	KEPCO	2014	2019	2019
Barakah 4	PWR	APR1400	1,340	KEPCO	2015	2020	2020

Source: Worthington Sawtelle LLC

3.2.1.21 U.K.

Hinkley Point, after massive investment from the Chinese and a feed in tariff twice wholesale rates, has an announced operation date of 2013. This particular reactor design has had difficulties meeting schedule.

Table 31 UK Nuclear Generation Plant Construction and Operation, 2014–2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Hinkley PointC-1	PWR	EPR	1,600	AREVA		2023	2025
Hinkley PointC-2	PWR	EPR	1,600	AREVA		2023	2025

Source: Worthington Sawtelle LLC

3.2.1.22 Ukraine

Ukraine's two NPPs under construction appear to be on schedule.

Table 32 Ukraine Nuclear Generation Plant Construction and Operation, 2014–2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Khmelnitski-3	PWR	VVER V-2392B	950	ASE	1986	2016	2016
Khmelnitski-4	PWR	VVER V-2392B	950	ASE	1987	2017	2017

Source: Worthington Sawtelle LLC

3.2.1.23 U.S.

Applications for new NPP licenses seems to have peaked at 24. At present, six reactors are in construction. While the two Vogtle units appear to remain on schedule, albeit at higher costs, the Summer and Watts Bar units have experienced recent schedule delays.

Table 33 U.S.A Nuclear Generation Plant Construction and Operation, 2014–2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Watts Bar 2	PWR	W	1,777	WH	2007	2015	2016
Vogtle-3	PWR	AP-1000	1,117	WH	2012	2016	2016
Turkey Point-6	PWR	AP-1000	1,117	WH		2017	>2030
Virgil Summer-2	PWR	AP-1000	1,117	WH	2011	2017	2017
Vogtle-4	PWR	AP-1000	1,117	WH	2012	2017	2017
Virgil Summer-3	PWR	AP-1000	1,117	WH	2011	2018	2018

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Bellefonte 1	PWR	EPR	1,600	AREVA	1985	2019	2029
Turkey Point-7	PWR	AP-1000	1,117	WH		2019	>2030
Bell Bend	PWR	EPR	1,600	AREVA		2020	>2030
North Anna-3	PWR	ESBWR	1,520	GE		2022	>2030
Comanche Peak-3	PWR	US-APWR	1,700	MITSUBISHI		2023	>2030
South Texas 3	BWR	ABWR	1,300	GE		2023	>2030
William Lee 1	PWR	AP-1000	1,117	WH		2023	>2030
Comanche Peak-4	PWR	US-APWR	1,700	MITSUBISHI		2024	>2030
Levy County-1	PWR	AP-1000	1,117	WH		2024	>2030
Levy County-2	PWR	AP-1000	1,117	WH		2024	>2030
South Texas 4	BWR	ABWR	1,301	GE		2024	>2030
William Lee 2	PWR	AP-1000	1,117	WH		2024	>2030
Enrico Fermi-3	BWR	ESBWR	1,520	GE		2025	>2030
Shearon Harris-2	PWR	AP-1000	1,117	WH		2027	>2030
Shearon Harris-3	PWR	AP-1000	1,117	WH		2027	>2030

Source: Worthington Sawtelle LLC

3.2.1.24 Vietnam

Vietnam has entered into a number of relationships with the goal of building NPPs. Russia seems quite interested in supplying their needs, although financing may be an issue.

Table 34 Vietnam Nuclear Generation Plant Construction and Operation, 2014–2030

Name	Type	Model	MWe	Vendor	Constr Start	Announced Operation	Likely Operation
Phuoc Dinh 1	PWR	VVER-1000	1,000	ROSATOM		2029	2029
Phuoc Dinh 2	PWR	VVER-1001	1,000	ROSATOM		2030	2030
Phuoc Dinh 3	PWR	VVER-1000	1,000	ROSATOM		2031	>2030
Phuoc Dinh 4	PWR	VVER-1001	1,000	ROSATOM		2031	>2030

Source: Worthington Sawtelle LLC

3.2.2 Global Capacity Additions Forecast by Major Countries

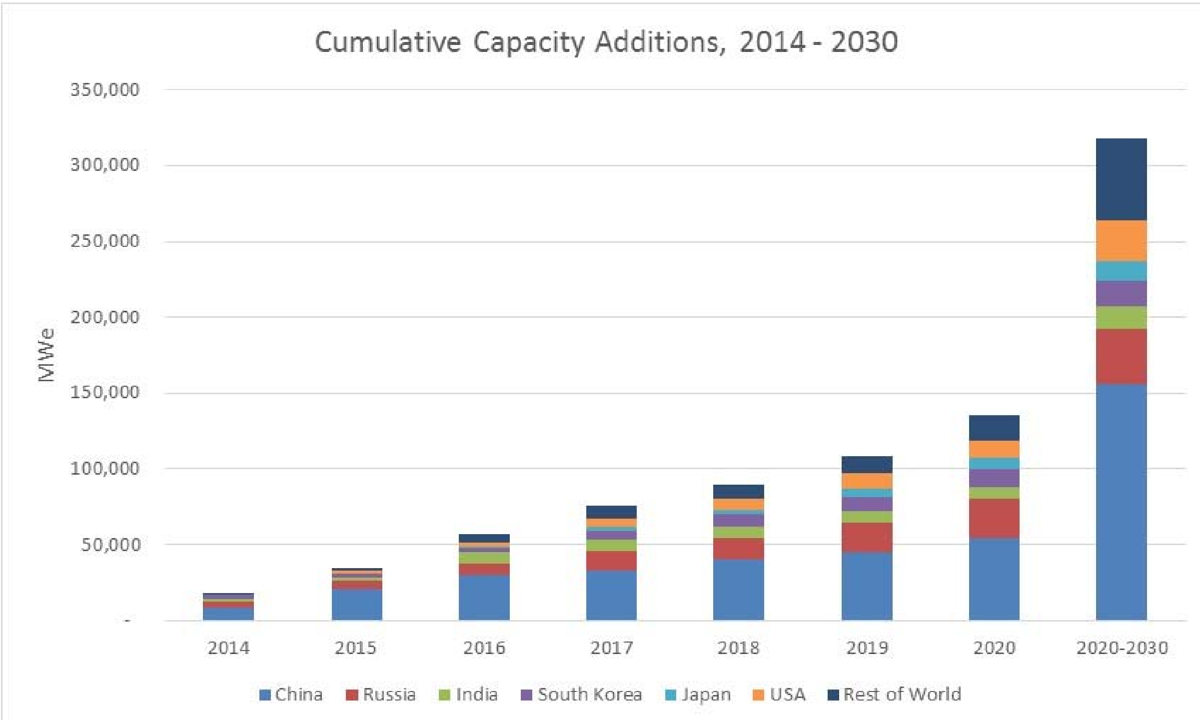
The following tables and charts summarize the global capital additions of NPPs by major countries in terms of MW.

Table 35 Commercial Nuclear Power Annual Capacity Additions through 2020 Based on Announced Plans, by Major Countries, MW

	2014	2015	2016	2017	2018	2019	2020	2021 - 2030
China	8,700	12,310	9,015	2,650	7,350	4,900	9,073	101,650
Russia	4,074	1,115	2,199	5,806	1,115	5,545	6,690	10,035
India	1,417	630	5,090	-	-	-	-	8,250
South Korea	2,680	391	-	2,681	2,682	1,340	2,300	4,023
Japan	-	-	1,325	1,343	-	2,668	2,240	5,468
USA	-	1,777	1,117	3,351	1,117	2,717	1,600	15,743
Rest of World	391	1,300	3,350	3,390	1,340	1,340	5,540	37,738
Global Total	17,262	17,523	22,096	19,221	13,604	18,510	27,443	182,907

Source: Worthington Sawtelle LLC

Figure 19 Commercial Nuclear Power Cumulative Capacity Additions through 2030 Based on Announced Plans, by Country, MW



Source: Worthington Sawtelle LLC

3.2.3 Global Overnight Capital Expenditures by Major Countries

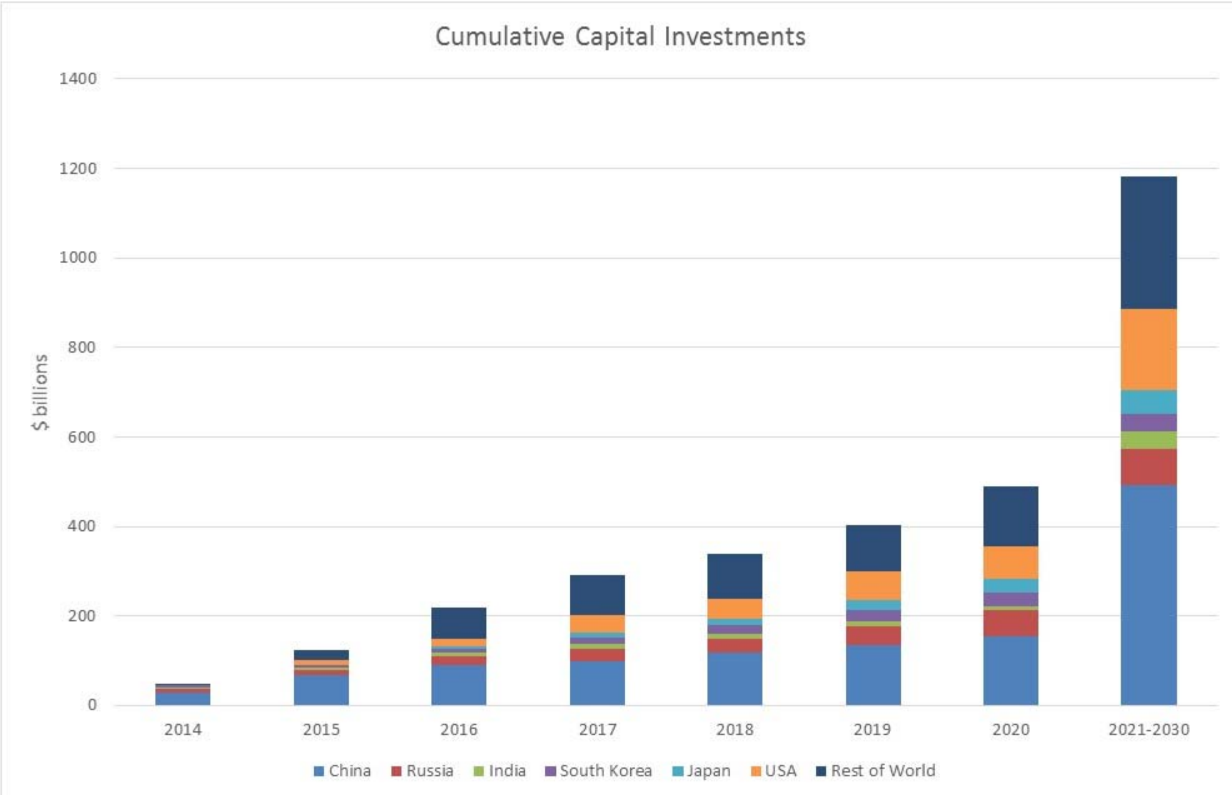
The tables and figures in this section show the "overnight" capital expenditure for NPPs by major countries. Overnight costs are the total cost of the NPP reflected entirely in the year of commercial operation.

Table 36 Commercial Nuclear Power Plant Annual Capital Expenditures (Overnight Cost) through 2030 Based on Announced Plans, by Major Countries, $ billions

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021-2030**
China	27.840	39.392	24.352	8.480	19.680	15.680	18.240	338.080
Russia	10	3	5	10	3	13	16	23.482
India	3	2	5	-	-	-	-	27.720
South Korea	7	-	-	7	7	4	6	10.573
Japan	-	-	5.963	6.044	-	12.006	5.963	22.527
USA	-	11.0	6.9	20.8	6.9	16.8	9.9	107.527
Rest of World	2.213	19.792	46.365	22.058	10.316	3.524	31.068	160.810

Source: Worthington Sawtelle LLC

Figure 20 Commercial Nuclear Power Plant Cumulative Capital Expenditures (Overnight Cost) through 2030 Based on Announced Plans, by Major Countries, $ billions



Source: Worthington Sawtelle LLC

Table 37 Global Cumulative Nuclear Plant Capital Expenditures (Overnight Costs) Based on Announced Plans, by Major Countries 2014-2030, billions of dollars

	2014	2015	2016	2017	2018	2019	2020	2021-2030
Annual	49	75	94	75	47	65	87	691
Cumulative	49	124	218	292	339	403	490	1,181

Source: Worthington Sawtelle LLC

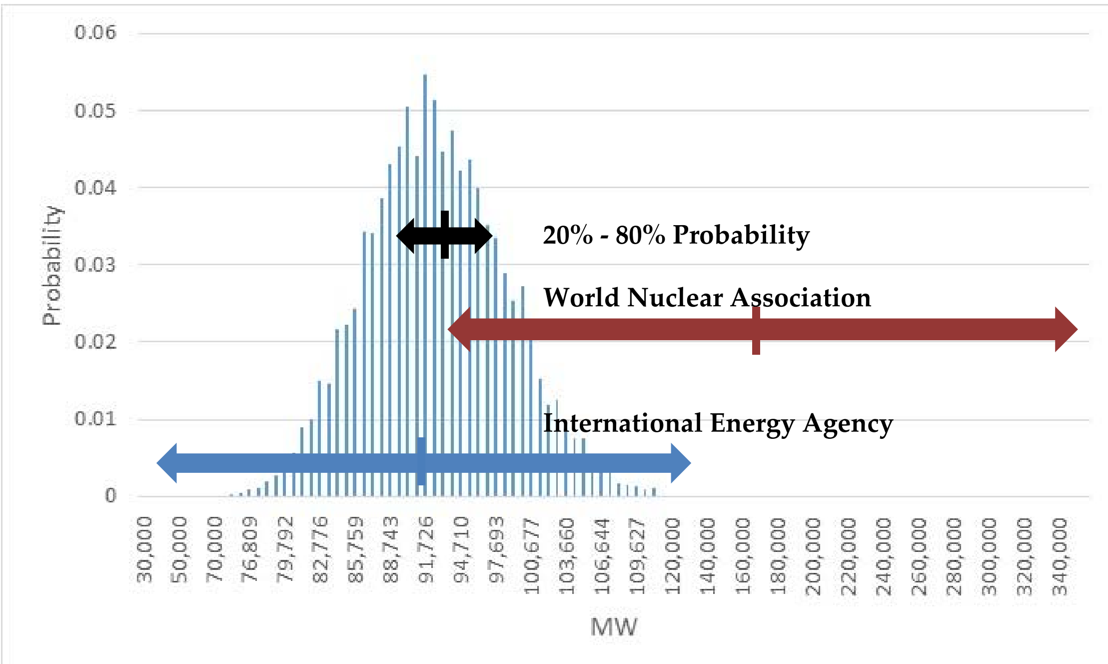
3.3 Probabilistic Analysis of Global Nuclear Power Plant Market

Taking the scenario forecasts one step further, a probabilistic forecast was made to develop a range of likely capacity additions and capital investments on a cumulative basis through 2020. The following figures display the results of those analyses, along with the "announced plans" equivalent amount.

3.3.1 Capacity Additions

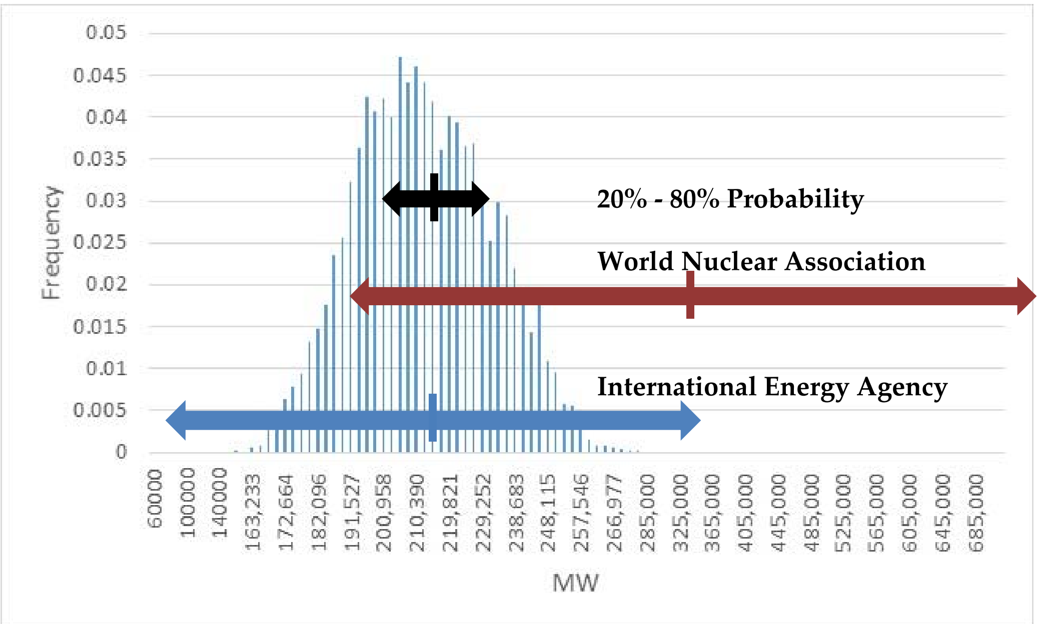
Figure 21 and Figure 22 present our forecast of cumulative new global nuclear capacity and the corresponding investment required. The figures indicate that the likely range of either metric are significantly less than that of the World Nuclear Association (WNA), but within the (rather broad) range of the International Energy Agency (IEA) forecast.

Figure 21 Probable Range of Cumulative Capacity Additions 2014 – 2020, MW



Source: Worthington Sawtelle LLC

Figure 22 Probable Range of Cumulative Capacity Additions 2014 – 2030, MW

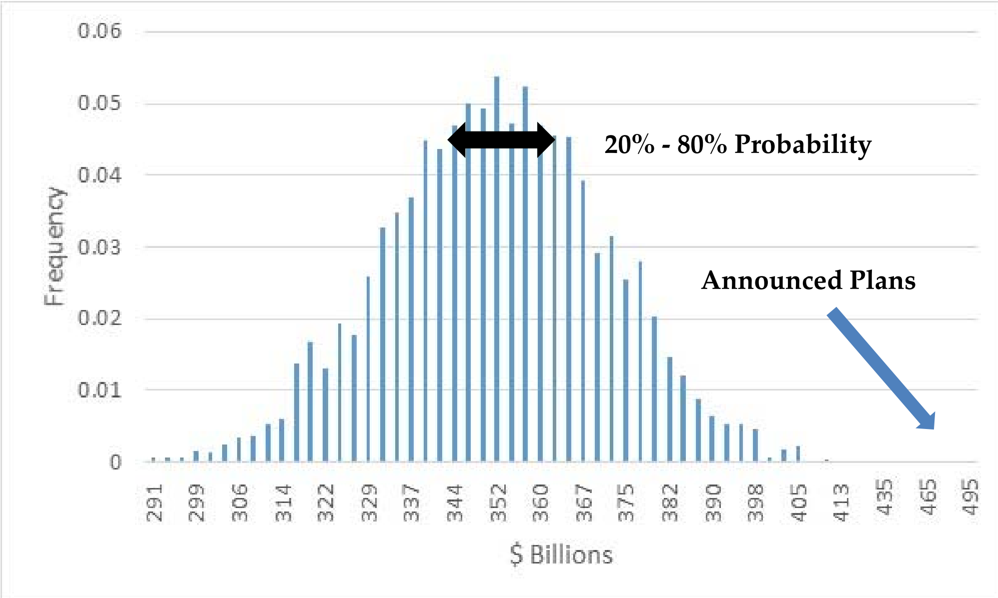


Source: Worthington Sawtelle LLC

3.3.2 Overnight Capital Expenditures

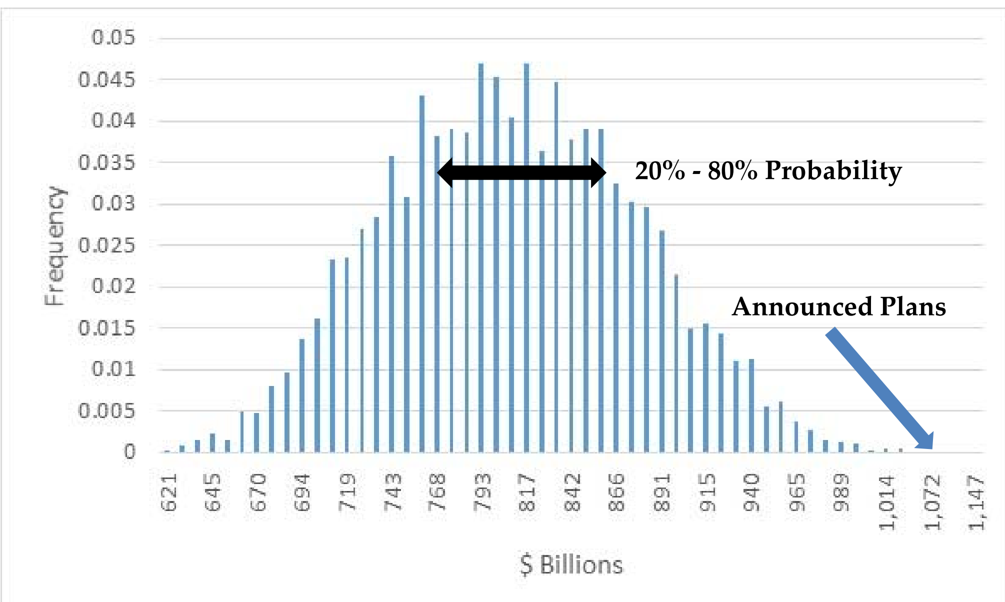
Figure 23 and Figure 24 present these capacity addition forecasts in terms of the necessary investment required (on an overnight cost of capital basis. $2013). Note the disparity between the probable range of investment and the amount that would be required if all announced plans were realized.

Figure 23 Probable Range of Overnight Capital Expenditures 2014 – 2020, $ Billions



Source: Worthington Sawtelle LLC

Figure 24 Probable Range of Overnight Capital Expenditures, 2014 – 2030, $ Billions



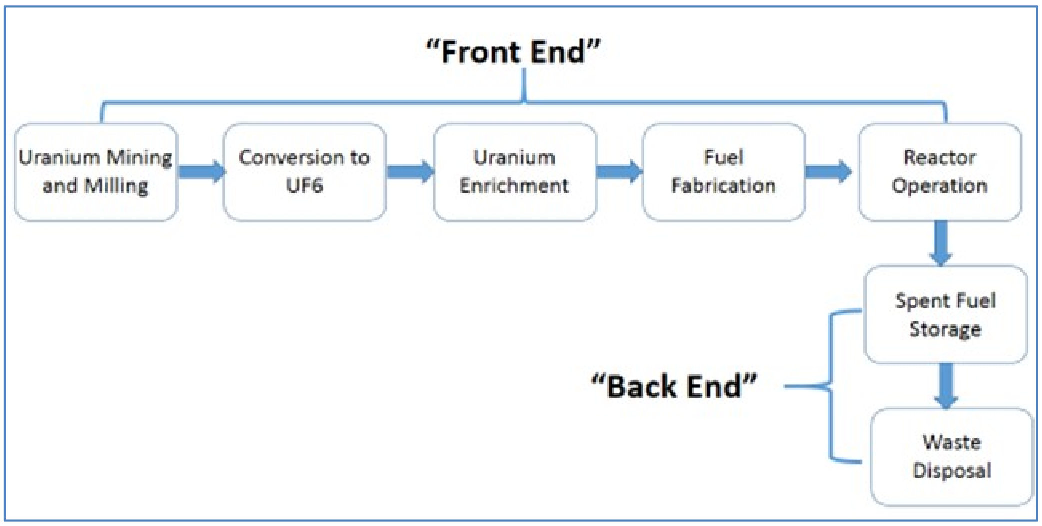
Source: Worthington Sawtelle LLC

4 APPENDIX A NUCLEAR FUEL CYCLE, SUPPLY CHAIN

4.1 Nuclear Fuel Cycle

The "front end" of the fuel cycle consists of all steps from the mining of uranium ore to the use of finished fuel in the reactor. The "back end" of the fuel cycle currently consists of placing used or "spent" fuel in storage on site, awaiting its transfer to a permanent disposal facility. In some countries the back end actually is a cycle, where the spent fuel is reprocessed, wastes separated and disposed, and fissile material reused in new fuel. The process in most countries is not cyclic, however, but rather one way. In simplest form, the nuclear fuel cycle consists of the following steps shown in Figure 25.

Figure 25 LWR Nuclear Fuel Cycle without Reprocessing



Source: Worthington Sawtelle LLC

<u>Mining and Milling</u>

High-grade uranium ore typically contains about 0.1% or more uranium. This ore is milled to extract the uranium in the form of triuranium octaoxide, U_3O_8, or "yellowcake." Yellowcake varies in its U_3O_8 content, normally between 60% and 70%. The commercial metric for yellowcake is pounds U_3O_8.

Conversion

LWRs require enriched uranium; however, yellowcake's chemical form cannot be enriched. Enrichment requires the uranium be in a gaseous state. The UF_6 is converted to uranium hexafluoride, UF_6. UF_6 is a solid at room temperature but becomes a gas at 56° C (133° F). The commercial metric for UF_6 is kilograms (kg) UF_6.

PHWRs use natural uranium and its fuel conversion step purifies the yellowcake and produces uranium oxides. The older U.K. GCRs use natural uranium produced in a metallic form.

Enrichment

Enrichment is the process whereby natural uranium is enriched in the U^{235} isotope. Natural uranium only contains about 0.7% of this isotope; depending on reactor design a few percent of this isotope is necessary. One of two methods accomplishes enrichment: gaseous diffusion or centrifuge. In the diffusion case, the uranium gas is pumped through a very large number of membranes where the isotope's concentration is increased in very small amounts at each step. In the centrifuge process the gas is spun at high speeds such that the heavier natural uranium separates from the lighter U^{235}. Considerable energy is consumed at this stage, the amount of which is dependent on the desired enrichment level. Commercial metrics for this process are called Separative Work Units, or SWU. The byproduct of this process is call depleted uranium or uranium tails. Depleted uranium is very dense and is used in a number of commercial applications.

Fabrication

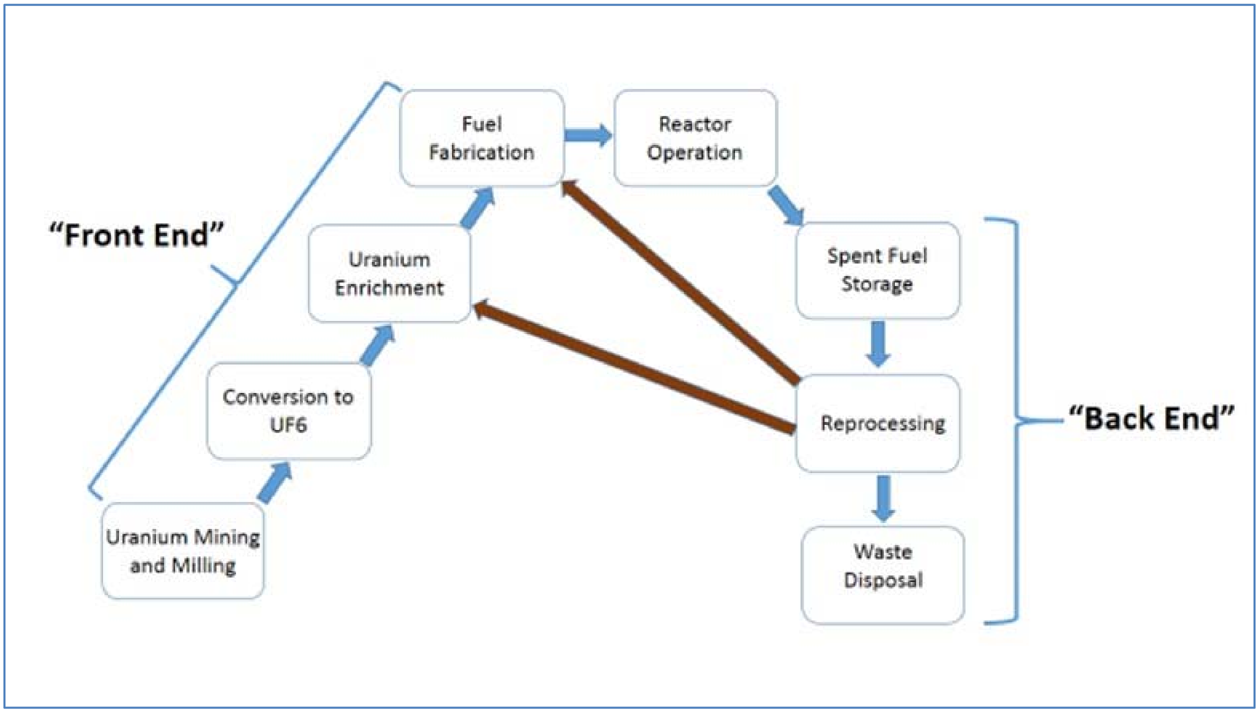
The enriched UF_6 is chemically converted into uranium oxide (UO_2) normally as ceramic pellets. The pellets are loaded into tubes made of zirconium alloys. Filled tubes are arrayed in fuel assemblies of various geometry. A large nuclear reactor fuel assembly is likely to contain over 200 rods in about a 20 centimeters square and about 3.5 meter long.

Spent Fuel Storage

In many countries, notably the U.S., no offsite storage or reprocessing of spent nuclear fuel is available. Spent fuel is stored in casks at the reactor site.

The full or closed fuel cycle, and especially the fuel cycle envisioned for FNRs is shown in Figure 26.

Figure 26 Nuclear Fuel Cycle with Reprocessing



Source: Worthington Sawtelle LLC

In the closed cycle, reprocessing extracts any remaining U^{235} as well as fissile plutonium for use in MOX fuels produced by the fabricator.

4.2 Nuclear Supply Chain

The nuclear supply chain consists of mix of conventional and rather unique power plant equipment. Many components are considered safety related and require specific quality assurance documentation. Other components require higher than normal quality. Table 38 summarizes the requirements for the major portions of the plant.

Table 38 Safety Related and Higher Than Normal Quality Component Requirements

Nuclear Island		Turbine Island		Balance of Plant	
Major Plant System	**Requirement**	**Major Plant System**	**Requirement**	**Major Plant System**	**Requirement**
Primary Containment	Most elements of this structure and interior components, including the consumable necessary for construction.	**Turbine Island Structural**	None	**BOP Island Structural**	None
Primary Support Systems	HVAC and radiation monitoring equipment.	**Secondary Support Systems**	Fire protection systems, lighting.	**BOP Support Systems**	Fire protection systems, lighting.
Reactor Coolant Systems	Vessel, internals, control rods, steam generators pressurizer, pumps and valves.	**Secondary Steam Cycle**	None	**Circulating Water Cycle**	High pressure service water pumps, emergency service water pumps.
Electrical Equipment	Cables, raceways and supports, batteries, meters.	**Electrical Equipment**	None	**Electrical Equipment**	None
Mechanical Equipment	Class 1, 2 and 3 Piping assemblies and supports, valves, tanks and pumps.	**Mechanical Equipment**	Class 1 and 2 piping assemblies.	**Mechanical Equipment**	Containment isolation valves, snubbers
Instrument & Controls	Computer, detectors, tubing and wiring.	**Instrument & Controls**	None	**Instrument & Controls**	None

Sources: NEI, Worthington Sawtelle LLC

The supply of this unique equipment has a direct impact on the overall costs and schedule of a project.

The long moratorium has reduced the number of suppliers/manufacturers that can meet all requirements.

Those that continue:

- Have limited capacity;
- Limited inventory or provide custom built products; and
- Are reluctant to invest the additional capital necessary to gain qualification for their products.

In addition, the skilled workforce necessary as well as qualified inspectors (both internal and external) has been reduced.

Consequently, significant lead times for orders are now necessary. Table 39 presents the lead times for orders prior to construction start, and the country of origin for major plant equipment.

Table 39 Major NPP Component Ordering Lead Times and Countries of Origin

	Order Lead Time, Months Prior to Construction Start	Country of Origin	Suppliers
Reactor vessel	33	Italy, Japan, Korea, Spain	Ansaldo, Doosan Heavy Industries, Equipos Nucleares, Hitachi, IHI, Mitsubishi, Toshiba
Steam generators	33	France, Italy, Japan, Korea Spain	Alstom, Ansaldo, Doosan Heavy Industries, Equipos Nucleares, Hitachi, IHI, Mitsubishi, Toshiba
Turbines	24	France, Japan, Korea, U.S.	Alstom, Ansaldo, Doosan Heavy Industries, GE, Hitachi, Mitsubishi, Toshiba
Condensers	24	France, Japan, Italy, Korea	Alstom, Ansaldo, Doosan Heavy Industries, Toshiba
Feed pumps and pressurizers	36	Domestic	Various
Piping	15	Domestic	Various

Sources: Worthington Sawtelle LLC, Deloitte, DOE

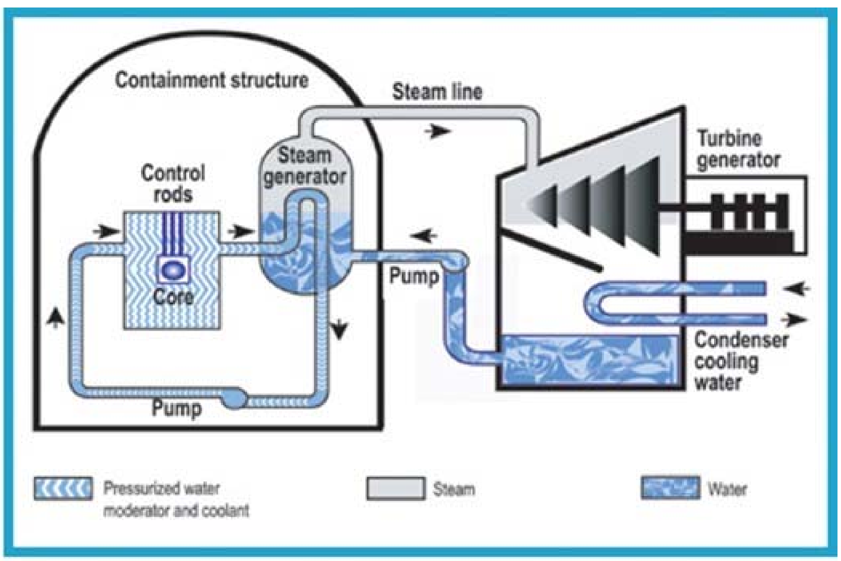
In addition, disruptions and slowdowns in the supply chain can quickly derail a project schedule and increase costs due to inflation and interest on borrowed capital.

5 APPENDIX B NUCLEAR POWER BASICS

5.1 Nuclear Power Generation Basics

Nuclear power generation is one of several forms of thermal power generation where steam is created, the steam used to turn a turbine, which then turns a generator. Instead of a boiler to make the steam, as would be the case with a coal or natural gas fired unit, a nuclear power plant uses a steam generator where very hot pressurized water passes in tubes through pipes containing external water, which then flashes to steam. Figure 27 provides a schematic of this process.

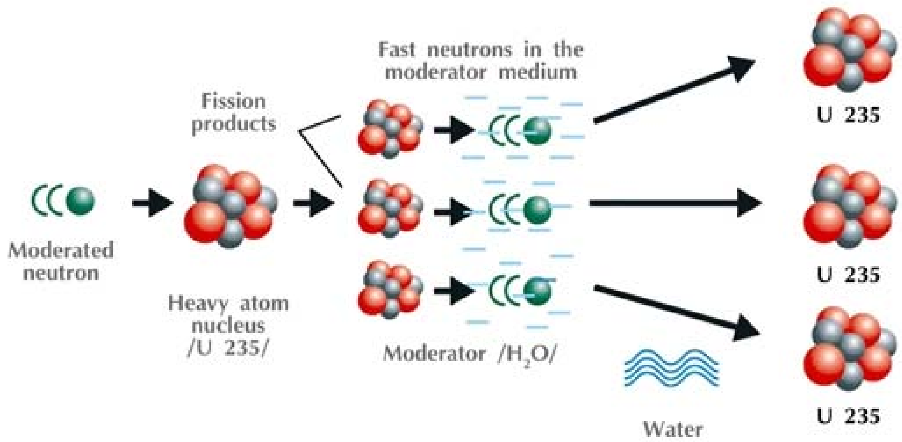
Figure 27 Nuclear Power Plant Schematic



Source: World Nuclear Association

Instead of burning a fuel to create heat, a NPP relies on the ***fission*** of uranium atoms. Fission is the process that occurs when the atom of a ***fissionable material*** absorbs a neutron from another source, breaks up into different atoms, releasing energy and two new neutrons. Once this reaction occurs, these extra neutrons collide with other atoms of fissionable material, resulting in the ***chain reaction*** of new fissions. Figure 28 shows the chain reaction begun with a moderated neutron.

Figure 28 Nuclear Chain Reaction



Source: Kozloduy NPP plc

Fissionable materials include a number of different isotopes. In commercial nuclear power, the isotope of interest is uranium 235 (U^{235}). Natural uranium (uranium 238 or U^{238}) contains about 0.7% U^{235}. Fuel in a reactor needs to have a U^{235} content of a few percent or more to sustain the chain reaction. In order to make nuclear fuel, natural uranium is "***enriched***" in U^{235}, made into ceramic pellets that are loaded into tubes. These tubes are arrayed into ***fuel assemblies*** which, when bundled together, comprise the ***core***.

The speed of the chain reaction, and therefore the reactor itself, is controlled by the use of a ***moderator***, which absorbs neutrons. Moderators are usually water, heavy water or graphite. The ***control rods*** contain moderators: when fully inserted into the core no reaction can take place. As they are slowly withdrawn, the amount of neutrons emitted increases and the speed of the chain reaction accelerates.

The ***coolant*** in the system can be water, gas, or a liquid salt or metal.

There are an enormous number of reactor designs that accomplish the generation of steam from a fission process using different fuels, moderators and coolants. Reactor designs of primary interest can be grouped into Light Water Reactors (LWR); Heavy Water Reactors (HWR); and Gas Cooled Reactors (GCR).

There is another group of reactors that do not use a moderator and use a liquid metal or molten salt as their coolant. These are referred to as Fast Neutron Reactors (FNR) and are discussed in Section 3.2.4.

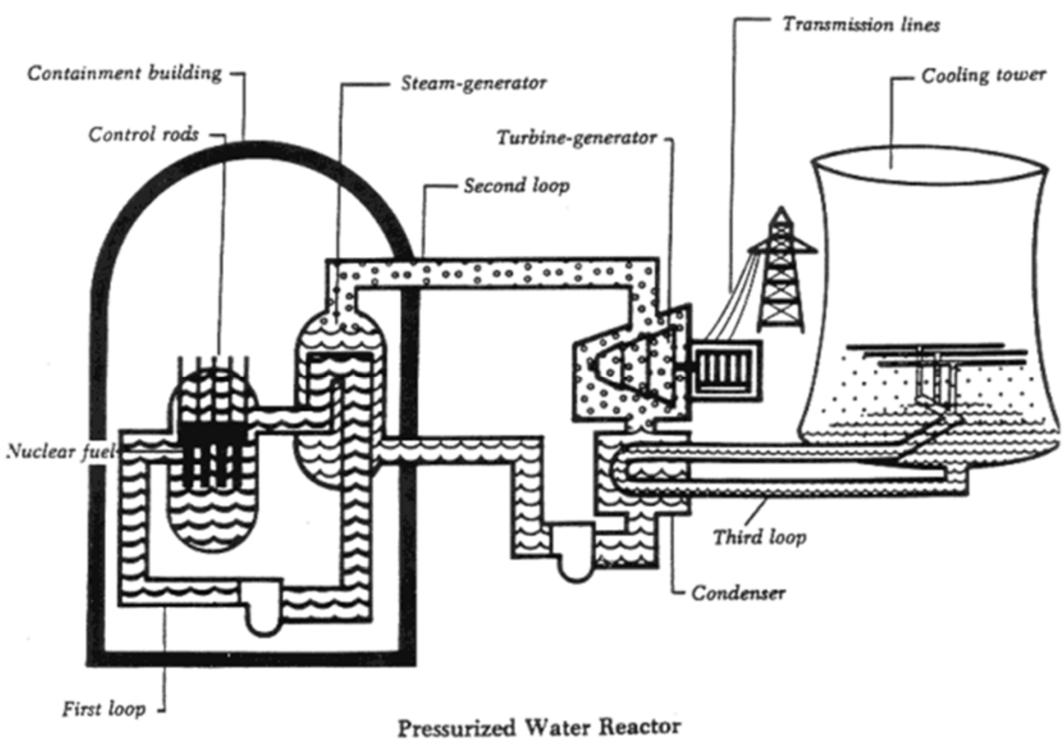
5.1.1 Light Water Reactors

5.1.1.1 Pressurized Water Reactor (PWR)

The Pressurized Water Reactor (PWR–in Russia the acronym is VVER) uses ordinary water as a coolant and moderator. Water flows in at least two loops: one to circulate through the core for cooling and the other to the steam generator to make steam. The pressurization referred to in its name refers to the high pressure under which the water is kept. Under this high pressure, temperatures of about 325° C can be attained, which is necessary for steam generation. This pressure is controlled by a pressurizer, which automatically increases pressure in the system when necessary.

PWRs are the most common reactor design in operation today, comprising about 62% of the global operating fleet. PWRs typically have a 100 tonne core of uranium, contained in several hundred vertically arranged fuel rods. The schematic shown in Figure 29 is a PWR.

Figure 29 Pressurized Water Reactor Schematic



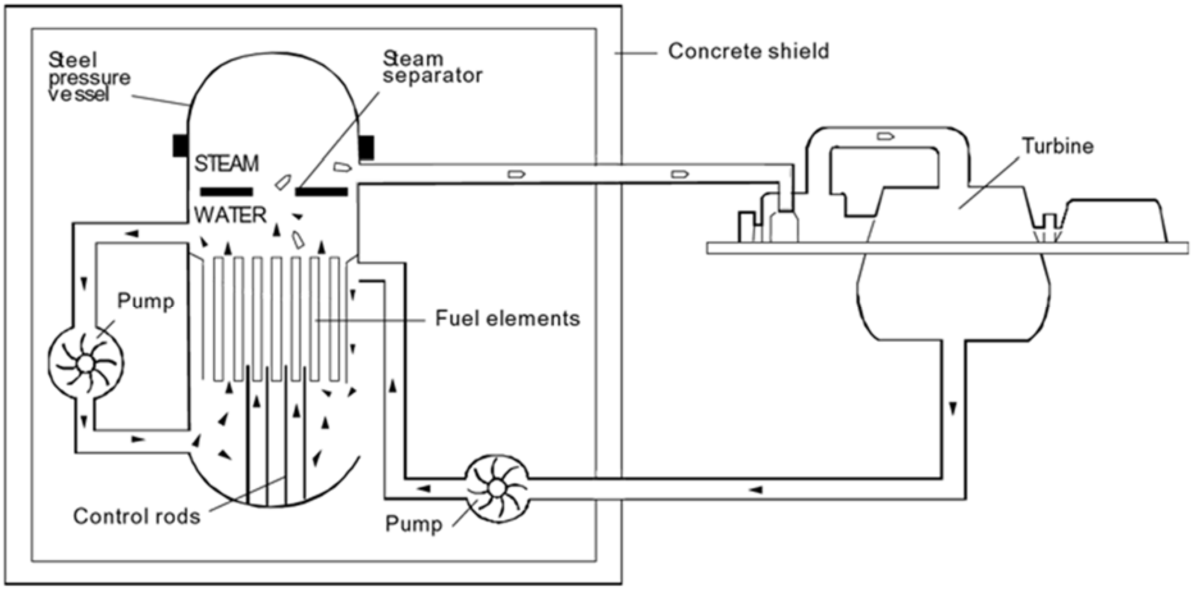
Source: U.S. N.R.C.

5.1.1.2 Boiling Water Reactor (BWR)

As the name implies, a Boiling Water Reactor boils water within the reactor vessel to create steam. The steam is separated and dried at the top of the vessel and piped to the turbine generator. The BWR is simpler than the PWR; however, there is no separation between the water coolant and the exterior of containment. Since all cooling water becomes contaminated with radionuclides during operation, the steam and therefore the turbine generator become contaminated as well. Although simpler, the fact that there is no separation between the reactor coolant and the turbine generator, which is outside of the reactor vessel, means that the turbine generator is contaminated. Contamination is only an issue when the unit is operating: radioactive decay rapidly reduces the levels of contamination when the unit is shut down for maintenance.

BWR fuel cores are normally a bit smaller than PWRs, with about 800 tonnes of uranium. Since the steam is taken off at the top of the reactor, the control rods enter the core from the bottom. Figure 30 shows a schematic of a BWR.

Figure 30 Schematic of a Boiling Water Reactor

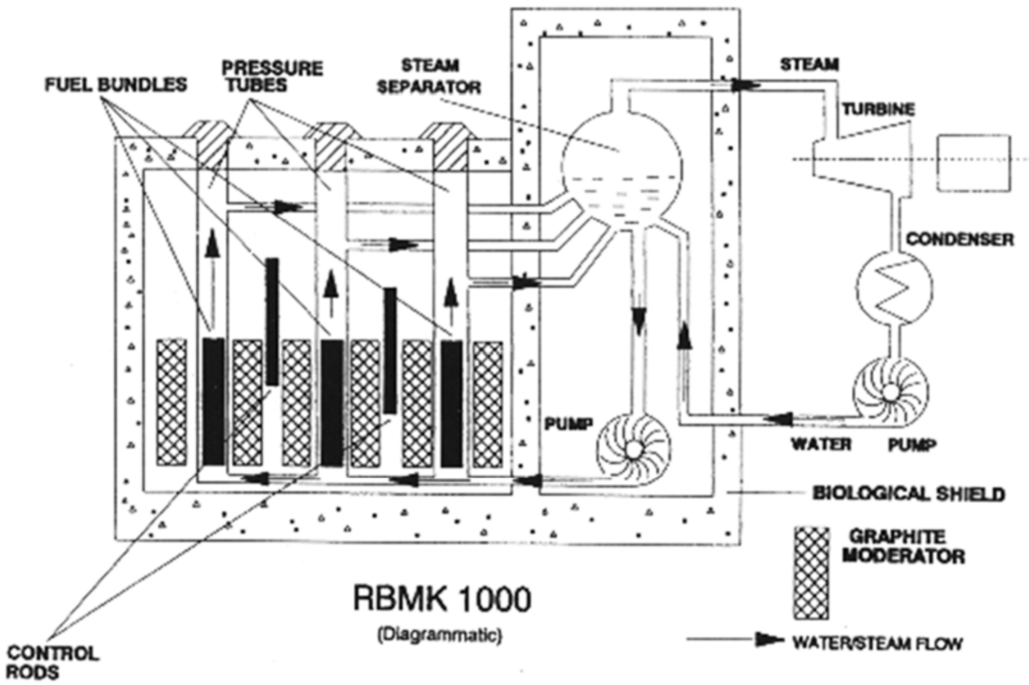


Source: World Nuclear Association

5.1.1.3 Light Water Graphite Moderated Reactor

Unique to the Soviet Union was the Light Water Graphite Moderated Reactor, shown in Figure 31. The Russian acronym is RMBK. The RBMK uses water as coolant but graphite as the moderator. The water is allowed to boil at the top of the reactor in a manner similar to a BWR. Chernobyl was a RBMK: the design is now considered flawed and unsafe. Some modifications have been made to the units still operating to improve their risk margins. The RBMK was intended to produce both electricity and plutonium for weapons.

Figure 31 Light Water Graphite Moderated Reactor Schematic



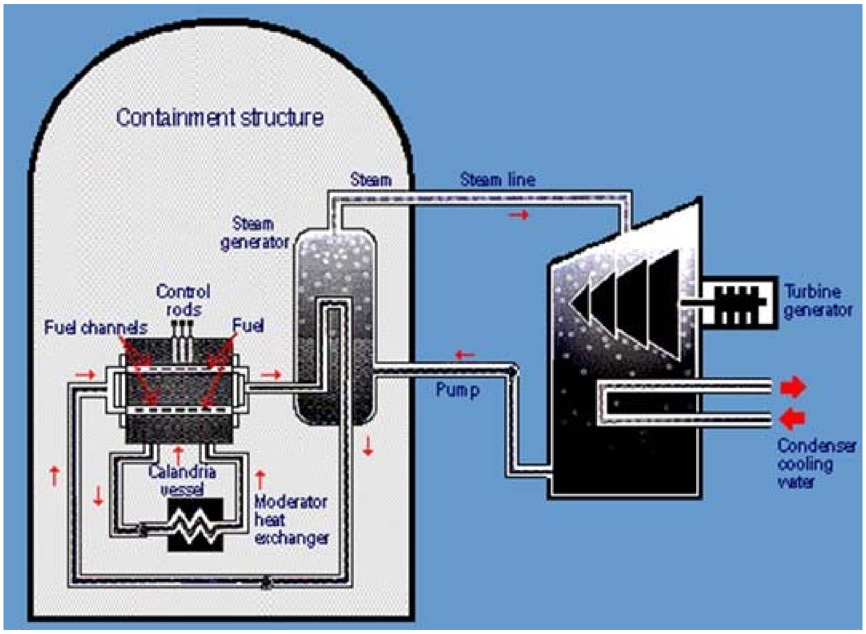
Source: World Nuclear Association

5.1.2 Pressurized Heavy Water Reactor (PHWR or CANDU)

The Pressurized Heavy Water Reactor (PHWR) is a design unique to Canada. The Atomic Energy Canada, Limited (AECL) developed what it calls the Canada Deuterium Uranium (CANDU) reactor. India operates a few CANDU units and is developing its own PHWR. PHWR's use natural uranium, rather than enriched uranium, and "heavy water" as coolant and moderator. The core of a PHWR has horizontal fuel rods with vertically inserted control rods. The fuel rods lay in channels, which allow for refueling during operation. As with the PWR, hot pressurized coolant is circulated through a steam generator to create steam for the turbine.

Figure 32 shows a schematic of the PHWR.

Figure 32 Pressurized Heavy Water Reactor (PHWR) Schematic



Source: World Nuclear Association

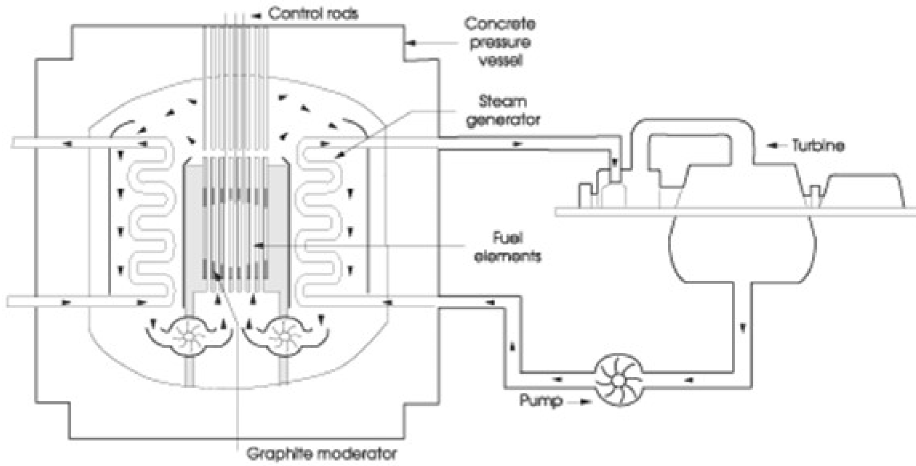
5.1.3 Gas Cooled Reactor (GCR), Advanced Gas Cooled Reactor (AGR), Very High Temperature Reactor (VHTR)

Gases can also be used as a coolant when combined with another moderator. Early Gas Cooled Reactors (GCR) were cooled with carbon dioxide and moderated with graphite. GCRs were considered the "European" reactor, competing with the primarily American PWR and BWRs and the Canadian CANDUs. Virtually all operating reactors in the U.K. are gas cooled. Gas cooled reactors using graphite moderators comprise the majority of operating reactors in the U.K.

Newer designs, referred to as Advanced Gas Cooled Reactors (AGR) use helium as a coolant because it has better heat transfer properties.

Figure 33 shows the schematic for an AGR.

Figure 33 Advanced Gas Cooled Reactor Schematic



Source: World Nuclear Association

GCRs and AGRs did not achieve a great deal of commercial success outside of the U.K. An American design, called a High Temperature Gas Cooled Reactor (HTGR), produced by General Atomics and using a helium coolant, was used for two U.S. plants; however, neither of these plants are still in operation.

A new generation of HTGRs is currently in development in several countries in small modular versions. A fourth generation, called the Very High Temperature Reactor (VHTR) is also in development. These future designs are discussed in section 6.3.2.

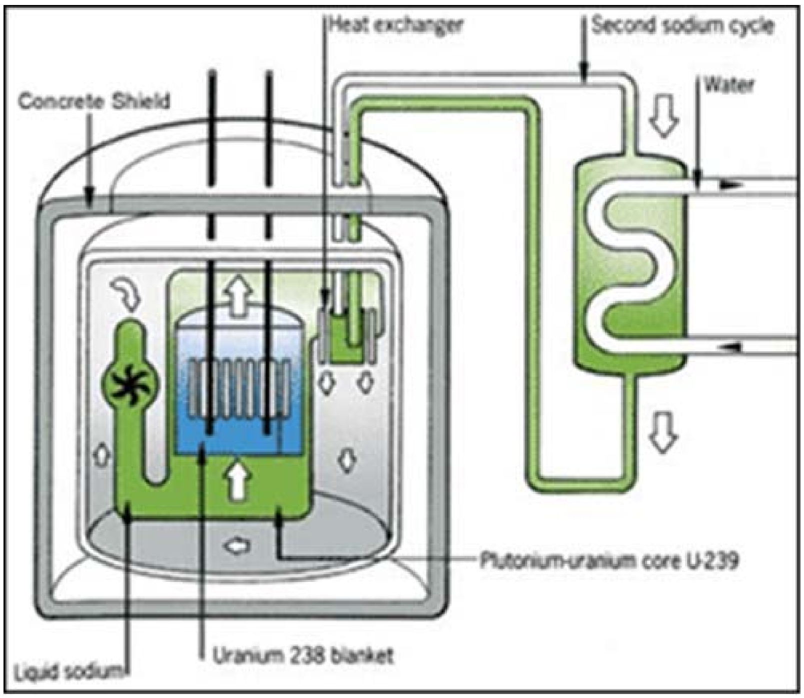
5.1.4 Fast Neutron Reactors

Figure 34 shows a fission reaction occurring where fast neutrons are released, then slowed in a moderator before they each trigger their own fission reactions. Fast neutrons, under the right circumstances can initiate a chain reaction when certain kinds of fissile material are available for fuel. These Fast Neutron Reactors (FNR) have a number of advantages over LWRs: they are more fuel efficient and can be used to transmute nuclear waste into more benign elements. They are also far more difficult to control than LWRs because no moderator is present. In addition, the optimum non-moderating coolants for an FNR are liquid metals or molten salts. The heat, corrosive properties and explosive properties in the environment present difficult engineering challenges.

A FNR is normally fueled with uranium enriched to much higher levels than LWRs (at least 5%), plutonium, or mixed oxide fuel (MOX) which is a mixture of fissile materials. Most MOX in use today is a mixture of plutonium and natural uranium.

FNR can be designed to "breed" new fuel. If the core of an FNR is surrounded with a natural uranium "blanket," neutrons from the core reactions will convert some of the blanket to fissile material. The blanket is then removed and reprocessed to access the fissile material, which is then blended in MOX. Once fully implemented, a fuel cycle incorporating breeders and reprocessing would radically reduce the need for new fuel and uranium mining. For some countries, a breeder fuel cycle meant energy independence. All of the FNRs built to date have been breeder reactors using liquid metal as coolants, called fast breeder reactors (LMFBR). Figure 34 shows a conceptual LMFBR.

Figure 34 Fast Breeder Reactor Schematic



Source: Cameco

6 APPENDIX C NEXT GENERATION NPP TECHNOLOGIES

6.1 Next Generation NPP Technologies

Over the last 10 years NPP designs have evolved considerably in an attempt to lower costs, offer more standardization among designs (to facilitate the regulatory process) and to incorporate what is generally referred to as "passive safety" measures. Passive safety encompasses a number of design features that would allow for the safe shutdown.

These new designs also depart from past designs in terms of capacity. Vendors are developing units that are in many cases bigger than the designs of the 70's and 80's exceeding one GW and in one case providing a capacity of 1700 MWe per unit. In addition to these larger units, a new class of reactors are about to emerge that are much smaller than units in the past. Most are less than 300 MWe and many are in the 100 MWe class or less.

Gen III+ is the generation that is currently entering service and that will include the primary designs through at least 2030. A number of very advanced reactors are in the R&D stage, these are the so-called Gen IV designs. An informal convention has emerged to classify these different generations of reactor design, which is presented in Table 40.

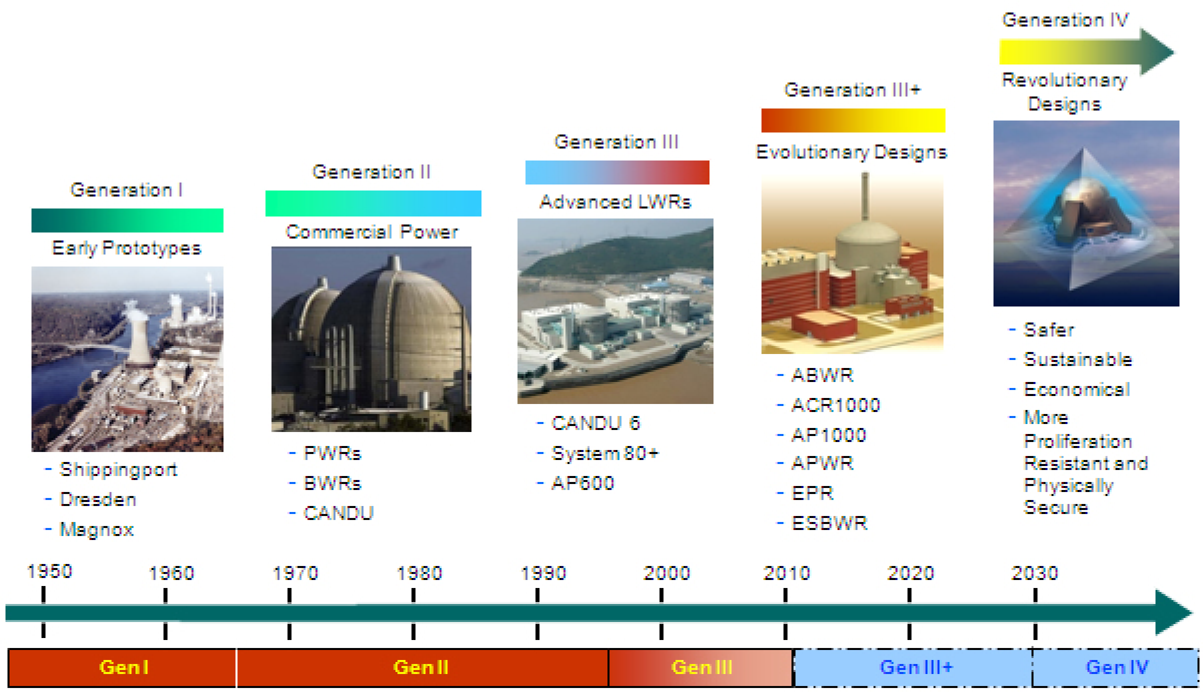
Figure 35 shows this evolution graphically.

Table 40 Evolution of NPP Design Generations

Reactor Generation	Time Frame Deployed	Characteristics
I	Through 1966	Prototypes and R&D reactors
II	1966-1995	Commercial reactors
III	1995-2010	Passive safety systems, higher efficiency and standardization of designs
III+	2010-2030	Improved Gen III
IV	No earlier than 2030	Reactor designs currently in R&D

Source: Worthington Sawtelle LLC

Figure 35 Evolution of NPP Design Generations



Source: Generation IV International Forum

6.2 Large 3rd Generation/Advanced NPP

Both LWR and HTGR configurations are being pursued in Gen III+ NPPs. In addition, large scale FNRs are evolving quickly. The primary Gen III+ products and their characteristics are summarized in Table 41.

Table 41 Advanced Large Scale (3rd Generation) Reactor Technology Characteristics

Moderator	Model Name	Type	Vendor	Gross Capacity (MWe)	Cost ($/kW)
Light Water	Advanced Boiling Water Reactor (ABWR)	BWR	GE, Toshiba, Hitachi	1,380	n/a
Light Water	Advanced Pressurized Water Reactor (APWR)	PWR	Mitsubishi	1,538 (Japan)	n/a
Light Water	AP1000	PWR	Westinghouse	1,700 (EU-APWR;	n/a
Light Water	APR1400	PWR	KEPCO	US-APWR)	2,300
Light Water	ATMEA1	PWR	Areva, MHI	1,150	n/a
Light Water	AP1000	PWR	Westinghouse	1,200	n/a
Light Water	APR1400	PWR	KEPCO	1,455-1,550 (APR1400-EU)	2,300
Light Water	CAP1400	PWR	Westinghouse, SNPTC, SNERDI	1,520	n/a
Light Water	Economic Simplified BWR (ESBWR)	BWR	GE Hitachi	1,600	n/a
Light Water	European Pressurized Water Reactor (EPR)	PWR	Areva	1,750	n/a
Light Water	US-EPR	PWR	Areva	1,710	n/a

Source: Worthington Sawtelle LLC

6.3 Small Modular Reactor Technologies

Small Modular Reactors (SMR) represent an entirely new class of commercial NPPs. Some are indeed "small" when compared with the Gigawatt (GW) sized plants currently in construction, but are all still rated in tens and hundreds of megawatt capacities. The IAEA classifies "small" as less than 300 MWe. In addition to smaller capacities, SMRs differentiate themselves from current large reactor designs with passive safety systems and integrated designs, all major systems are incorporated in the reactor vessel.

Integrated primary system configurations move external pumps, pressurizers and loop piping inside the reactor vessel, which enables smaller plant size and therefore reduced cost. In the event of a loss of cooling, safety is theoretically improved because everything is within the reactor vessel.

In addition to the design differences, SMRs present less of an issue in terms of their impact on the transmission grid.

The primary nuclear technologies under development for SMRs are the same as those for 3rd Generation/Advanced large reactors: LWR, HTGR, and LMFR. The LWR technologies are the closest to commercialization. This is not to say that small nuclear reactors do not yet exist. Table 42 presents the list of SMRs in operation or under construction.

Table 42 SMRs in Operation or Under Construction

Country	Model	Capacity (MWe)	Status
Argentina	CAREM-25	27	1 module in construction
China	HTR-PM	250	2 modules in construction
	CNP-300	300	3 units operating; 2 under construction
India	PHWR-220	220	16 units operating
Russia	KLT-40S	70	2 units under construction

Source: Worthington Sawtelle LLC

6.3.1 Small LWR

Four vendors are each pursuing their own design of a SMLWR. Two of these vendors, B&W and Westinghouse, offer 3rd Gen products as well as their SMR. NuScale and Holtec are essentially startup companies. Table 43 presents the technology characteristics of the LWR class of SMRs that are in development for stationary electricity generation applications. All but the Russian VK-300 are PWRs.

Table 43 Small Modular Light Water Reactor Technology Characteristics

	mPower Reactor	NuScale Reactor	Westinghouse SMR	HI-SMUR SMR-160	SMART	ACP100	VK-300
Developer	B&W	NuScale	Westinghouse	Holtec	KEPCO	CNNC	NIKIET
Type	PWR	PWR	PWR	PWR	PWR	PWR	BWR
Module Capacity (MWe)	160	45	225	160	100	100	250
Modules per Plant	2 minimum up to 4	6 minimum up to 12	1	1	1	1	1
Refueling Interval	5 years	2 years	3 – 3.5 years	3.5 years	3 years	2 years	
IAEA Classification	Ready for near-term Deployment	Ready for near-term Deployment	Ready for near-term Deployment		Ready for near-term Deployment		Ready for near-term Deployment
Status	Company expects first unit operating 2020	Company expects first unit operating 2018	Expects design certification in 2013	Company expects first unit operating 2018	Company expects 90 MWe demo operating 2017	Company expects 2 100 MWe demos operating 2018	Company expects first unit operating 2017-2020

Source: Worthington Sawtelle LLC

6.3.2 Small HTGR

A smaller group of developers are working on High Temperature Gas Reactor (HTGR) technologies, as shown in Table 44.

Table 44 Small Modular High Temperature Gas Reactor Technology Characteristics

	HTR-PM	Antares	GTHTR	GT-MHR
Developer	China Huaneng Group	AREVA	JAERI	General Atomics
Type	PWR	PWR	PWR	PWR
Module Capacity (MWe)	100	250	100	45
Modules per Plant	1 or 2	n/a	n/a	n/a
Refueling Interval	3.5 years	n/a	4 years	n/a
IAEA Classification	Ready for near-term Deployment	n/a	n/a	Long term deployment
Status	In construction, 2 units startup 2015	n/a	Company expects 90 MWe demo operating 2017	n/a

Source: Worthington Sawtelle LLC

6.3.3 Small Liquid Metal-Cooled and Fast Neutron Reactors

Small Liquid Metal Cooled (LMC) and Fast Neutron Reactor (FNR) technologies are the least advanced in terms of commercial readiness. Table 45 presents the four major designs.

Table 45 Small Modular Fast Neutron Reactor Technology Characteristics

	HTR-PM	Antares	GTHTR	GT-MHR
Developer	China Huaneng Group	AREVA	JAERI	General Atomics
Type	PWR	PWR	PWR	PWR
Module Capacity (MWe)	100	250	100	45
Modules per Plant	1 or 2	n/a	n/a	n/a
Refueling Interval	3.5 years	n/a	4 years	n/a
IAEA Classification	Ready for near-term Deployment	n/a	n/a	Long term deployment
Status	In construction, 2 units startup 2015	n/a	Company expects 90 MWe demo operating 2017	n/a

Source: Worthington Sawtelle LLC

6.4 Fourth Generation Reactor Designs

Gen II and Gen III reactor designs were developed either by large corporations competing in the free market or through nationally directed programs such as in the former Soviet Union and France. Many of the Gen III+ designs are being developed by cross national partnerships among very large companies and quasi-government organizations.

Fourth Generation (Gen IV) designs include a number of technologies that are in early stages of R&D and which are not expected to become commercial until about 2030 and certainly later than the scope of this report. Some are being developed through an internationally coordinated effort led by the Generation IV International Forum (GIF). GIF has thirteen members: Argentina, Brazil, Canada, China, EURATOM, France, Japan, Republic of Korea, Russia, Republic of South Africa, Switzerland, U.K. and the U.S. Whether developed through the GIF coordination or in a national program, Gen IV designs include the technologies shown in Table 46, by the various countries shown in Table 47.

Table 46 Generation 4 Reactor Designs and Characteristics

Type	Coolant/Moderator	Capacity (MWe)	Advantages	Challenges
Gas Cooled Fast Reactor (GFR)	Helium/None	1,200	Very high fuel efficiency	New fuels and materials required; helium turbine
Very High Temperature Reactor (VHR)	Helium/Graphite	600	Cogeneration electricity, hydrogen, process heat	Very high temperature materials development
Supercritical Water Cooled Reactor (SCWR)	Water/Water	1,700	High thermal efficiency, simplified system	Materials corrosion resistance in SCWR conditions
Sodium Cooled Fast Reactor (SFR)	Sodium/None	600 – 1,500	High efficiency; reduced actinides in waste	Capital costs and passive safety
Lead Cooled Fast Reactor (LFR)	Lead/None	600	Reduced production high level waste	Lead corrosion and seismic design; refueling in liquid lead
Molten Salt Reactor (MSR): Fluoride Cooled Fast Reactor (FSR); Molten Salt Fast Reactor (MSFR)	Fluoride salts/None	1,200	FHR – compactness; MSFR thorium fuel cycle	Liquid salt operational issues

Sources: GIF; Worthington Sawtelle LLC

Table 47 Country Assignments GIF Technologies

Country	**Technology**
Canada	SCWR, VHTR
China	SFR, SCWR
EURATOM	GFR, SFR, SCWR, VHTR
France	GFR, SFR, VHTR
Japan	GFR, SFR, SCWR, VHTR
Republic of Korea	SFR, VHTR
Russia	SFR
Switzerland	GFR, VHTR
USA	SFR, VHTR

Source: GIF

7 APPENDIX D GLOBAL MARKET CONDITIONS

7.1 Market Drivers

7.1.1 Global Electricity Supply and Demand

NPPs are one component of a portfolio of generation sources that are used to meet demand. Electricity demand growth is correlated with economic growth, population growth and influenced by any governmental initiatives to conserve use. Even in the relatively short term of this forecast horizon, forecasts of demand and of how that demand might be met can vary depending on the prevailing economic outlook and the mix of generation sources any particular country or region might select.

7.1.1.1 Electricity Demand Forecasts

The two most prominent global energy forecasts are produced by the U.S. Energy Administration (EIA) and the International Energy Agency (IEA). They each use their own regional formatting for forecasts. Both the IEA and EIA forecasts are presented in Table 48, using the EISA format.

Table 48 EIA and IAEA Global Electricity Demand Forecasts, 2012-2020, thousands of GWh

	Region/Countries	2012	2013	2014	2015	2020	CAGR, 2012-2020
U.S. EIA International Energy Outlook 2011	**OECD Americas**	5,082	5,134	5,165	5,231	5,576	1.2%
	U.S.	4,157	4,200	4,209	4,253	4,453	0.9%
	Canada	607	603	612	622	695	1.7%
	Mexico/Chile	319	332	344	357	428	3.7%
	OECD Europe	3,626	3,671	3,722	3,776	4,040	1.4%
	OECD Asia	1,788	1,816	1,846	1,873	1,992	1.4%
	Japan						1.0%

		1,032	1,045	1,060	1,072	1,117	
	South Korea	451	460	471	482	530	2.0%
	Australia and New Zealand	305	310	315	319	345	1.6%
	Total OECD	10,496	10,620	10,733	10,880	11,609	1.3%
	Non-OECD **Europe and Eurasia**	1,596	1,622	1,648	1,681	1,792	1.5%
	Russia	976	992	1,007	1,028	1,080	1.3%
	Other	620	631	641	653	712	1.7%
	Non-OECD Asia	6,517	6,798	7,113	7,436	8,989	4.1%
	China	4,384	4,565	4,780	5,011	6,041	4.1%
	India	1,022	1,078	1,137	1,181	1,444	4.4%
	Other	1,111	1,155	1,196	1,244	1,504	3.9%
	Middle East	789	813	839	866	1,000	3.0%
	Africa	665	686	708	733	860	3.3%
	Central and South America	972	1,004	1,038	1,056	1,211	2.8%
	Brazil	454	488	524	544	661	4.8%

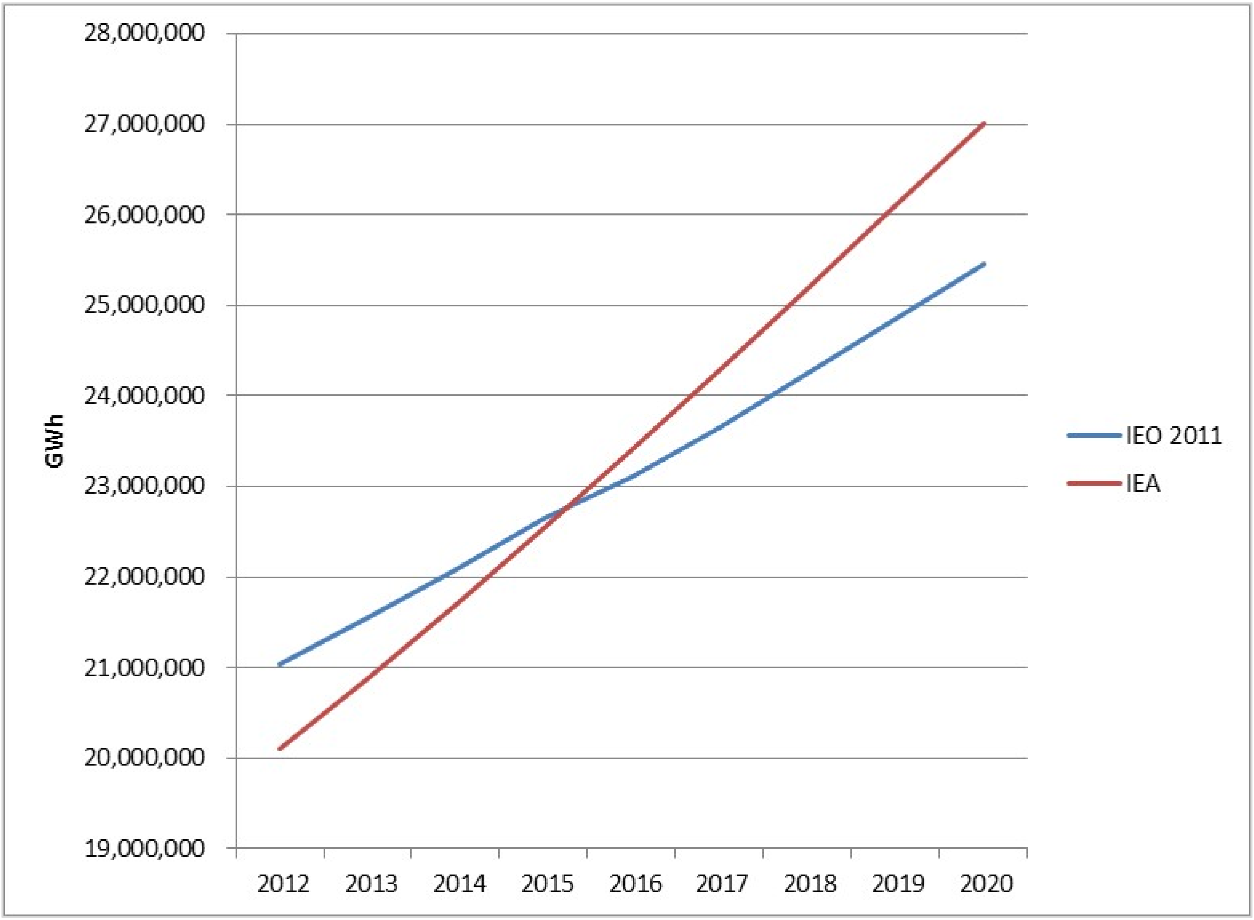
	Other	518	516	514	512	550	0.8%
	Total Non-OECD	10,540	10,924	11,347	11,772	13,852	3.5%
	Total World	21,035	21,544	22,080	22,652	25,462	2.4%
International Energy Agency World Energy Outlook 2012	**OECD Americas**	5,062	5,112	5,162	5,209	5,442	0.9%
	U.S.	4,220	4,250	4,278	4,304	4,425	0.6%
	Canada	532	539	546	553	587	1.2%
	Mexico/Chile	310	323	337	353	429	4.1%
	OECD Europe	3,148	3,154	3,174	3,199	3,353	0.8%
	OECD Asia	1,774	1,879	1,971	2,052	2,339	3.5%
	Japan	951	1,028	1,090	1,140	1,250	3.5%
	South Korea	520	541	564	586	715	4.1%
	Australia and New Zealand	303	310	318	326	374	2.7%
	Total OECD	9,984	10,145	10,307	10,460	11,134	1.4%
	Non-OECD Europe and Eurasia	1,532	1,576	1,620	1,666	1,924	2.9%

	Russia	981	1,019	1,056	1,094	1,306	3.6%
	Other	551	556	564	572	617	1.4%
	Non-OECD Asia	6,451	6,939	7,441	7,986	10,923	6.8%
	China	4,657	5,054	5,454	5,889	8,184	7.3%
	India	860	912	971	1,032	1,385	6.1%
	Other	933	972	1,017	1,066	1,353	4.8%
	Middle East	440	468	498	529	689	5.8%
	Africa	719	762	805	856	1,149	6.0%
	Central and South America	972	992	1,016	1,041	1,190	2.6%
	Brazil	485	505	527	550	681	4.3%
	Other	487	487	489	491	509	0.5%
	Total Non-OECD	10,114	10,737	11,379	12,078	15,874	5.8%
	Total World	20,098	20,882	21,686	22,538	27,008	3.8%

Sources: EIA and IEA data modified by Worthington Sawtelle LLC

Figure 36Figure 36 plots the total world forecasts from each source: note the crossover in 2015. The differences in 2013 are related to the vintages of the two forecasts.

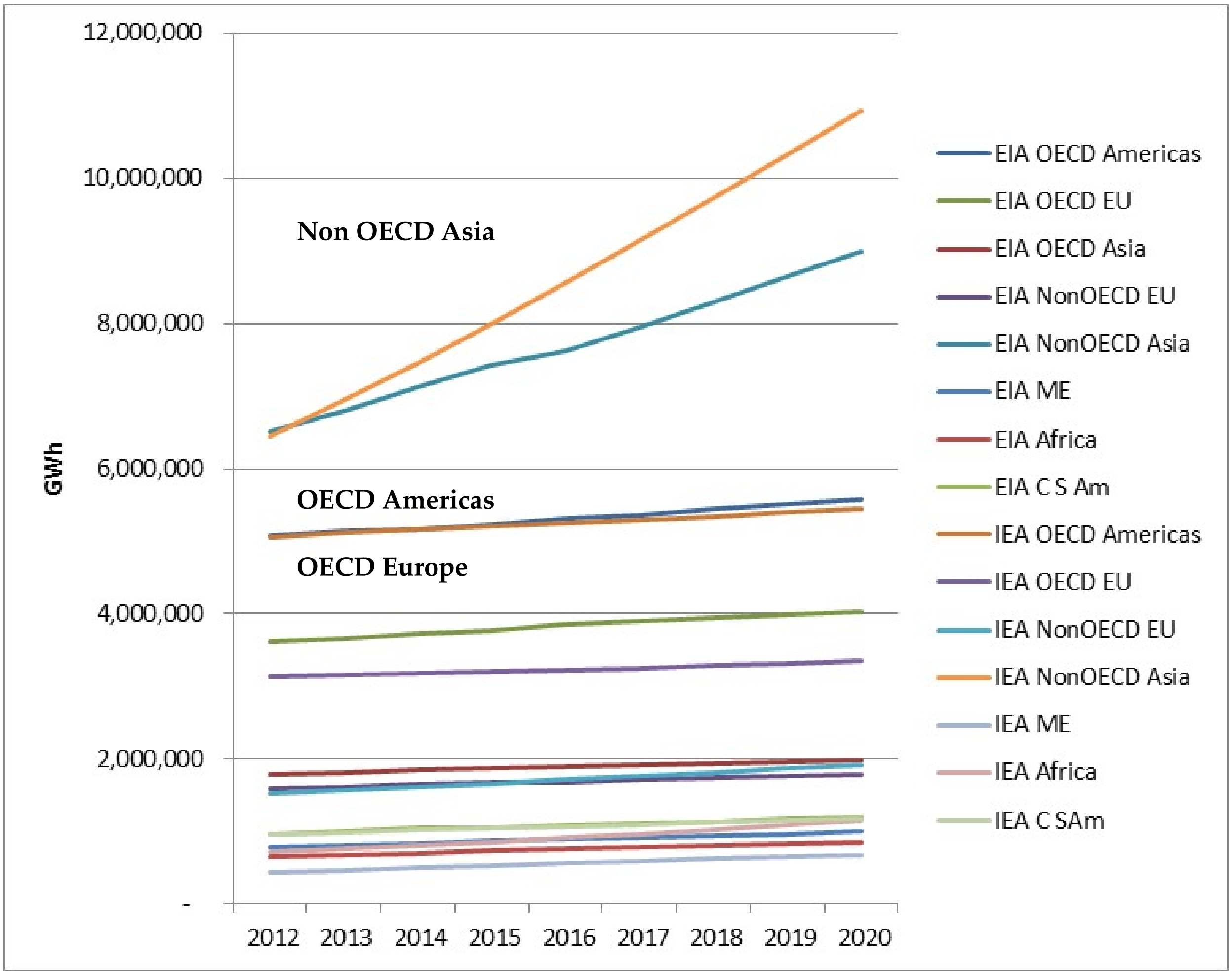
Figure 36 EIA and IEA Global Electricity Demand Forecasts, 2012–2020, GWh



Sources: EIA and IEA data modified by Worthington Sawtelle LLC

Figure 37Figure 37 examines the regional differences among the forecasts. While consistent in most areas, the IEA is forecasting much more robust growth for Non OECD Asia, which includes China and India.

Figure 37 Regional EIA and IEAE Global Forecasts, 2012-2020, GWh



Sources: Worthington Sawtelle LLC developed from EIA and IEA data

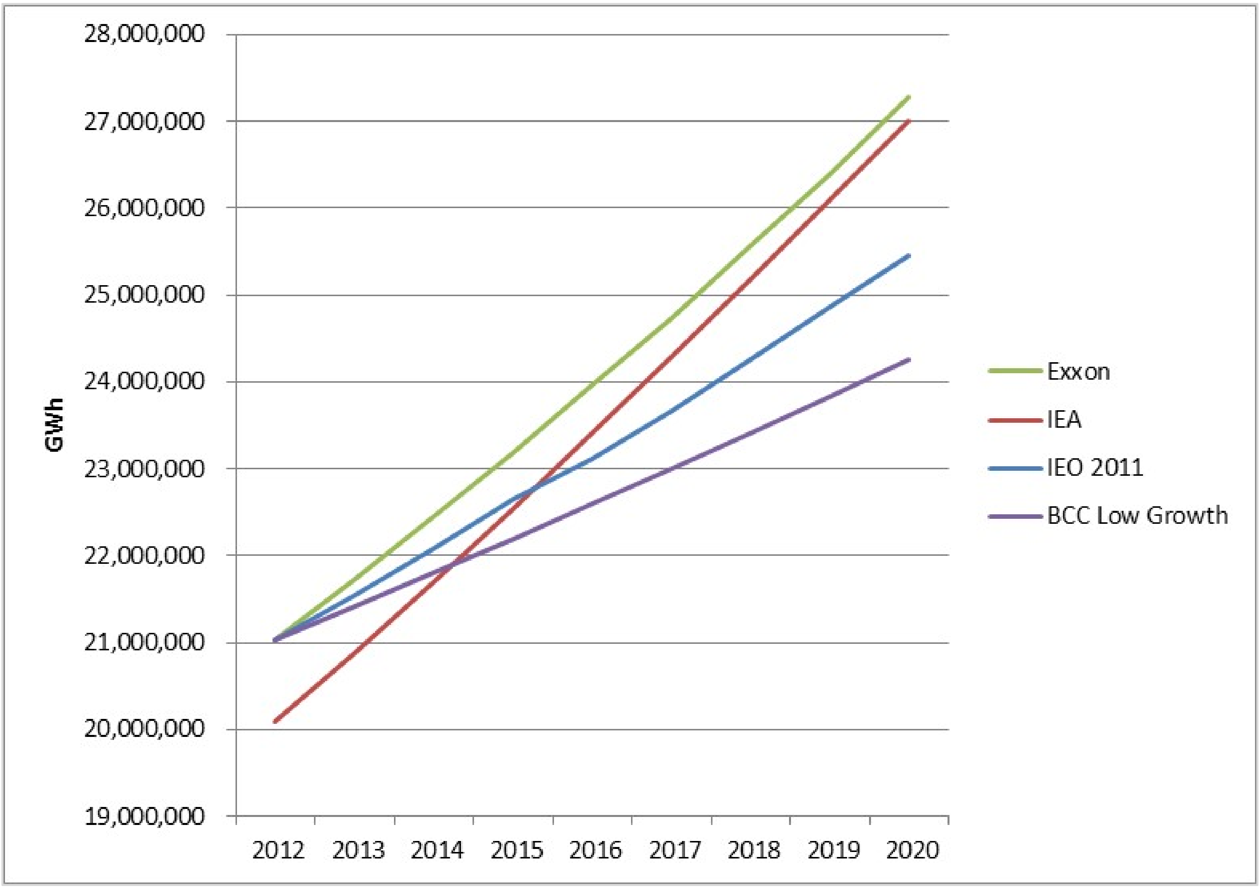
Because of the temporal differences in the data, it is quite possible that a new IEA forecast would reduce Chinese growth, given the recent slowdown in that economy.

7.1.1.2 Demand Scenarios

Clearly uncertainties exist in these forecasts, and, indeed, they differ from their previous releases. A higher global growth scenario is envisioned by Exxon Corporation, with an overall 2% growth for OECD countries and 4.5% for non-OECD countries. Worthington Sawtelle LLC postulated a low growth scenario reflecting only 1.8% growth from the EIA reference case forecast. This growth rate is equivalent to the global growth experienced in the period 2007–2010 and hypothesizes a continuingly stagnant economy. Figure 38 displays these forecasts.

In 2020, the differential between the forecasts is about three million GWh. In the case of the U.S., the differential is about 525,000 GWh, or about 65 new 1,000 MW electric generating station operating at 85% capacity, any one of which must begin construction in the next year or two to be available to meet that demand. At $5,000/kW installed, the "bet" on meeting new demand is about $325 billion.

Figure 38 Global Electricity Demand Growth Scenarios, 2012-2020, GWh



Source: Worthington Sawtelle LLC

7.1.1.3 Electricity Generation Supplies

For a sense of scale regarding the need for new generation plant capacity, the multiple of 2012 actual generation to meet the high demand case in Figure 38 was calculated and is presented in Table 49.

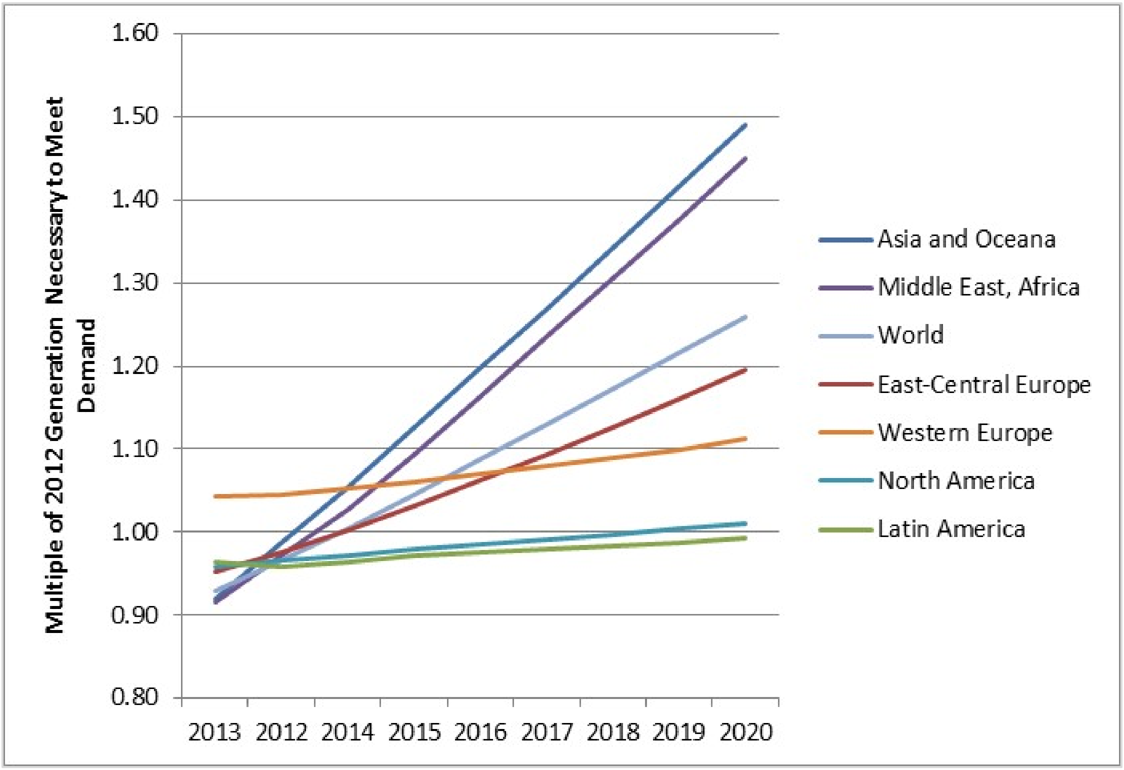
Table 49 Electricity Demand and Electricity Supply Deficit Forecasts by Region through 2020, Thousands GWh

	2012 Actual Generation Net of Forecasted Demand, thousands GWh					Multiple of 2012 Generation Necessary to Meet 2020 Demand
	2012	2013	2014	2015	2020	
Asia and Oceana	717.41	-9.38	-10.02	-10.66	-13.29	1.49
East-Central Europe	13.42	-0.33	-0.33	-0.34	-0.38	1.20
Latin America	2.46	-1.11	-1.16	-1.21	-1.43	0.99
Middle East, Africa	5.92	-1.20	-1.29	-1.38	-1.74	1.45
North America	8.58	-4.78	-4.81	-4.84	-4.96	1.01
Western Europe	21.01	-2.86	-2.88	-2.91	-3.03	1.11
World	9.92	-20.68	-21.52	-22.38	-25.94	1.26

Source: Worthington Sawtelle LLC

This calculation indicates that Asia and Oceana need to construct half as much generation as currently exists; Western Europe and North America far less so. Figure 39 provides a sense of how these multiples grow over the course of the forecast period.

Figure 39 Multiple of 2012 Electricity Generation Necessary to Meet Demand by Region, 2012-2020



Source: Worthington Sawtelle LLC

Table 50 identifies the three countries in each region requiring the greatest multiple of new generation.

Table 50 Top Three Countries by Region With Greatest Forecasted Supply Deficit Assuming No New Generation above 2012, GWh

	2012	2013	2014	2015	2020	Multiple of 2012 Generation Necessary to Meet 2020 Demand
Asia and Oceana						
Vietnam	13,905	78	-16,215	-34,917	-163,126	2.30
China	337,271	-59,373	-459,122	-893,997	-3,189,584	1.64
South Korea	15,089	-5,474	-28,036	-50,642	-179,791	1.34
East Central Europe						
Russia	130,333	92,127	55,254	17,101	-194,705	1.18
Hungary	87	-260	-724	-1,315	-5,406	1.14
Slovakia	140	-331	-931	-1,514	-5,019	1.17
Latin America						
Peru	1,298	-2,271	-5,678	-9,244	-24,152	1.57
Chile	4,461	406	-3,834	-8,266	-34,590	1.48
Brazil	21,007	677	-21,159	-44,035	-175,352	1.35
Middle East, Africa						
Nigeria	3,007	656	-2,632	-7,198	-49,890	2.91
Egypt	16,410	7,148	-2,707	-13,474	-80,50	1.51
Saudi Arabia	15,323	-1,229	-18,478	-36,544	-113,316	1.44

North America						
U.S.	96,580	66,050	38,196	12,497	-109,157	1.03
Canada	113,010	106,160	98,905	92,496	57,776	0.00
Western Europe						
Finland	-8,751	-9,334	-10,346	-11,592	-18,901	1.26
Ireland	254	-61	-493	-996	-4,197	1.16
Italy	-23,077	-23,582	-26,103	-28,492	-43,859	1.15

Source: Worthington Sawtelle LLC

The generation technologies chosen to meet this new demand include coal, natural gas, nuclear and renewable sources, however the relative share of the market held by these technologies varies by region. Table 51 provides the relative shares of each of the technologies by region in 2011. Coal and natural gas are used for over three quarters of electricity generation globally.

Table 51 Electricity Generation Sources by World Region, 2011, Thousands GWh

	Thermal		**Nuclear**		**Renewables**		**Hydro**		**Total**
	Thousands GWh	**%**	**Thousands GWh**	**%**	**Thousands GWh**	**%**	**Thousands GWh**	**%**	**Thousands GWh**
North America	8,389	70%	2,667	22%	278	2%	722	6%	12,056
Latin America	1,528	61%	83	3%	111	4%	778	31%	2,500
Western Europe	4,000	55%	2,417	33%	306	4%	528	7%	7,250
Eastern Europe	4,944	79%	1,028	16%	8	0%	278	4%	6,250
Africa	1,694	92%	28	2%	17	1%	111	6%	1,833
Middle East and South Asia	6,361	95%	111	2%	-	0%	194	3%	6,667

Southeast Asia and the Pacific	2,083	91%	-	0%	111	5%	83	4%	2,278
Far East	13,500	85%	1,306	8%	194	1%	861	5%	15,833
Total	42,472	78%	7,639	14%	1,028	2%	3,556	7%	54,667

Source: IEA

There are several forecasts of the relative share of each of these technologies over time. The lowest cast presumes only those units in construction by the end of 2012 complete construction; the World Nuclear Association (WNA) forecast is regarded as the most optimistic; and the EIA forecast was considered as the reference case. gion.

Table 52 presents the three cases by region.

Table 52 Three Forecasts of World Nuclear Capacity Additions by Region, 2012–2020, GW

	No additions beyond units in construction end 2012			**World Nuclear Association**			**US EIA**		
	2012	**2020**	**Additions**	**2012**	**2020**	**Additions**	**2012**	**2020**	**Additions**
OECD									
OECD Americas	**117**	**118**	**1**	**117**	**137**	**20**	**117**	**129**	**12**
U.S.	102	104	2	102	110	8	102	111	9
Canada	14	13	-1	14	20	6	14	18	4
Mexico/Chile	1	1	0	1	7	6	1	1	0
OECD Europe	**133**	**136**	**3**	**133**	**176**	**43**	**133**	**137**	**4**
OECD Asia	**70**	**71**	**1**	**70**	**93**	**23**	**70**	**82**	**12**
Japan	50	50	0	50	60	10	50	55	5
South Korea	20	21	1	20	30	10	20	27	7
Australia and New Zealand	0	0	0	0	3	3	0	0	0
Total OECD	**320**	**325**	**5**	**320**	**406**	**86**	**320**	**349**	**29**

Non-OECD Europe and Eurasia	**44**	**47**	**3**	**44**	**51**	**7**	**44**	**63**	**19**
Russia	25	29	4	25	29	4	25	39	14
Other	19	18	-1	19	22	3	19	24	5
Non-OECD Asia	**32**	**47**	**15**	**32**	**120**	**88**	**32**	**83**	**51**
China	18	34	16	18	100	82	18	55	37
India	7	10	3	7	10	3	7	16	9
Other	7	3	-4	7	10	3	7	12	5
Middle East	**0**	**1**	**1**	**0**	**11**	**11**	**0**	**4**	**4**
Africa	**2**	**2**	**0**	**2**	**12**	**10**	**2**	**2**	**0**
Central and South America	**4**	**5**	**1**	**4**	**11**	**7**	**4**	**5**	**1**
Brazil	2	3	1	2	3	1	2	3	1
Other	1	2	1	1	8	7	1	2	1
Total Non-OECD	**82**	**154**	**72**	**82**	**336**	**254**	**82**	**157**	**75**
Total World	**402**	**479**	**77**	**402**	**742**	**340**	**402**	**505**	**103**

Sources: WNA; EIA; Worthington Sawtelle LLC

The WNA forecast would indicate that in the eight year period, over four times the capacity currently in construction also be built. EIA presents a much more conservative case, allowing for some new construction beyond that already under way. A means to better assess these forecasts based on probability is presented in Section 3.4.

There is no question that for several regions, especially Asia and the Middle East, robust growth in nuclear capacity additions will occur, regardless of forecast used.

7.1.2 Energy Independence and Security

Countries and electric utilities opt for nuclear power generation as a means to assure greater energy independence and security. Large central generation stations within the country lessen the need to import power, and use of uranium significantly mitigates reliance on imported fuels. Even if the country does not have a domestic source of uranium, the relatively small volumes of uranium necessary for operating nuclear plants can be easily stockpiled.

7.1.3 Regulatory/Government Incentives

Although far less apparent than those available to fossil fuels and various renewable technologies, incentives and subsidies for nuclear power do exist. Historically, nuclear has benefitted from facilities and R&D expenditures by various countries that had originally been performed for weapons programs. In the U.S. it has been estimated that past assistance would amount to as much as 5.5 cents/kWh. For the most part, many incentives offered by governments are not publically available, especially those investing most heavily in nuclear: China, India, Russia and South Korea. The U.S. is the only country which quantifies all subsidies. Many countries provide “off budget” assistance in the form of direct but unreported financial support. Some data is available for the U.K. and France, but it is not complete. Table 53 summarizes some of this information.

Table 53 Subsidies and Incentives to Nuclear Power

Specific Type	Country	Value, Billions USD	U.S. c/ kWh
Production Tax Credit	U.S.	6-8.6	1.1 – 1.5
Loan Guarantees	U.S., investor owned utilities	22.5	2.5 – 3.7
	France	~2.5 to AREVA	
Interest Rate Discount	U.S., publicly owned utilities	NA	3.1
	France	Low rates to AREVA	
Stranded Asset Recovery	U.S. utilities having sold reactors	110	1.1
Export Credits	France		
Liability Caps	U.S.	.487	0.1 – 2.5
	France	.122	NA
	U.K.	.222	NA
	Sweden	.457	NA
	Ukraine	.242	NA

Source: Worthington Sawtelle LLC

7.1.4 Uranium Fuel Resource Availability

As noted in Section 3.8 and illustrated in Figure 41, the fuel cost component of nuclear power is quite low when compared with other fossil fueled generation sources. As a consequence, even relatively large swings in price are far more tolerable than in other technologies. From a volume standpoint, one ton of uranium fuel is the equivalent of about 16,000 tons of coal. Additionally, uranium is sourced from a number of different countries, none of which plagued by the difficulties of some oil producing countries. Many of these countries have their own domestic nuclear power requirements and thereby a certain security of supply.

From a reserves standpoint, defined as recoverable at or below current market pricing of $130/kgU, sufficient reserves exist to fuel the current fleet of reactors for 200 years. The reserves distribution at this price point is as shown in Table 54.

Table 54 Global Uranium Proven Reserves Distribution by Country as of 2009

Country	Reserves, tonnes	% share
Australia	1,673,000	31.0%
Kazakhstan	651,800	12.1%
Canada	485,300	9.0%
Russia	480,300	8.9%
South Africa	295,600	5.5%
Namibia	284,200	5.3%
Brazil	278,700	5.2%
Niger	272,900	5.0%
US	207,400	3.8%
China	171,400	3.2%

Source: IAEA

The actual production figures differ somewhat in terms of rankings, but include the same list of countries, as shown in Table 55.

Table 55 Global Uranium Production by Country, 2009

Country	Production, tons U3O8	% World Production
Canada	10,636	21%
Kazakhstan	10,066	19%
Australia	9,962	19%
Namibia	5,189	10%
Russia	4,151	8%
Niger	3,580	7%
Uzbekistan	2,750	5%
USA	1,764	3%
Other	1,193	2%
Ukraine	986	2%
China	934	2%
South Africa	675	1%

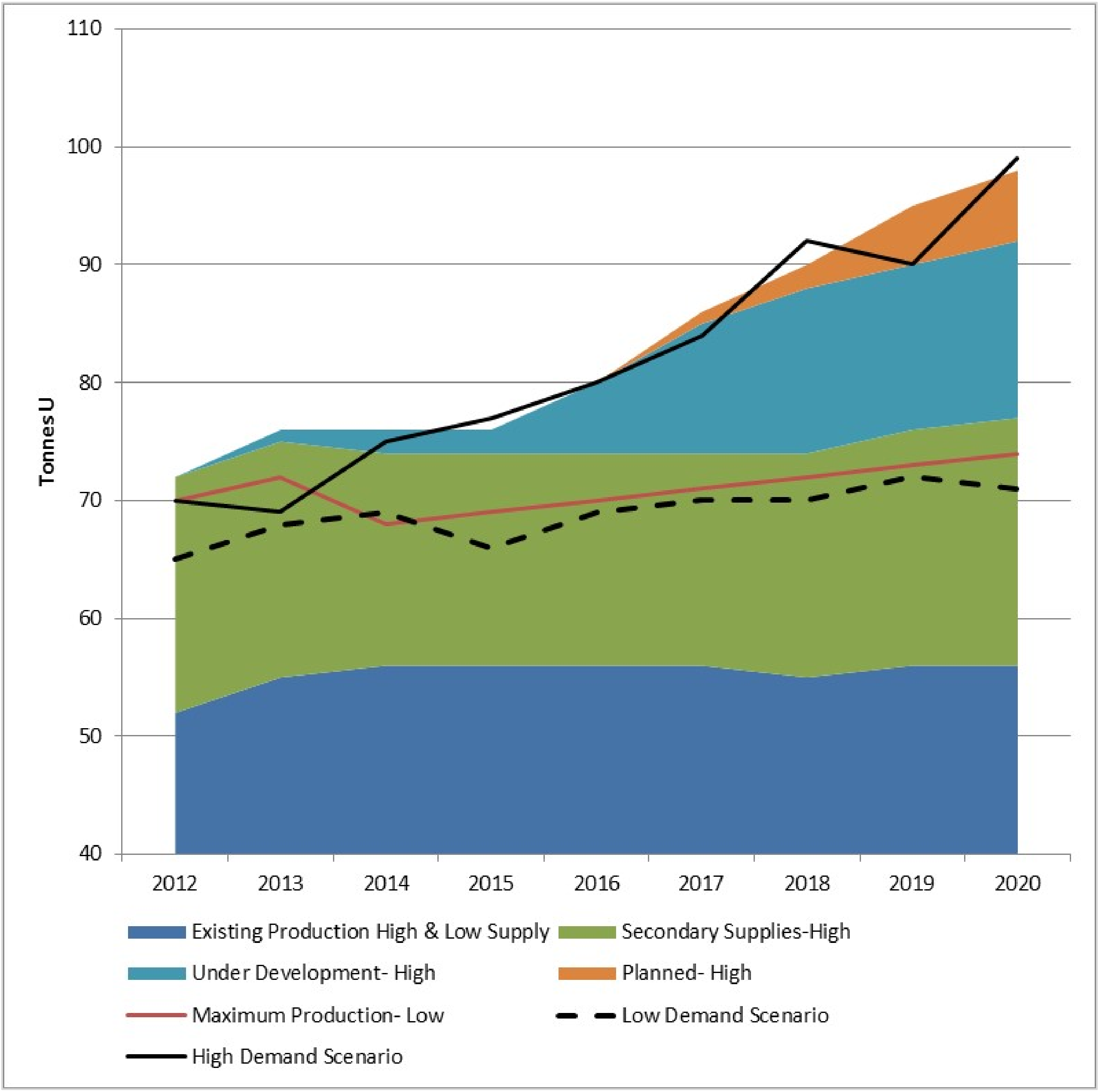
Source: WNA

Over the last few years, uranium production has been less than demand, in part because uranium fuel can be sourced both from natural resource producers (e.g., mined), or from what are referred to as "secondary sources." Secondary sources includes fuel retrieved from weapons stockpiles, enrichment of the tails waste of enrichment facilities (see Section 3.4), use of mixed oxide fuels and by specifying lower enrichment levels for new fuel.

In terms of resource adequacy, sufficient uranium at these price levels exists to fuel any of the growth scenarios describe in Section 7.1.1.3.

Figure 40Figure 40 presents the WNA supply forecast with the low and high demand cases discussed in Section 7.1.1.2. To the extent that a combination of both high scenarios occurs, market dynamics will likely cause price to rise, opening up new levels of resources that are available at higher cost.

Figure 40 Global Uranium Supply and Demand under Low and High Scenarios, 2012 – 2020, tonnes U



Sources: WNA and Worthington Sawtelle LLC

7.1.5 Environmental Benefits and Carbon Mitigation

Nuclear power plants emit virtually no conventional emissions and are viewed by some either as "zeroemissions" or as "carbon free." Table 56 shows the annual emissions of primary pollutants for three large power plants in Pennsylvania in 2009, as compiled by the U.S. Environmental Protection Agency (EPA).

Table 56 Emissions Profile, Large Electricity Generating Stations 2009

			Nitrogen Oxides		Sulfur Oxides		Carbon Dioxide	
	Fuel	**GWh**	**Tons**	**Tons/kWh**	**Tons**	**Tons/kWh**	**Tons**	**Tons/kWh**
Homer City Unit 3	Coal	4,118	4,507	1.09	55,431	13.46	4,165,058	1,011.43
Fayette Energy Facility	Natural Gas	983	72	0.07	6	0.01	1,176,466	1,196.81
Limerick 1	Nuclear	10,019	0.0	0.0	0.0	0.0	0.0	0.0

Source: EPA

Nuclear has therefore begun to figure more prominently in national generation portfolios as part of carbon mitigation strategies.

This is, however, an area of controversy. Like the electric car, emissions are not limited to what the device produces but what emissions occurred to construct and fuel it. While the power plant does not emit carbon or other harmful compounds, the processes used to manufacture the fuel, plant construction, nuclear waste management and decommissioning all have their own carbon footprint. And as with most technologies that are politically charged, there are studies that will support almost any position.

The IAEA conducted a study to assess the full range of emissions over the life cycle of the power plant. The results of their most recent work are shown in Table 57.

Table 57 IAEA Life Cycle Carbon Emissions, Nuclear Generation

	Grams CO2/kWh		
Generation Source	**Minimum**	**Mean**	**Maximum**
Lignite	800	1,100	1,700
Coal	770	1,000	1,300
Oil	500	800	1,200

Natural Gas	400	500	800
Coal with Carbon Sequestration	10	100	300
Biomass	35	65	100
Solar PV	40	50	80
Wind	10	10	30
Hydro	0	5	35
Nuclear	3	7	25

Source: IAEA

A researcher at the University of Singapore surveyed 103 different life cycle greenhouse gas emissions studies involving nuclear power. Of that population he qualified a subset as havi8ng sufficient detail and appropriate methodology. The result is summarized in Table 58.

Table 58 Summary Statistics of Qualified Nuclear Life Cycle Emission Studies

	Grams CO2/kWh		
Life Cycle Segment	**Minimum**	**Mean**	**Maximum**
Front-end	0.58	25.09	118
Construction	.027	8.20	35
Operation	0.1	11.58	40
Back-end	0.4	9.2	40.75
Decommissioning	0.01	12.01	54.5
Total	**1.36**	**66.08**	**288.25**

Source: National University of Singapore

The results of this survey give a more realistic appraisal of nuclear carbon emissions; nonetheless nuclear remains low in the list of alternatives.

7.1.6 Low Cost Solution

As noted in Section 3.6.1, nuclear power, from an operations cost standpoint, is very low cost and certainly lower than any other large scale power plant available. This can be a very compelling argument in the context of an unregulated wholesale power market where bidding on sales into the grid is based on a combination of fuel and variable O&M costs. Table 59 provides a summary of the cost components, both fixed and variable, of a number of electricity generation options and expresses the results in terms of LCOE. A number of the generation options noted are not technologies with which nuclear power plants compete. Nuclear power plants operate in the base load regime: units that operate around the clock for 90% of the year. Solar and wind technologies, for example, are intermittent generators and others simply do not have the scale of GW sized plants. At some point in the future, with added scale or by using hybrid combinations that allow for electricity storage, competition will occur.

Table 59 Cost of Electricity Generation by Technology

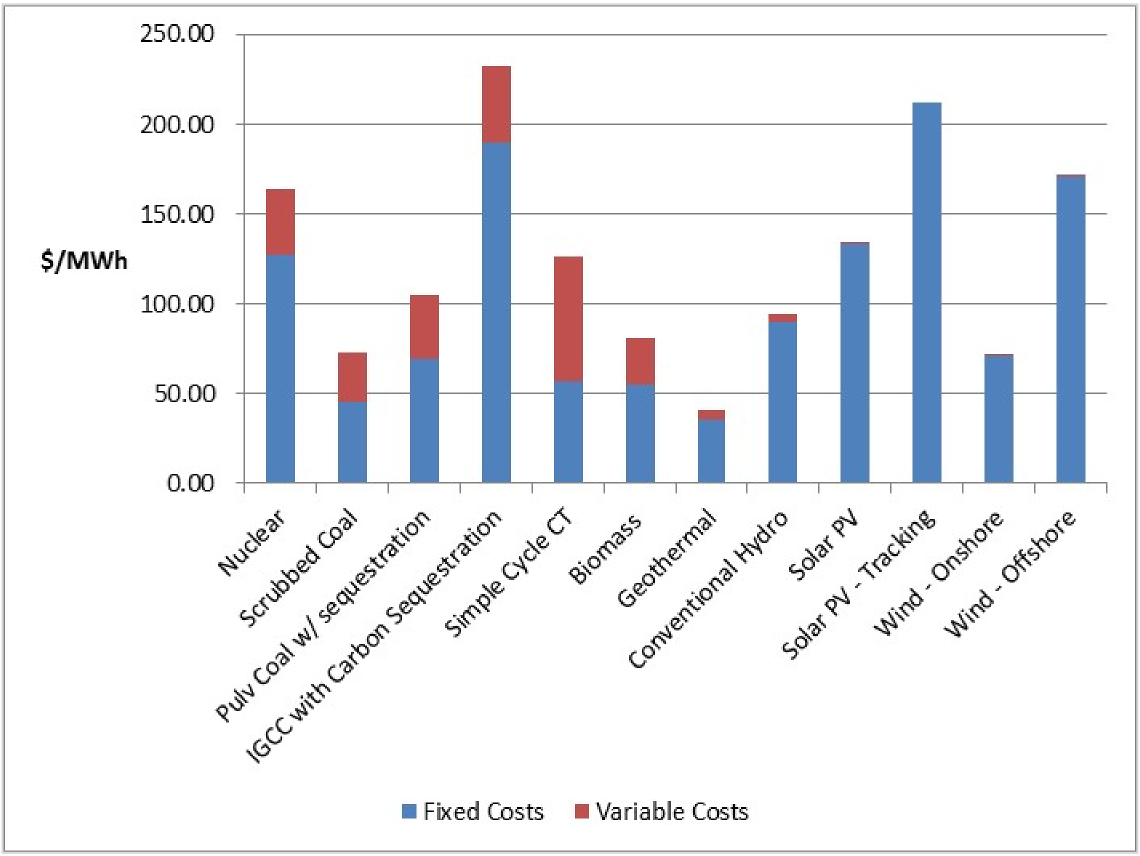
	Biomass	MSW - Landfill Gas	Pulv Coal w/ sequestration	Simple Cycle CT	Scrubbed Coal	IGCC with Carbon Sequestration	Nuclear	Geothermal	Conventional Hydro	Solar Thermal	Solar PV	Solar PV - Tracking	Wind - Onshore	Wind - Offshore
Plant Capacity MW	50	50	650	85	1,300	520	1,117	50	500	100	150	1	100	400
Life, yrs.	20	20	30	20	30	30	40	30	20	20	20	20	20	20
Capacity Factor %	85%	80%	87%	30%	87%	75%	85%	90%	50%	20%	25%	27%	33%	33%
Capital Cost $/kW	$3,685	$7,858	$4,662	$910	$2,694	$9,000	$7,000	$2,444	$2,800	$4,653	$3,624	$5,700	$2,032	$4,452
Fixed O&M $/kW-yr	$103	$381	$65	$7	$30	$25	$91	$110	$25	$66	$21	$65	$39	$72
Fixed O&M escal.	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.50%	2.5%	2.5%	2.5%	2.5%	2.5%
Variable O&M $/MWh	$5	$9	$4	$15	$4	$10	$2	$5	$4	$0	$0	$0	$0	$0
Variable O&M escal.	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.50%	2.5%	2.5%	2.5%	2.5%	2.5%
Fuel Type	Wood	Bio	Coal	Gas	Coal	Coal	Uranium							
Fuel Cost $/MMBtu	$1.11	$2.22	$1.94	$4.50	$1.94	$1.94	$2.44	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Fuel Cost escal.	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.50%	2.5%	2.5%	2.5%	2.5%	2.5%

Heat Rate BTU/kWh	14,800	12,070	12,000	9,300	8,700	12,000	10,400	9,756	9,756					
Levelized Variable Cost ($/MWh)	$26.04	$40.30	$35.71	$69.41	$27.63	$43.01	$36.66	$6.06	$4.31	$0.01	$0.01	$0.00	$0.01	$0.01
Levelized Fixed Cost ($/MWh)	54.84	211.41	69.31	57.14	45.74	189.68	120.53	35.28	89.92	242.67	133.95	211.87	71.02	171.32
Levelized Cost ($/MWh)	**$80.9**	**$251.7**	**$105.0**	**$126.6**	**$73.3**	**$232.7**	**$157.19**	**$41.34**	**$94.23**	**$242.7**	**$133.9**	**$211.9**	**$71.0**	**$171.3**

Source: Worthington Sawtelle LLC

Figure 41 plots these costs as total fixed and variable costs.

Figure 41 Fixed and Variable Levelized Costs of Electricity, Various Generation Technologies, $/MWh

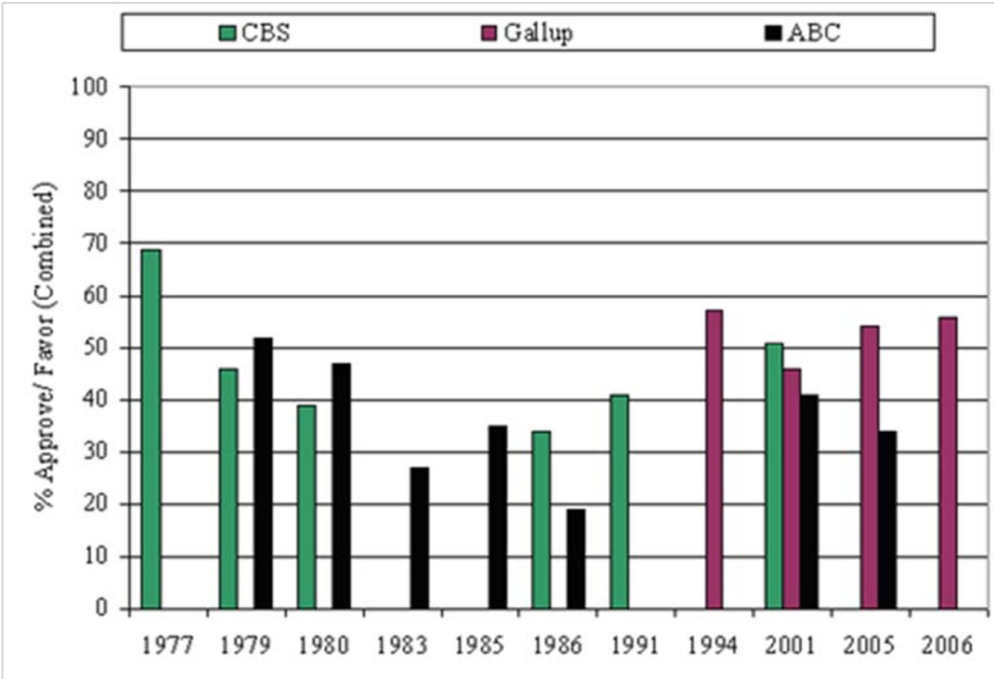


Source: NREL

7.1.7 National and Local Risk Appetite

National and sometimes local risk appetites (or lack thereof) can determine the fate of a plant. As with several drivers/barriers in this market, public acceptance is clearly a driver in several countries but not in others. Negative public opinion will be discussed in Section 7.2.3. Public acceptance or rejection of nuclear power has varied over the last 30 years in the U.S. Figure 42 shows the results of three separate surveys repeated on roughly a two year cycle between 1976 and 2006. Public acceptance was over 50% until the TMI accident. It remained below 50% until 1991 and has been above 50% through 2006.

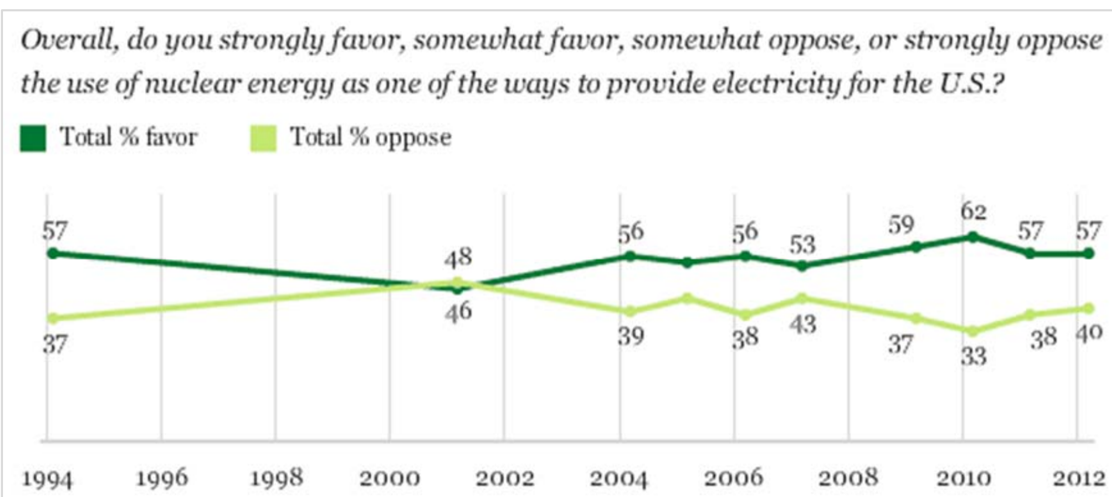
Figure 42 Public Approval of Nuclear Power, 1977-2006



Source: NC State University

Figure 43 shows that a Gallup poll begun in 1994 and conducted annually from 2004 through 2012 shows that, with the exception of 2001; public acceptance has been above 50%.

Figure 43 Gallup Poll on Nuclear Power Favorability in U.S., 1994 - 2012



Source: Gallup Group

In several other countries public acceptance of nuclear power is high. These include India (75%); China (59%), Great Britain (59%), Saudi Arabia (59%), Poland (53%) and Sweden (52%). In France, the population is split with 50% in support and 50% opposed.

7.2 Market Barriers

7.2.1 Financial Risk

Construction and operation of a nuclear plant involves a number of financial risks that represent barriers to investors. These risks include:

Uncertainties in total cost of construction. Figure 12 illustrated the inability to accurately forecast the total cost of construction in the 70's; accuracy has not improved. Table 60 shows the evolution of cost estimates for several plants which began construction within the last seven years.

Table 60 Recent Unit Cost Estimate Evolution, 2007 - 2012

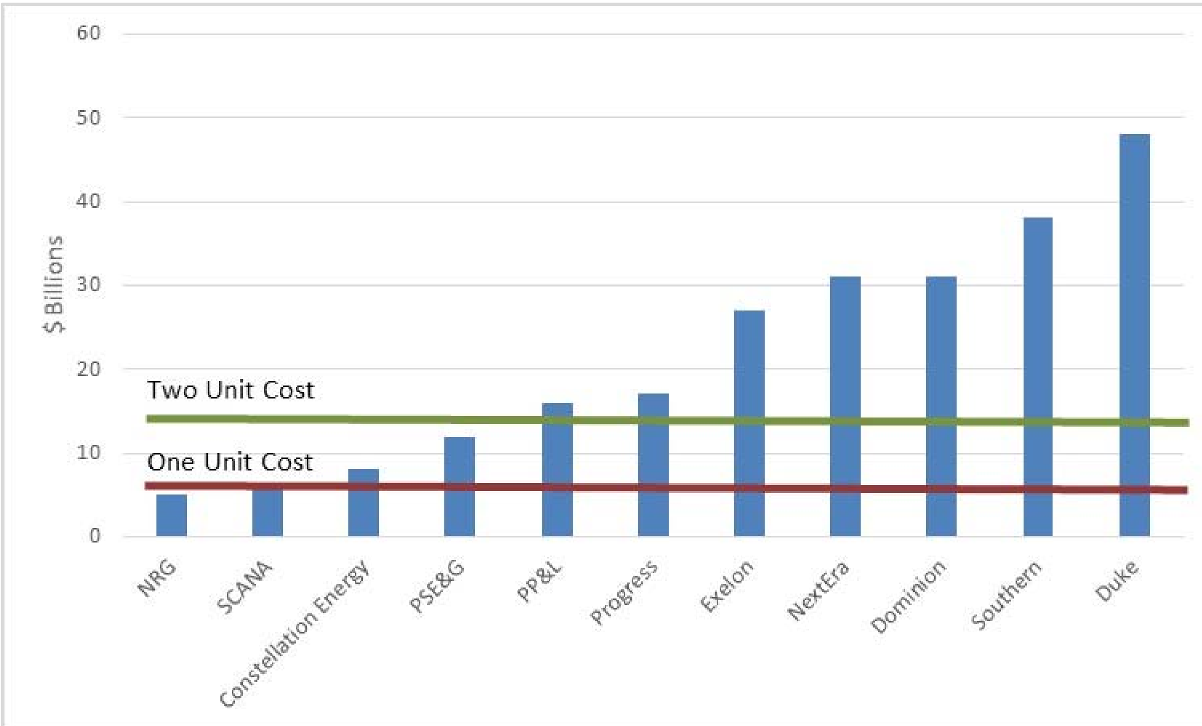
Utility	Unit	Year of Forecast	Cost, $/kW
Georgia Power	Vogtle 3 & 4	2009	6,500
		2012	7,400
EDF	Flamanville	2007	3,200
		2012	6,700
TVO	Olkiluoto	2005	3,200
		2012	8,500

Source: Worthington Sawtelle LLC

Magnitude of capital required. The amount of capital necessary to complete a new nuclear plant can be staggering. Georgia Power's Plant Vogtle units 2 and 3 are likely to cost nearly $15 billion; TVO's Olkiluoto as a single unit at $8.5 billion. Such costs can consume the entire balance sheet of a utility.

Figure 44 plots the market capitalization of a number of large U.S. utilities and compares them with one and two unit installation costs.

Figure 44 Utility Market Cap for Several Large US Utilities Compared with One and Two Unit Costs



Sources: Worthington Sawtelle LLC; Google Finance

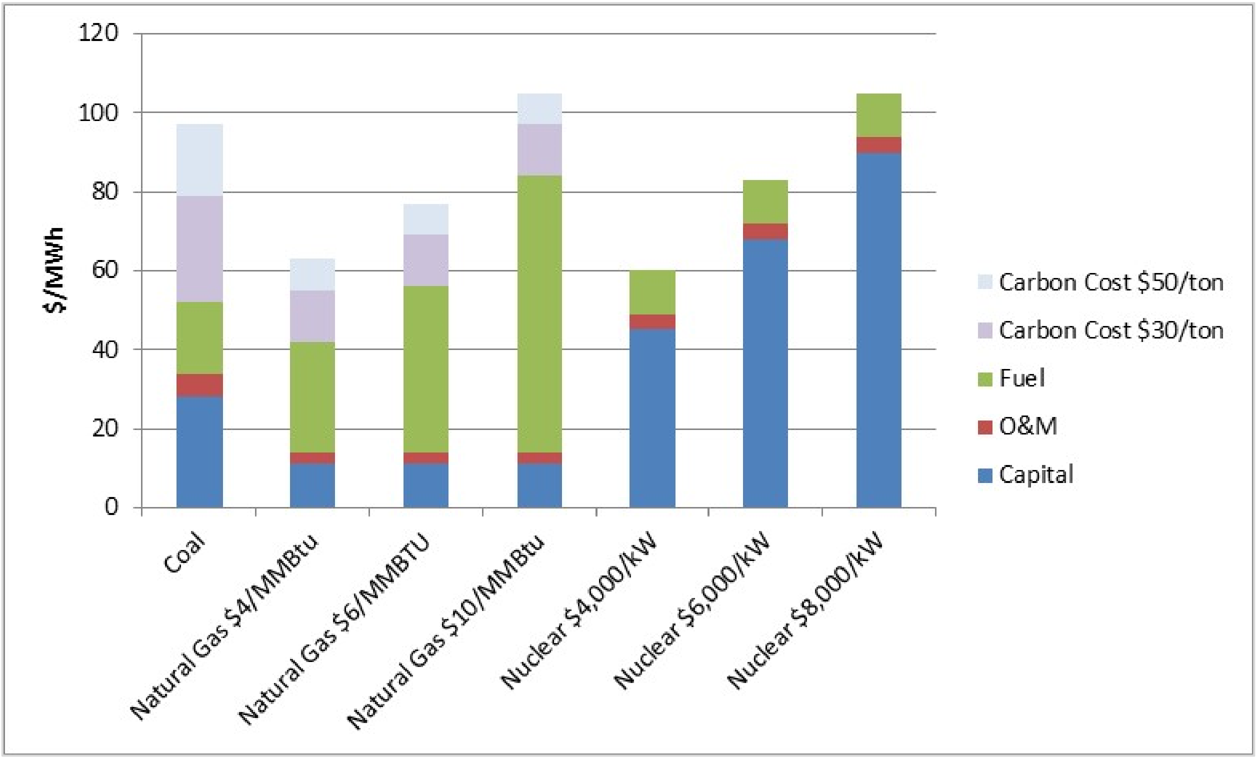
Situations where utilities attempt to construct plants that constitute their entire market capitalization are not rewarded in the market and drive up interest costs.

<u>High fixed cost impact competitiveness in retail electricity markets.</u>

Figure 45 provides a comparison of the levelized cost of electricity for coal, nuclear and natural gas. The operations component of those estimates, based on today's cost, is the metric upon which units bid into a wholesale power grid. Traditionally, nuclear has usually been less expensive than coal and always less expensive than natural gas, however this is changing. "Fracked" natural gas is flooding several national markets with low cost fuels, increasing its competitiveness over nuclear. In 4Q12 Dominion Resources announced the shutdown of Kewaunee, one of its older nuclear plants primarily because of concerns regarding the unit's declining competitiveness with natural gas. Coal's price has been experiencing a very slow decline. Even though they are referred to as "variable" costs, nuclear operating costs are quite fixed and represent about 25% of total cost recovery required.

Figure 45 also illustrates the degree to which natural gas could penetrate nuclear markets, depending on fuel costs and capital, and whether or not natural gas is assigned a carbon tax.

Figure 45 Levelized Cost of Electricity under Differing Capital and Fuel Cost Assumptions, Coal, Natural Gas, and Nuclear Plants

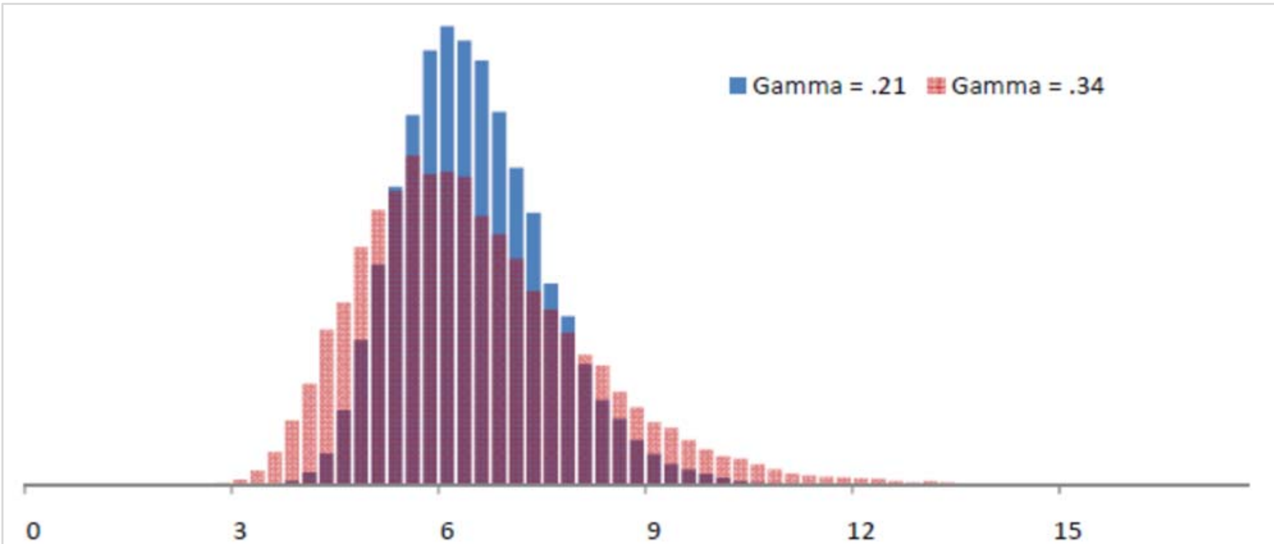


Source: EIA

<u>Uncertainties in overall construction duration</u>

Figure 46 displays the probability distribution of construction times. The minimum period is 3.25 years, the maximum 12.25 years and the mean at six years.

Figure 46 Realized Plant Construction Outcomes in Years



Source: Duke University

The fact that the construction period could increase, even by only a few years, increases overall costs through added interest charges.

The Risk Premium

Ratings agencies take these uncertainties into account when they rate the investment quality of nuclear utilities or independent nuclear generating stations and incorporate a "risk premium" in their analysis. The risk premium can add points to interest rate to compensate for the greater risk, based on the issuing company's overall rating. There are no uniform standards or generally published values because each company and to a certain extent, each nuclear project have their own unique set of characteristics. Table 61 gives the current ratings for a number of unregulated operators and for several regulated and unregulated utilities that have new units under construction. Oglethorpe Generation and Transmission Cooperative, for example, has a high and stable rating, however NRG's unregulated subsidiary has a negative outlook.

Table 61 Recent Ratings Changes of Unregulated Utilities and Utilities with Nuclear Plants Under Construction

New Nuclear Construction						
Region: Utility Type	**Utility**	**Rating**	**Outlook**	**Revenue**	**Debt**	**Assets**
Asia: regulated	Korea Hydro & Nuclear Power	A1	Stable	Private	Private	Private
U.S.: municipal	Municipal Electric Authority of Georgia	A1	Stable	$0.7	$4.0	$5.0
U.S: unregulated	NRG	Ba3 CFR	Negative	$9.0	$10.0	$24.1
U.S: cooperative	Oglethorpe	Baa2	Stable	$1.3	$5.5	$6.9
U.S: municipal	Santee Cooper	Aa2	Stable	$1.7	$4.9	$7.5
U.S: regulated	SCANA	Baa2	Negative	$4.6	$4.9	$13.1
U.S: regulated	Southern	Baa1	Stable	$15.7	$22.1	$56
Unregulated Utility Operators						
Europe	Czech Power Company	A2	Stable	$10.4	$9.9	$28.3
U.S	Constellation	Baa3	Stable	$15.6	$5.5	$23.8
U.S	Dominion	Baa2	Stable	$15.2	$18.7	$43.7
Europe	E.ON	A2	Stable	$111.5	$73.3	$219.9
Europe	EDF	Aa3	Stable	$82.4	$116.6	$350.0
U.S	Energy Future Holdings	Caa2 CFR	Negative	$9.5	$37.0	$60.3
Europe	Energie Baden Wurtemburg	A2	Stable	$21.7	$22.4	$50.3
Europe	Endesa	A3	RUR-down	$34.1	$32.4	$86.5
Europe	ENEL	A2	RUR-down	$86.7	$103.6	$234.7

Region: Utility Type	Utility	Rating	Outlook	Revenue	Debt	Assets
U.S	Entergy	Baa3	Stable	$10.8	$14.1	$38.0
U.S	Exelon	Baa1	Stable	$17.3	$16.9	$52.9
U.S	First Energy	Baa3	Stable	$13.3	$18.5	$37.0
Europe	Fortum	A2	Stable	$7.6	$10.9	$29.4
Europe	GDF SUEZ	A1	Stable	$111.4	$76.4	$251.2
Europe	Iberdrola	A3	Negative	$36.1	$45.2	$124.6
U.S	Nextera	Baa1	Stable	$15.3	$19.4	$52.9
U.S	NRG	Ba3 CFR	Negative	$9.0	$10.0	$24.1
U.S	PP&L	Baa3	Stable	$8.5	$15.0	$33.6
U.S	PSEG	Baa2	Stable	$11.8	$9.8	$29.9
Europe	RWE	A2	Negative	$64.4	$46.3	$116.1
Europe	Vattenfall	A2	Stable	$27.0	$33.7	$84.8

Source: Moody's Investor Services

Capital Availability. The amount of capital and its cost available to any firm or consortium that intends to build a nuclear plant is entirely a matter of how their risk profile looks to the funding agency. Projects backed by governments, or those whose owners operate in a regulated environment are perceived as being more secure than unregulated independent operators and therefore can access capital easier and at less cost.

7.2.2 Regulatory Risk

NPP owners and operators certainly encounter regulatory risk, however its impact on performance is sometimes less than actual. For example, regulatory risk has also been used as an excuse for why a project was cancelled to mask other issues such as inordinate costs. There are several real regulatory risk issues that are important factors in project decisions.

Someone Else's Accident Becomes Everyone's Accident. Every time a nuclear accident or incident occurs it prompts a reexamination of the licensing process in most countries, which may cause delays in getting authorizations to proceed. In addition, findings from these reexaminations may require retrofits or changes to other facilities that can add unexpected costs. Reactors can also end up being cancelled because of these examinations, as appears to be the case with the 8.2 GW Kashiwazaki-Kariwa Power Station in Japan that does not now meet new seismic standards promulgated post-Fukushima.

Regulatory Processes are Precedent Driven. The regulatory process to license a particular reactor is necessarily complex and lengthy. Its efficiency as a process only comes with experience: a new process does not get tested and streamlined until it's been used a few times. In the U.S. the process for a Combined Construction and Operating License (COL) is only now being made more effective as the first two applications work their way through the process. New judgments on issues are easier to resolve if the problem has been examined before in the same context. It will be a while before the COL process is improved and only with throughput experience.

7.2.3 Public Opposition

Although a strong public attitude in support of nuclear power exists in the U.S., India, Poland, China, Saudi Arabia, the U.K. and Sweden, the majority opinion in all other countries is in opposition to nuclear power. Countries with negative opinions include; Argentina, Australia, Belgium, Canada, Germany, France, Hungary, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, Spain, and Turkey.

7.2.4 Transmission Grid Impacts

Transmission grids can become a barrier to new NPP if new transmission lines are required to accommodate the unit. Siting GW sized generation sources in an electric grid poses a number of grid integration issues. Adequate flow capability must exist to take the full output of the unit and get that electricity to centers of demand without this additional flow congesting the existing system, impacting grid reliability or adding costs to the existing transmission customers. This is not a problem when a NPP is sited at an existing site that already has its own infrastructure, especially if it is replacing some amount of retiring generation. In lightly settled areas or remote areas where the existing infrastructure is minimal, considerable additional costs can be incurred to get the electricity output to where it is needed.

In many unregulated systems, the responsibility for solving transmission issues, and shouldering the costs, falls on the plant owner. In the U.S., for example, the Federal Energy Regulatory Commission (FERC) enacted two standardized rules: Large Generator Interconnection Procedures (LGIP); and Large Generator Interconnection Agreements (LGIA). Under the LGIP the party needing the interconnection must complete permitting and construction no more than seven years after making the request. During that time, any large project falling short of objectives could lose its place in the processing sequence if other projects with faster implementation plans are present. Under the LGIA, the NPP is responsible for all interconnection costs. There is a long history in the U.S. of large transmission projects stalled by the lack of uniform systems and local opposition. These costs can be very substantial.

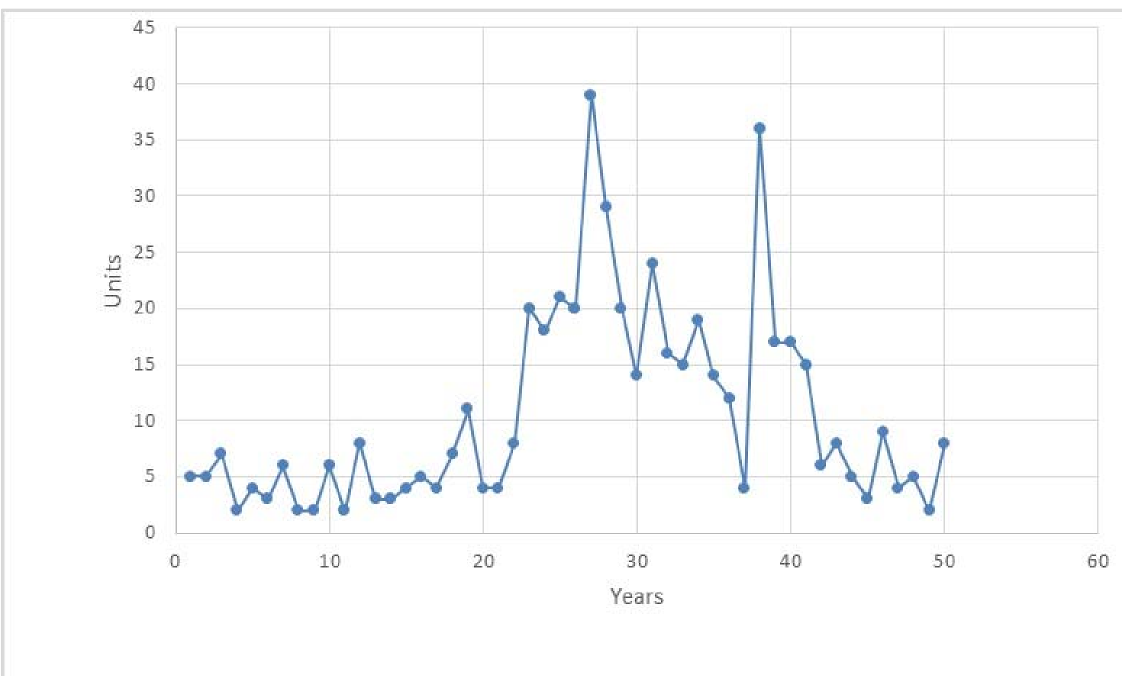
In the U.K., transmission plays another, quite different role. Under its market reform initiatives, The U.K. hopes to encourage low carbon investments and maintain predictable electricity pricing using what is referred to as Contracts for Differences (CFD). As units bid into the transmission grid, if market prices fall below what is called the strike price, the government reimburses the generator that difference in cost, and vice versa. Each technology will have its own strike price, which are currently under negotiation.

In more centrally planned countries, transmission systems require the same level of upgrading; however the issue of cost is not a major factor.

7.2.5 Decommissioning Costs

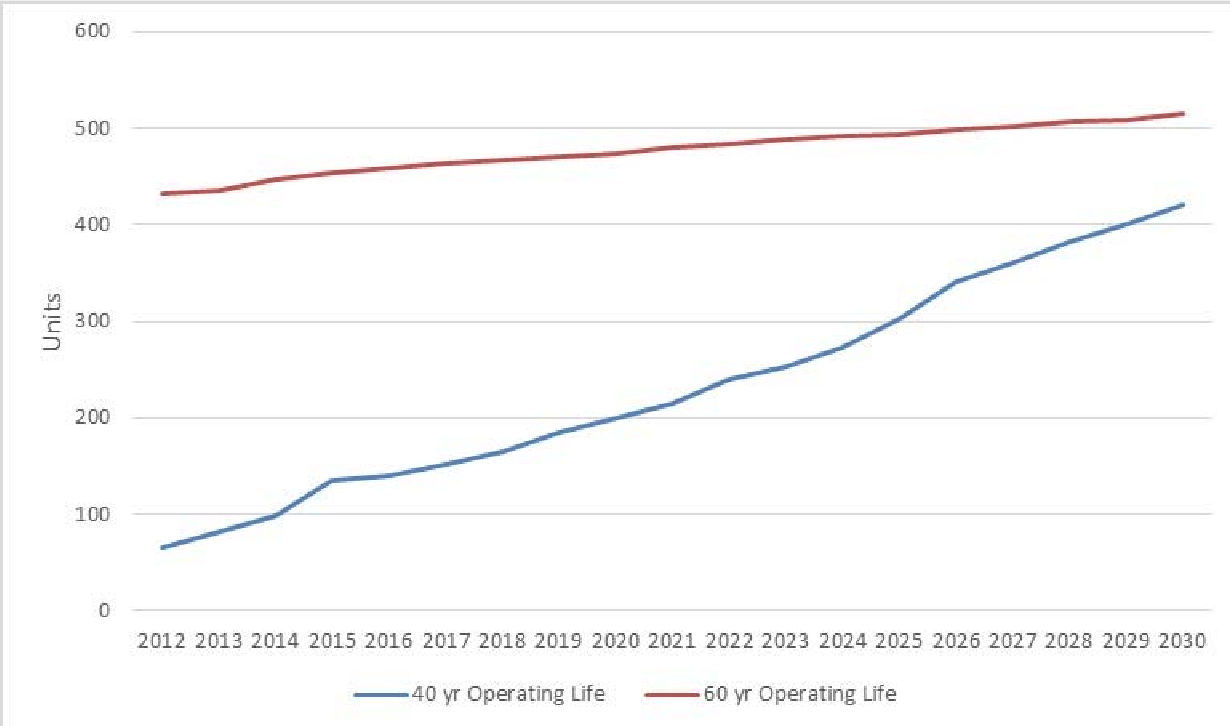
All NPPs must, at some point be decommissioned, meaning the site must be restored to specified environmentally safe conditions. Decommissioning is now gaining some prominence as relatively current reactors begin the process. Figure 47 plots the age of currently operating NPPs. Figure 48 shows the cumulative number of NPPs eligible for decommissioning under 40 and 60-year lifetimes. Originally, most of these units anticipated a 40-year life. Many have sought license extensions to add between 10 and 20 years to the original license. In the U.S., most applications for license extension are approved.

Figure 47 Global NPP Age Profile



Source: Worthington Sawtelle LLC

Figure 48 Cumulative Global NPPs Eligible for Decommissioning, 40 year and 60 year Operating Lives



Source: Worthington Sawtelle LLC

As already shutdown reactors begin decommissioning, there is mounting evidence that decommissioning costs are a frequently underestimated cost of a nuclear unit. On average, decommissioning seems to be averaging about $1,600/kW. Most statutory requirements for accumulating sufficient funds for decommissioning require amounts one quarter to one fifth of that amount. Decommissioning costs are becoming a contributing barrier to NPP construction, although they also appear to give evidence for a growing and substantial market for decommissioning services that could be equal or greater than that for NPP supply. Table 62 presents costs of decommissioning projects. The average unit cost of decommissioning for this group of 54 units is $1,635/kW. Averages are by no means conclusive, however. On the one hand, some of these projects are, or were, first of a kind and might have been lower cost with more experience. On the other hand, many of these numbers understate costs. Three Mile Island 2, for example, required about $1.2 billion to get it into its current state: the cost cited in the table is the rest of its decommissioning costs when the site begins decommissioning.

Table 62 Decommissioning Cost Experience

<table>
<tr><th rowspan="2">Country</th><th rowspan="2">Unit</th><th rowspan="2">Reactor Type</th><th rowspan="2">Capacity MWe</th><th colspan="2">Decommissioning Cost</th></tr>
<tr><th>$ million</th><th>$/kWe</th></tr>
<tr><td>Austria</td><td>Zwentendorf NPP</td><td>PWR</td><td>732</td><td>1,300</td><td>1,776</td></tr>
<tr><td>Belgium</td><td>Doel Units 1&2</td><td>PWR</td><td>824</td><td>280</td><td>340</td></tr>
<tr><td>Belgium</td><td>Tihange 1</td><td>PWR</td><td>1,009</td><td>213</td><td>212</td></tr>
<tr><td>Bulgaria</td><td>Kozloduy NPP-1,2,3,4</td><td>VVER-440</td><td>1,760</td><td>377</td><td>429</td></tr>
<tr><td>Canada</td><td>Gentilly Units 1 & 2</td><td>CANDU</td><td>885</td><td>1,800</td><td>2,034</td></tr>
<tr><td>Canada</td><td>Pickering Units A2 and A3</td><td>CANDU</td><td>4,336</td><td>3,800</td><td>876</td></tr>
<tr><td>France</td><td>Brennilis</td><td>GCR</td><td>70</td><td>768</td><td>10,971</td></tr>
<tr><td>France</td><td>Bugey 1</td><td>GCR</td><td>540</td><td rowspan="4">3,040</td><td rowspan="4">1,176</td></tr>
<tr><td>France</td><td>Chinon 1,2,3</td><td>GCR</td><td>750</td></tr>
<tr><td>France</td><td>Chooz A</td><td>PWR</td><td>300</td></tr>
<tr><td>France</td><td>Saint-Laurent</td><td>GCR</td><td>995</td></tr>
<tr><td>France</td><td>Superphénix</td><td>LMFBR</td><td>1,200</td><td>4,800</td><td>4,000</td></tr>
<tr><td>Germany</td><td>Greifswald NPP-1, 2,3,4,5</td><td>VVER-440</td><td>2,040</td><td>673</td><td>330</td></tr>
</table>

Germany	Niederaichbach		100	190	1,900
Germany	Rheinsberg NPP-1	VVER-210	80	26	330
Germany	Stendal NPP-1,2,3,4	VVER-1000	4,000	2,000	500
Germany	Gundremmingen-A	BWR	250	138	550
Italy	Caorso NPP	BWR	840	720	857
Italy	Garigliano NPP	BWR	150	263	1,644
Italy	Latina NPP	Magnox	210	520	3,248
Italy	Trino Vercellese NPP	PWR	210	245	909
Japan	Tokai NPP (Reactor 2)	BWR	1,100	1,040	945
Netherlands	Dodewaard	BWR	58	133	2,300
Slovakia	Jaslovske Bohunice NPP-1,2	VVER 440/230	880	464	527
Slovenia	Krsko NPP	PWR	707	332	479
Spain	Vandellós NPP-1	UNGG	480	360	721
UK	Berkeley	Magnox	265	1,409	2,658
UK	Dorset -Winfrith	Magnox	265	1,409	2,658
UK	Windscale	WAGR	32	156	4,875

USA	Fort St. Vrain	HTGR	380	195	513
USA	Rancho Seco	PWR	913	517	566
USA	Three Mile Island 2	PWR	913	805	882
USA	Trojan	PWR	1,180	296	256
USA	Yankee Rowe	PWR	185	650	3,514
USA	Maine Yankee	PWR	860	635	738
USA	Connecticut Yankee	PWR	590	820	1,390
USA	Zion 1 & 2	PWR	2,080	1,000	481

Sources: IAEA, Worthington Sawtelle LLC

Decommissioning a NPP involves taking the site to one of three different states. The nomenclature differs from country to country, however the end state for each of the three scenarios is virtually the same, as shown in Table 63.

Table 63 Three Decommissioning End State Objectives

U.S. Term	End State Objectives	EU Term	End State Objectives
DECON	A method of decommissioning, in which structures, systems, and components that contain radioactive contamination are removed from a site and safely disposed at a commercially operated low-level waste disposal facility, or decontaminated to a level that permits the site to be released for unrestricted use shortly after it ceases operation.	**Immediate decontamination and dismantling**	Decontamination and dismantling immediately after operation period. All contaminated material is cleaned until no more regulatory control is required. It is then dismantled as soon as the end of operation period.
SAFSTOR	A method of decommissioning in which a nuclear facility is placed and maintained in a condition that allows the facility to be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use.	**Deferred decontamination and dismantling (safe enclosure / safe storage**	The nuclear plant is kept intact and placed in protective storage to enable the radionuclides activity to decay until it reaches levels that reduce difficulties of handling. First, spent fuel is removed from the facility. The plant is then put and kept in a safe and stable state, until actual decontamination and dismantling. During this period, all remaining fluids are drained from the systems and adequately treated.
ENTOMB	A method of decommissioning, in which radioactive contaminants are encased in a structurally long-lived material, such as concrete. The entombed structure is maintained and surveillance is continued until the entombed radioactive waste decays to a level permitting termination of the license and unrestricted release of the property. During the entombment period, the licensee maintains the license previously issued by the NRC.	**Entombment**	This option involves encasing radioactive structures, systems and components in a long-lived substance, such as concrete. The encased plant would be appropriately maintained, and surveillance would continue until the radioactivity decays to a level that permits termination of the plant's license and end any regulatory control. Most nuclear plants will have radionuclide concentrations exceeding the limits for unrestricted use even after 100 years. Therefore, special provisions would be needed for the extended monitoring period this option requires. To date, no facility owners have proposed the

			entombment option for any nuclear power plants undergoing decommissioning. In fact, this is more an emergency option than a strategy option, so far used only in the case of Chernobyl.

Sources: NRC; European Commission

In addition to the issue of underestimating cost, there is also the issue of under investment, even to achieve underestimated cost balances. Most countries require their operators to demonstrate that they have made provisions that adequate funding will be in place when a NPP retires. Funding is accomplished by prepayment; surety bonds or insurance; or by use of a sinking fund.

In Europe, the methods to fund decommissioning accounts vary considerably from country to country, as shown in Table 64, as well as the actual type of decommissioning planned, Table 65.

Table 64 Decommissioning Requirements EU Countries

	Provisions Based on Discounted Costs				
No Provisions	**Country**	**Nominal Discount Rate Applied**	**Inflation Rate**	**Real Discount Rate**	**Provisions based on undiscounted costs**
U.K. (Magnox)	Germany (varies with tax code)	5.5%	Indirectly	5.5%	Germany (varies with tax code)
Romania	France	5.0%	2.0%	2.94%	Czech Republic
	Sweden			Various	Slovakia
	Spain			1.5$	Italy
	Netherlands	4.0%	Indirectly	4.0%	Finland
	Slovenia	4.29%	0.73%	3.53%	Lithuania
	Lithuania			3.0%	
	Hungary			3.0%	

Source: European Commission

Table 65 EU Types of Decommissioning Chosen, by Country

Immediate Dismantling	Deferred Dismantling		No preference yet
	Countries	Duration of Safe Enclosure	
Belgium	Belgium	35 years	SK
Germany	Czech Republic	35 – 50 years	Romania
Spain	Finland (Olkiluoto)	30 years	
France	Hungary	70 years	
Finland (Loviisa)	Netherlands (Dodewaard)	40 years	
Italy	Sweden	10-40 years	
Lithuania	UK	>100 years	
Netherlands (Borselle)	Hungary		
Slovenia	Belgium		

Source: Worthington Sawtelle LLC

Currently the European Commission is looking into this issue. It is estimated that the dismantling of the 150 nuclear reactors in Europe will cost around €150 billion (USD 207 billion), with an average cost of €1 billion (USD 1.37 billion) per reactor, as shown in Table 66.

Table 66 EU Estimate of Decommissioning Expenses, Current Reactor Fleet, Millions USD

	Shutdown date				
	Before 1986	1986 – 2005	2006 – 2025	Later or unknown	Total
Belgium	-	15	7,947	-	7,962
Czech Republic	-	-	-	4,861	4,861
Germany	927	7,216	27,815	-	35,958
Spain	-	658	195	10,196	11,048
France	954	4,829	-	86,807	92,590

Italy	206	1,744	-	-	1,950
Lithuania	1,623	1,623	-	-	3,247
Hungary	-	-	-	2,404	2,404
Netherlands	-	75	-	615	690
Slovenia	-	-	-	899	899
Slovakia	151	-	1,118	2,228	3,496
Finland	-	-	-	3,639	3,639
Sweden	14	1,644	-	12,126	13,784
United Kingdom	63	3,299	14,610	1,628	19,599
Bulgaria	-	1,118	1,118	2,611	4,847
Total EU+BG	2,314	22,221	54,426	128,013	206,974

Source: European Commission

Only the Netherlands, Sweden and Germany appear to have accumulated 100% of funds necessary to decommission their NPPs. Several billion dollars in shortfalls have been identified in Bulgaria and Slovakia.

Similar concerns exist in the U.S. The U.S. Government Accounting Office reviewed the adequacy of various NPP decommissioning funds by comparing the amount being raised to meet the NRC formula with a site-specific study cost estimate. The NRC formula estimate was only a fraction of a site-specific cost estimates for decommissioning several anonymous NPPs. Table 67 shows percentages of various NPP funds not covered by the NRC formula amount.

Table 67 Comparison of NRC and Site-Specific Formula Estimates for Decommissioning Costs at 12 Operating NPPs

NPP #	Original License Date	Extended License Date	NRC Formula Cost, $ millions	Year of NRC Formula Calculation	Site Specific Study Cost Est, $ millions	Year of Site Specific Cost Est, $ millions	% Site Specific Study Covered by NRC Formula
1	2015	2035	$474.22	2010	$836.45	2010	57
2	2017	2037	447.33	2010	525.48	2010	85

3	2026	—	616.28	2010	710.54	2010	87
4	2014	2034	345.50	2008	537.98	2008	64
5	2013	2033	345.50	2008	487.99	2008	71
6	2014	2034	384.74	2008	504.12	2008	76
7	2026	2046	554.16	2008	725.26	2008	76
8	2014	2034	503.37	2008	499.00	2008	101
9	2014	2034	520.90	2008	506.08	2008	103
10	2012	2032	478.16	2006	468.84	2006	102
11	2020	2040	354.70	2002	420.14	2002	84
12	2016	2036	$354.70	2002	$390.13	2002	91

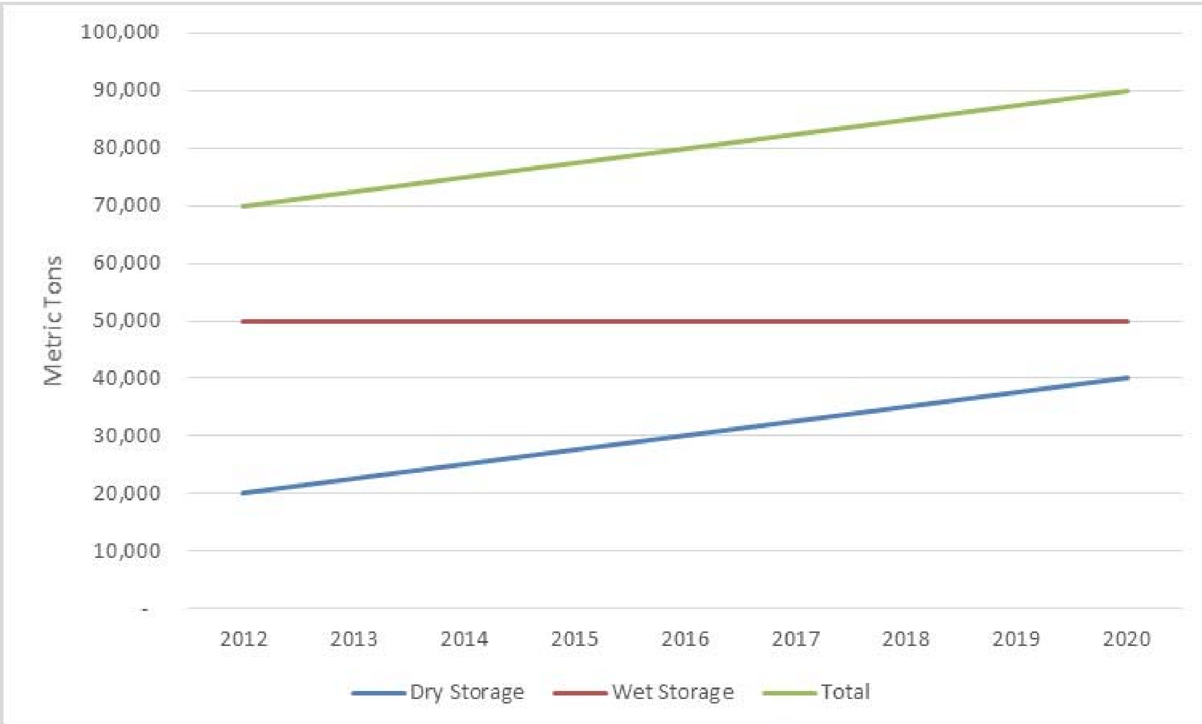
Source: U.S. Government Accounting Office

7.2.6 Spent Fuel Storage and Waste Disposal

Spent nuclear fuel, referred to by some as "used fuel" and the associated wastes from NPPs is perhaps more of a barrier for policy makers than payers in the market. A lot of spent nuclear fuel and waste material has, and continues to be accumulated in some countries where no long term solution has been found. The early vision for the nuclear fuel cycle – where fuel was recycled into the system (Figure 26) rather than the one way path that it has become (Figure 25)–was never achievable, at least on an economic basis. As such, these issues are more of a policy issue for governments, rather than of market participants. Were solutions to be implemented, the issues would lose their effectiveness as one more weapon in the hand of those who oppose nuclear power.

In the U.S. about 69,000 metric tons (MT) have been accumulated and this number grows by about 2,000 MT a year, a little less than one fifth of the global total. Figure 49 shows this steady growth.

Figure 49 U.S. Cumulative Metric Tons of Stored Nuclear Fuel, 2012-2020



Source: GAO

The picture is much the same at all the other key nuclear countries, as shown in Table 68. Virtually all current spent fuel is being put into dry or wet storage, with only two countries close to resolving the issue of a final repository.

Table 68 Spent Fuel and Nuclear Waste Repository Status, Selected Countries

	Number Operating NPP	2007 Spent Fuel Inventory (t HM)	Reprocessing?	Centralized Interim Storage?	Geologic Repository?
Canada	18	38,400	No	No	No
Japan	50	19,000	Yes	Yes, but full	No
Russia	33	17,895	Yes	Yes	No
France	58	13,500	Yes	No	No
South Korea	23	10,900	No	Under Construction	No
Germany	9	5,850	Not since 2005	Yes	No
U.K.	18	5,850	Yes	No	No
Sweden	10	5,400	No	Yes	Under Construction
Finland	4	1,600	Not since 1991	No	Sited

Source: GAO

8 APPENDIX F NUCLEAR POWER STATISTICS

8.1 Currently Operating NPPs by Country and Technology

Table 69 List of Currently Operating NPPs by Country and Technology

Country	**NPP Name**	**Type**	**Model**	**Net Capacity (MWe)**	**Vendor**	**Year of Commercial Operation**
Argentina	Atucha-1	PHWR	PHWR KWU	335	SIEMENS	1974
	Aucha-2	PHWR	PHWR	692	SIEMENS	2013
	Embalse	PHWR	CANDU 6	600	AECL	1984
Armenia	Armenia-2	PWR	VVER V-270	375	FAEA	1980
Belgium	Doel-1	PWR	W 2 loop	433	AECO WEN	1975
	Doel-2	PWR	W 2 loop	433	AECO WEN	1975
	Doel-3	PWR	W 3 loop	1,006	AECO WEN	1982
	Doel-4	PWR	W 3 loop	1,039	AECO WEN	1985
	Tihange-1	PWR	FRAM 3	962	ACLF	1975
	Tihange-2	PWR	W 3 loop	1,008	FRAMA CEC	1983
	Tihange-3	PWR	W 3 loop	1,046	AECO WEN	1985
Brazil	Angra-1	PWR	W 2 loop	609	W	1985
	Angra-2	PWR	PWR	1,275	KWU	2001
Bulgaria	Kozloduy-5	PWR	VVER V-320	953	AEE	1988
	Kozloduy-6	PWR	VVER V-320	953	AEE	1993
Canada	Bruce-3	PHWR	CANDU 750A	730	OH/AECL	1978
	Bruce-4	PHWR	CANDU 750A	730	OH/AECL	1979
	Bruce-5	PHWR	CANDU 750B	817	OH/AECL	1985

	Bruce-6	PHWR	CANDU 750B	817	OH/AECL	1984
	Bruce-7	PHWR	CANDU 750B	817	OH/AECL	1986
	Bruce-8	PHWR	CANDU 750B	817	OH/AECL	1987
	Darlington-1	PHWR	CANDU 850	878	OH/AECL	1992
	Darlington-2	PHWR	CANDU 850	878	OH/AECL	1990
	Darlington-3	PHWR	CANDU 850	878	OH/AECL	1993
	Darlington-4	PHWR	CANDU 850	878	OH/AECL	1993
	Gentilly-2	PHWR	CANDU 6	635	AECL	1983
	Pickering-1	PHWR	CANDU 500A	515	OH/AECL	1971
	Pickering-4	PHWR	CANDU 500A	515	OH/AECL	1973
	Pickering-5	PHWR	CANDU 500B	516	OH/AECL	1983
	Pickering-6	PHWR	CANDU 500B	516	OH/AECL	1984
	Pickering-7	PHWR	CANDU 500B	516	OH/AECL	1985
	Pickering-8	PHWR	CANDU 500B	516	OH/AECL	1986
	Point Lepreau	PHWR	CANDU 6	635	AECL	1983
China	Guangdong-1	PWR	M310	944	FRAM	1994
	Guangdong-2	PWR	M310	944	FRAM	1994
	Lingao 1	PWR	M310	938	FRAM	2002
	Lingao 2	PWR	M310	938	FRAM	2003
	Tianwan 1	PWR	VVER V-428	990	IZ	2007
	Tianwan 2	PWR	VVER V-429	990	IZ	2007
	Lingao 3	PWR	CPR-1000	1,007	DFEC	2010
	Lingao 4	PWR	CPR-1000	1,007	DFEC	2011

	Ningde 1	PWR	CPR-1000	1,007	DFEC	2012
	Qinshan 1	PWR	CNP-300	298	CNNC	1994
	Qinshan 2-1	PWR	CNP-600	610	CNNC	2002
	Qinshan 2-2	PWR	CNP-600	610	CNNC	2004
	Qinshan 2-3	PWR	CNP-600	610	CNNC	2010
	Qinshan 2-4	PWR	CNP 600	610	CNNC	2011
	Qinshan 3-1	PHWR	CANDU 6	650	AECL	2002
	Qinshan 3-2	PHWR	CANDU 6	650	AECL	2003
Czech Republic	Dukovany-1	PWR	VVER V-213	471	SKODA	1985
	Dukovany-3	PWR	VVER V-213	471	SKODA	1986
	Dukovany-2	PWR	VVER V-213	427	SKODA	1986
	Dukovany-4	PWR	VVER V-213	471	SKODA	1987
	Temelin-1	PWR	VVER V-320	963	SKODA	2002
	Temelin-2	PWR	VVER V-320	963	SKODA	2003
Finland	Loviisa-1	PWR	VVER V-213	488	AEE	1977
	Loviisa-2	PWR	VVER V-213	488	AEE	1981
	Olkiluoto-1	BWR	BWR-2500	880	ASEASTAL	1979
	Olkiluoto-2	BWR	BWR-2500	880	ASEASTAL	1982
France	Belleville-1	PWR	EDF P4	1,363	FRAM	1988
	Belleville-2	PWR	EDF P4	1,363	FRAM	1988
	Blayais-1	PWR	CP1	910	FRAM	1981
	Blayais-2	PWR	CP1	910	FRAM	1983
	Blayais-3	PWR	CP1	910	FRAM	1983
	Blayais-4	PWR	CP1	910	FRAM	1983
	Bugey-2	PWR	CP0	910	FRAM	1979

	Bugey-3	PWR	CP0	910	FRAM	1979
	Bugey-4	PWR	CP0	880	FRAM	1979
	Bugey-5	PWR	CP0	880	FRAM	1980
	Cattenom-1	PWR	EDF P4	1,362	FRAM	1987
	Cattenom-2	PWR	EDF P4	1,362	FRAM	1988
	Cattenom-3	PWR	EDF P4	1,362	FRAM	1991
	Cattenom-4	PWR	EDF P4	1,362	FRAM	1992
	Chinon- B -1	PWR	CP2	905	FRAM	1984
	Chinon- B -2	PWR	CP2	905	FRAM	1984
	Chinon- B -3	PWR	CP2	905	FRAM	1987
	Chinon- B -4	PWR	CP2	905	FRAM	1988
	Chooz- B -1	PWR	EDF P4	1,560	FRAM	2000
	Chooz- B -2	PWR	EDF P4	1,560	FRAM	2000
	Civaux-1	PWR	EDF P4	1,561	FRAM	2002
	Civaux-2	PWR	EDF P4	1,561	FRAM	2002
	Cruas-1	PWR	EDF P4	915	FRAM	1983
	Cruas-2	PWR	EDF P4	915	FRAM	1984
	Cruas-3	PWR	EDF P4	915	FRAM	1984
	Cruas-4	PWR	EDF P4	915	FRAM	1984
	Dampierre-1	PWR	EDF P4	890	FRAM	1980
	Dampierre-2	PWR	EDF P4	890	FRAM	1980
	Dampierre-3	PWR	EDF P4	890	FRAM	1981
	Dampierre-4	PWR	EDF P4	890	FRAM	1981
	Fessenheim-1	PWR	EDF P4	880	FRAM	1977
	Fessenheim-2	PWR	EDF P4	880	FRAM	1977

	Flamanville-1	PWR	EDF P4	1330	FRAM	1985
	Flamanville-2	PWR	EDF P4	1330	FRAM	1986
	Golfech-1	PWR	EDF P4	1310	FRAM	1990
	Golfech-2	PWR	EDF P4	1310	FRAM	
	Gravelines-1	PWR	EDF P4	910	FRAM	
	Gravelines-2	PWR	EDF P4	910	FRAM	
	Gravelines-3	PWR	EDF P4	910	FRAM	
	Gravelines-4	PWR	EDF P4	910	FRAM	
	Gravelines-5	PWR	EDF P4	910	FRAM	
	Gravelines-6	PWR	EDF P4	910	FRAM	
	Nogent-1	PWR	EDF P4	1310	FRAM	
	Nogent-2	PWR	EDF P4	1310	FRAM	
	Paluel-1	PWR	EDF P4	1330	FRAM	1993
	Paluel-2	PWR	EDF P4	1330	FRAM	1980
	Paluel-3	PWR	EDF P4	1330	FRAM	1980
	Paluel-4	PWR	EDF P4	1330	FRAM	1980
	Penly-1	PWR	EDF P4	1330	FRAM	1981
	Penly-2	PWR	EDF P4	1330	FRAM	1984
	St. Alban-1	PWR	EDF P4	1335	FRAM	1985
	St. Alban-2	PWR	EDF P4	1335	FRAM	1987
	St. Laurent- B 2	PWR	CP2	915	FRAM	1983
	St. Laurent-B-1	PWR	CP2	915	FRAM	1983
	St. Laurent-B-1	PWR	EDF P4	915	FRAM	1988
	St. Laurent--B-2	PWR	EDF P4	915	FRAM	1984
	Tricastin-1	PWR	CP1	915	FRAM	1980

	Tricastin-2	PWR	CP1	915	FRAM	1980
	Tricastin-3	PWR	CP1	915	FRAM	1981
	Tricastin-4	PWR	CP1	915	FRAM	1981
Germany	Brokdorf	PWR	PWR	1,410	KWU	1985
	Emsland	PWR	KWU 95	1,329	KWU	1983
	Grafenrheinfeld	PWR	PWR	1,275	KWU	1986
	Grohnde	PWR	PWR	1,360	KWU	1990
	Gundremmingen- B	BWR	BWR-72	1,284	KWU	1984
	Gundremmingen-C	BWR	BWR-72	1,288	KWU	1985
	Isar-2	PWR	KWU 95	1,410	KWU	1986
	Neckarwestheim-2	PWR	KWU 95	1,310	KWU	1983
	Philippsburg-2	PWR	PWR	1,402	KWU	1992
Hungary	Paks-1	PWR	VVER V-213	470	AEE	1983
	Paks-2	PWR	VVER V-213	473	AEE	1984
	Paks-3	PWR	VVER V-213	473	AEE	1986
	Paks-4	PWR	VVER V-213	473	AEE	1987
India	Kaiga-1	PHWR	CANDU	202	NPCIL	2000
	Kaiga-2	PHWR	CANDU	202	NPCIL	2000
	Kaiga-3	PHWR	CANDU	202	NPCIL	2007
	Kaiga-4	PHWR	CANDU	202	NPCIL	2011
	Kakrapar-1	PHWR	CANDU	202	NPCIL	1993
	Kakrapar-2	PHWR	CANDU	202	NPCIL	1995
	Madras-1	PHWR	CANDU	205	NPCIL	1984
	Madras-2	PHWR	CANDU	205	NPCIL	1986
	Narora-1	PHWR	CANDU	202	NPCIL	1991

	Narora-2	PHWR	CANDU	202	NPCIL	1992
	Rajasthan-1	PHWR	CANDU	90	AECL	1973
	Rajasthan-2	PHWR	CANDU	187	AECL/DAE	1981
	Rajasthan-3	PHWR	CANDU	202	NPCIL	2000
	Rajasthan-4	PHWR	CANDU	202	NPCIL	2000
	Rajasthan-5	PHWR	CANDU	202	NPCIL	2010
	Rajasthan-6	PHWR	CANDU	202	NPCIL	2010
	Tarapur-1	BWR	BWR-1	150	GE	1969
	Tarapur-2	BWR	BWR-1	150	GE	1969
	Tarapur-3	PHWR	CANDU	540	NPCIL	2006
	Tarapur-4	PHWR	CANDU	540	NPCIL	2005
Iran	Bushehr 1	PWR	VVER V-446	915	ASE	2012
Japan	Fukushima-Daiichi-1	BWR	BWR-3	439	GE	1970
	Fukushima-Daiichi-2	BWR	BWR-4	760	GE	1973
	Fukushima-Daiichi-3	BWR	BWR-4	760	TOSHIBA	1974
	Fukushima-Daiichi-4	BWR	BWR-4	760	HITACHI	1978
	Fukushima-daiichi-5	BWR	BWR-4	760	TOSHIBA	1978
	Fukushima-daiichi-6	BWR	BWR-5	1,067	GE/T	1979
	Fukushima-daini-1	BWR	BWR-5	1,067	TOSHIBA	1982
	Fukushima-daini-2	BWR	BWR-5	1,067	HITACHI	1984
	Fukushima-daini-3	BWR	BWR-5	1,067	TOSHIBA	1985
	Fukushima-daini-4	BWR	BWR-5	1,067	HITACHI	1987
	Genkai-1	PWR	M 2 loop	529	MHI	1975

	Genkai-2	PWR	M 2 loop	529	MHI	1981
	Genkai-3	PWR	M 4 loop	1,127	MHI	1994
	Genkai-4	PWR	M 4 loop	1,127	MHI	1997
	Hamaoka-3	BWR	BWR-5	1,056	TOSHIBA	1987
	Hamaoka-4	BWR	BWR-5	1,092	TOSHIBA	1993
	Hamaoka-5	BWR	ABWR	1,325	TOSHIBA	2005
	Higashi Dori 1 (Tohuku)	BWR	BWR-5	1,067	TOSHIBA	2005
	Ikata-1	PWR	M 2 loop	538	MHI	1977
	Ikata-2	PWR	M 3 loop	538	MHI	1982
	Ikata-3	PWR	M 2 loop	846	MHI	1994
	Kariwa-1	BWR	BWR-5	1,067	TOSHIBA	1985
	Kariwa-2	BWR	BWR-5	1,067	TOSHIBA	1990
	Kariwa-3	BWR	BWR-5	1,067	TOSHIBA	1993
	Kariwa-4	BWR	BWR-5	1,067	HITACHI	1994
	Kariwa-5	BWR	BWR-5	1,067	HITACHI	1990
	Kariwa-6	BWR	ABWR	1,315	TOSHIBA	1996
	Kariwa-7	BWR	ABWR	1,315	HITACHI	1997
	Mihama-1	PWR	W 2 loop	320	W	1970
	Mihama-2	PWR	M 2 loop	470	MHI	1972
	Mihama-3	PWR	M 3 loop	780	MHI	1976
	Ohi-1	PWR	W 4 loop	1,120	W	1979
	Ohi-2	PWR	W 4 loop	1,120	W	1979
	Ohi-3	PWR	M 4 loop	1,127	MHI	1991
	Ohi-4	PWR	M 4 loop	1,127	MHI	1993

	Onagawa-1	BWR	BWR-4	498	TOSHIBA	1984
	Onagawa-2	BWR	BWR-5	796	TOSHIBA	1995
	Onagawa-3	BWR	BWR-5	796	TOSHIBA	2002
	Sendai-1	PWR	M 3 loop	846	MHI	1984
	Sendai-2	PWR	M 3 loop	846	MHI	1985
	Shika-1	BWR	BWR-5	505	HITACHI	1993
	Shika-2	BWR	ABWR	1,108	HITACHI	2006
	Shimane-1	BWR	BWR-3	439	HITACHI	1974
	Shimane-2	BWR	BWR-5	789	HITACHI	1989
	Takahama-1	PWR	M 3 loop	780	W/MHI	1974
	Takahama-2	PWR	M 3 loop	780	MHI	1975
	Takahama-3	PWR	M 3 loop	830	MHI	1985
	Takahama-4	PWR	M 3 loop	830	MHI	1985
	Tokai-2	BWR	BWR-5	1,060	GE	1978
	Tomari-1	PWR	M 2 loop	550	MHI	1989
	Tomari-2	PWR	M 2 loop	550	MHI	1991
	Tomari-3	PWR	M 3 loop	866	MHI	2009
	Tsuruga-1	BWR	BWR-2	340	GE	1970
	Tsuruga-2	PWR	M 4 loop	1,108	MHI	1987
Mexico	Laguna Verde 2	BWR	BWR-5	650	GE	1990
Netherlands	Borssele	PWR	LWR	482	S/KWU	1973
Pakistan	Kanupp	PHWR	CANDU-137	125	CGE	1972
	Chasnupp 1	PWR	CNP-300	300	CNNC	2000
	Chasnupp 2	PWR	PWR	300	CNNC	2011
Romania	Cernavoda-1	PHWR	CANDU 6	650	AECL	1996

	Cernavoda-2	PHWR	CANDU 6	650	AECL	2007
Russia	Balakovo-1	PWR	VVER V-320	950	ROSATOM	1986
	Balakovo-2	PWR	VVER V-320	950	ROSATOM	1988
	Balakovo-3	PWR	VVER V-320	950	ROSATOM	1989
	Balakovo-4	PWR	VVER V-320	950	ROSATOM	1993
	Baltiisk-1	PWR	VVER V-491	1109	ROSATOM	2012
Russia	Beloyarsky-3	FBR	BN-600	560	ROSATOM	1981
	Bilibino-1	LWGR	EGP-6	11	ROSATOM	1974
	Bilibino-2	LWGR	EGP-6	11	ROSATOM	1975
	Bilibino-3	LWGR	EGP-6	11	ROSATOM	1976
	Bilibino-4	LWGR	EGP-6	11	ROSATOM	1977
	Kalinin-1	PWR	VVER V-338	950	ROSATOM	1985
	Kalinin-2	PWR	VVER V-338	950	ROSATOM	1987
	Kalinin-3	PWR	VVER V-320	950	ROSATOM	2005
	Kalinin-4	PWR	VVER V-320	950	ROSATOM	2011
	Kola-1	PWR	VVER V-230	411	ROSATOM	1973
	Kola-2	PWR	VVER V-230	411	ROSATOM	1975
	Kola-3	PWR	VVER V-213	411	ROSATOM	1982
	Kola-4	PWR	VVER V-213	411	ROSATOM	1984
	Kursk-1	LWGR	RBMK-1000	925	ROSATOM	1977
	Kursk-2	LWGR	RBMK-1000	925	ROSATOM	1979
	Kursk-3	LWGR	RBMK-1000	925	ROSATOM	1984
	Kursk-4	LWGR	RBMK-1000	925	ROSATOM	1986
	Kursk 2-1	PWR	RBMK-1000	1,115	ROSATOM	1976
	Kursk 2-2	PWR	RBMK-1000	1,115	ROSATOM	1979

	Kursk 2-3	PWR	RBMK-1000	1,115	ROSATOM	1983
	Kursk 2-4	PWR	RBMK-1000	1,115	ROSATOM	1985
	Leningrad-1	LWGR	RBMK-1000	925	ROSATOM	1974
	Leningrad-2	LWGR	RBMK-1000	925	ROSATOM	1976
	Leningrad-3	LWGR	RBMK-1000	925	ROSATOM	1980
	Leningrad-4	LWGR	RBMK-1000	925	ROSATOM	1981
	Novovoronezh-3	PWR	VVER V-179	385	ROSATOM	1972
	Novovoronezh-4	PWR	VVER V-179	385	ROSATOM	1973
	Novovoronezh-5	PWR	VVER V-187	950	ROSATOM	1981
	Rostov-1	PWR	VVER V-320	950	ROSATOM	2001
	Rostov-2	PWR	VVER V-320	950	ROSATOM	2010
	Smolensk-1	LWGR	RBMK-1000	925	ROSATOM	1983
	Smolensk-2	LWGR	RBMK-1000	925	ROSATOM	1985
	Smolensk-3	LWGR	RBMK-1000	925	ROSATOM	1990
Slovakia	Bohunice-4	PWR	VVER V-213	472	SKODA	1985
	Bohunice-3	PWR	VVER V-213	472	SKODA	1985
	Mochovce-1	PWR	VVER V-213	436	SKODA	1998
	Mochovce-2	PWR	VVER V-213	436	SKODA	2000
Slovenia	Krsko	PWR	W 2 loop	688	W	1982
South Africa	Koeberg-1	PWR	CP1	930	FRAM	1984
	Koeberg-2	PWR	CP1	900	FRAM	1985
South Korea	Kori-1	PWR	W	576	W	1978
	Kori-2	PWR	W	637	W	1983
	Kori-3	PWR	W	1,011	W	1985
	Kori-4	PWR	W	1,009	W	1986

	Shin-Kori-1	PWR	OPR-1000	985	DHICKOPC	2011
	Shin-Kori-2	PWR	OPR-1000	985	DHICKOPC	2012
	Shin Wolsong 1	PWR	OPR-1000	985	DHICKOPC	2012
	Ulchin-1	PWR	CP1	2785	FR	1989
	Ulchin-2	PWR	CP1	2775	FR	1988
	Ulchin-3	PWR	OPR-1000	994	DHICKOPC	1998
	Ulchin-4	PWR	OPR-1000	998	DHICKOPC	1999
	Ulchin-5	PWR	OPR-1000	997	DHICKOPC	2004
	Ulchin-6	PWR	OPR-1000	997	DHICKOPC	2005
	Wolsong-1	PHWR	CANDU 6	660	AECL	1983
	Wolsong-2	PHWR	CANDU 6	710	AECL/DHI	1997
	Wolsong-3	PHWR	CANDU 6	707	AECL/DHI	1998
	Wolsong-4	PHWR	CANDU 6	708	AECL/DHI	1999
	Yonggwang-1	PWR	W	953	W	1986
	Yonggwang-2	PWR	W	947	W	1987
	Yonggwang-3	PWR	OPR-1000	997	DHICKAEC	1995
	Yonggwang-4	PWR	OPR-1000	994	DHICKAEC	1996
	Yonggwang-5	PWR	OPR-1000	988	DHICKOPC	2002
	Yonggwang-6	PWR	OPR-1000	996	DHICKOPC	2002
Spain	Almaraz-1	PWR	W 3 loop	1,011	W	1983
	Almaraz-2	PWR	W 3 loop	1,006	W	1984
	Asco-1	PWR	W 3 loop	995	W	1984
	Asco-2	PWR	W 3 loop	997	W	1986
	Cofrentes	BWR	BWR-6	1,110	GE	1984
	Santa Maria de Gerona	BWR	BWR-3	446	GE	1971

	Trillo-1	PWR	PWR	1,003	KWU	1988
	Vandellos-2	PWR	W 3 loop	1,045	W	1988
Sweden	Forsmark-1	BWR	BWR-75	984	ABBATOM	1980
	Forsmark-2	BWR	BWR-75	996	ABBATOM	1981
	Forsmark-3	BWR	BWR-3000	1,170	ABBATOM	1985
	Oskarshamn-1	BWR	ABB BWR	473	ABBATOM	1972
	Oskarshamn-2	BWR	ABB BWR	638	ABBATOM	1975
	Oskarshamn-3	BWR	BWR-75	1,400	ABBATOM	1985
	Ringhals-1	BWR	BWR	854	ABBATOM	1976
	Ringhals-2	PWR	W 3 loop	809	W	1975
	Ringhals-3	PWR	W 3 loop	1,057	W	1981
	Ringhals-4	PWR	W 3 loop	945	W	1983
Switzerland	Muehleberg	BWR	BWR-4	373	GETSCO	1972
	Leibstadt	BWR	BWR-6	1,190	GETSCO	1984
	Beznau-1	PWR	W 2 loop	365	AG	1969
	Beznau-2	PWR	W 2 loop	365	AG	1971
	Goesgen	PWR	PWR	970	KWU	1979
Taiwan	Chin Shan 2	BWR	BWR-4	604	GE	1978
	Chin Shan 2	BWR	BWR-4	604	GE	1979
	Kuosheng-1	BWR	BWR-6	985	GE	1981
	Kuosheng-2	BWR	BWR-6	985	GE	1983
	Maanshan-1	PWR	W	918	W	1984
	Maanshan-2	PWR	W	922	W	1985
UK	Dungeness- B 1	GCR	AGR	520	APC	1985
	Dungeness- B 2	GCR	AGR	520	APC	1989

	Hartlepool-a1	GCR	AGR	595	NPC	1989
	Hartlepool-a2	GCR	AGR	595	NPC	1989
	Heysham- B 2	GCR	AGR	605	NPC	1989
	Heysham-A1	GCR	AGR	585	NPC	1989
	Heysham-A2	GCR	AGR	575	NPC	1989
	Heysham-B1	GCR	AGR	605	NPC	1989
	Hinkley Point B 1	GCR	AGR	435	TNPG	1978
	Hinkley Point B 2	GCR	AGR	435	TNPG	1976
	Hunterston- B 1	GCR	AGR	460	TNPG	1976
	Hunterston- B 2	GCR	AGR	430	TNPG	1977
	Oldbury-a1	GCR	MAGNOX	217	TNPG	1967
	Sizewell- B	PWR	SNUPPS	1,191	PPC	1995
	Torness 1	GCR	AGR	600	NNC	1988
	Torness 2	GCR	AGR	605	NNC	1989
	Wylfa 1	GCR	MAGNOX	490	EE/B&W/T	1971
	Wylfa 2	GCR	MAGNOX	490	EE/B&W/T	1971
Ukraine	Khmelnitski-1	PWR	VVER V-320	950	NNEGC	1988
	Khmelnitski-2	PWR	VVER V-320	950	NNEGC	2005
	Rovno-1	PWR	VVER V-213	381	NNEGC	1981
	Rovno-2	PWR	VVER V-213	376	NNEGC	1982
	Rovno-3	PWR	VVER V-320	950	NNEGC	1987
	Rovno-4	PWR	VVER V-320	950	NNEGC	2006
	South Ukraine 1	PWR	VVER V-302	950	NNEGC	1983
	South Ukraine 2	PWR	VVER V-338	950	NNEGC	1985
	South Ukraine 3	PWR	VVER V-320	950	NNEGC	1989

	Zaporozhe-1	PWR	VVER V-320	950	NNEGC	1985
	Zaporozhe-2	PWR	VVER V-320	950	NNEGC	1986
	Zaporozhe-3	PWR	VVER V-320	950	NNEGC	1987
	Zaporozhe-4	PWR	VVER V-320	950	NNEGC	1988
	Zaporozhe-5	PWR	VVER V-320	950	NNEGC	1989
	Zaporozhe-6	PWR	VVER V-320	950	NNEGC	1996
USA	Arkansas Nuclear One 1	PWR	B&W L Loop	842	B&W	1974
	Arkansas Nuclear One 2	PWR	CE 2 loop	993	CE	1980
	Beaver Valley 1	PWR	W 3 loop	892	W	1976
	Beaver Valley 2	PWR	W 3 loop	885	W	1987
	Braidwood-1	PWR	W 4 loop	1,178	W	1988
	Braidwood-2	PWR	W 4 loop	1,152	W	1988
	Browns Ferry 1	BWR	BWR-4	1,101	GE	1974
	Browns Ferry 2	BWR	BWR-4	1,104	GE	1975
	Browns Ferry 3	BWR	BWR-4	1,105	GE	1977
	Brunswick-1	BWR	BWR-4	938	GE	1977
	Brunswick-2	BWR	BWR-4	920	GE	1975
	Byron-1	PWR	W 4 loop	1,164	W	1985
	Byron-2	PWR	W 4 loop	1,136	W	1987
	Callaway-1	PWR	W 4 loop	1,190	W	1984
	Calvert Cliffs 1	PWR	CE 2 loop	855	CE	1975
	Calvert Cliffs 2	PWR	CE 2 loop	850	CE	1977
	Catawba-1	PWR	W 4 loop	1,129	W	1985
	Catawba-2	PWR	W 4 loop	1,129	W	1986
	Clinton-1	BWR	BWR-6	1,065	GE	1987

	Columbia	BWR	BWR-5	1,131	GE	1984
	Comanche Peak 1	PWR	W 4 loop	1,209	W	1990
	Comanche Peak 2	PWR	W 4 loop	1,197	W	1993
	Cooper	BWR	BWR-4	774	GE	1974
	Crystal River 3	PWR	B&W L Loop	860	B&W	1977
	Davis Besse 1	PWR	B&W L Loop	894	B&W	1978
	Diablo Canyon 1	PWR	W 4 loop	1,122	W	1985
	Diablo Canyon 2	PWR	W 4 loop	1,118	W	1986
	Donald Cook 1	PWR	W 4 loop	1,009	W	1975
	Donald Cook 2	PWR	W 4 loop	1,077	W	1978
	Dresden-2	BWR	BWR-3	867	GE	1970
	Dresden-3	BWR	BWR-3	867	GE	1971
	Duane Arnold 1	BWR	BWR-4	601	GE	1975
	Enrico Fermi 2	BWR	BWR-4	1,085	GE	1988
	Farley-1	PWR	W 3 loop	874	W	1977
	Farley-2	PWR	W 3 loop	860	W	1981
	Fitzpatrick	BWR	BWR-4	855	GE	1975
	Fort Calhoun 1	PWR	CE 2 loop	482	CE	1973
	Grand Gulf	BWR	BWR-6	1,251	GE	1985
	H.R. Robinson 1	PWR	W 3 loop	724	W	1971
	Hatch-1	BWR	BWR-4	876	GE	1975
	Hatch-2	BWR	BWR-4	883	GE	1979
	Hope Creek 1	BWR	BWR-4	1,191	GE	1986
	Indian Point 2	PWR	W 4 loop	1,022	W	1974
	Indian Point 3	PWR	W 4 loop	1,040	W	1976

	Kewaunee	PWR	W 2 loop	566	W	1974
	Lasalle-1	BWR	BWR-5	1,118	GE	1984
	Lasalle-2	BWR	BWR-5	1,120	GE	1984
	Limerick-1	BWR	BWR-4	1,130	GE	1986
	Limerick-2	BWR	BWR-4	1,134	GE	1990
	Mcguire-1	PWR	W 4 loop	1,100	W	1981
	Mcguire-2	PWR	W 4 loop	1,100	W	1984
	Millstone-2	PWR	CE	869	CE	1975
	Millstone-3	PWR	W 4 loop	1,233	W	1986
	Monticello	BWR	BWR-3	572	GE	1971
	Nine Mile Point 1	BWR	BWR-2	621	GE	1969
	Nine Mile point 2	BWR	BWR-5	1,119	GE	1988
	North Anna 1	PWR	W 3 loop	920	W	1978
	North Anna 2	PWR	W 3 loop	943	W	1980
	Oconee-1	PWR	B&W L Loop	846	B&W	1973
	Oconee-2	PWR	B&W L Loop	846	B&W	1974
	Oconee-3	PWR	B&W L Loop	846	B&W	1974
	Oyster Creek	BWR	BWR-2	619	GE	1969
	Palisades	PWR	CE	793	CE	1971
	Palo Verde 1	PWR	CE 2 loop	1,311	CE	1986
	Palo Verde 2	PWR	CE80	1,314	CE	1986
	Palo Verde 3	PWR	CE80	1,312	CE	1988
	Peach Bottom 2	BWR	BWR-4	1,122	GE	1974
	Peach Bottom 3	BWR	BWR-4	1,122	GE	1974
	Perry-1	BWR	BWR-6	1,240	GE	1987

	Pilgrim-1	BWR	BWR-3	685	GE	1972
	Point Beach 1	PWR	W 2 loop	512	W	1970
	Point Beach 2	PWR	W 2 loop	586	W	1972
	Prairie Island 1	PWR	W 2 loop	521	W	1973
	Prairie Island 2	PWR	W 2 loop	519	W	1974
	Quad Cities 2	BWR	BWR-3	882	GE	1973
	Quad Cities 2	BWR	BWR-3	892	GE	1973
	R.E. Ginna	PWR	W 2 loop	580	W	1970
	River Bend 1	BWR	BWR-6	967	GE	1986
	Salem-1	PWR	W 4 loop	1,174	W	1977
	Salem-2	PWR	W 4 loop	1,158	W	1981
	San Onofre 2	PWR	CE 2 loop	1,070	CE	1983
	San Onofre 3	PWR	CE 2 loop	1,080	CE	1984
	Seabrook-1	PWR	W 4 loop	1,247	W	1990
	Sequoyah-1	PWR	W 4 loop	1,152	W	1981
	Sequoyah-2	PWR	W 4 loop	1,126	W	1982
	Shearon Harris 1	PWR	W 3 loop	900	W	1987
	South Texas 1	PWR	W 4 loop	1,280	W	1988
	South Texas 2	PWR	W 4 loop	1,280	W	1989
	St. Lucie 1	PWR	CE	839	CE	1976
	St. Lucie 2	PWR	COMB	839	CE	1983
	Surry-1	PWR	W 3 loop	839	W	1972
	Surry-2	PWR	W 3 loop	839	W	1973
	Susquehanna-1	BWR	BWR-4	1,260	GE	1983
	Susquehanna-2	BWR	BWR-4	1,260	GE	1985

	Three Mile Island 1	PWR	B&W L Loop	805	B&W	1974
	Turkey Point 3	PWR	W 3 loop	693	W	1972
	Turkey Point 4	PWR	W 3 loop	693	W	1973
	Vermont Yankee	BWR	BWR-4	620	GE	1972
	Virgil C. Summer 1	PWR	W 3 loop	966	W	1984
	Vogtle-1	PWR	W 4 loop	1,150	W	1987
	Vogtle-2	PWR	W 4 loop	1,152	W	1989
	Waterford-3	PWR	CE 2 loop	1,168	CE	1985
	Watts Bar 1	PWR	W 4 loop	1,123	W	1996
	Wolf Creek	PWR	W 4 loop	1,195	W	1985

Sources: IEA; WNA; Worthington Sawtelle LLC

8.2 Gross Electricity Generation and Nuclear Generation by Country in 2012, Ranked by Percentage Nuclear, GWH

Table 70 Gross Electricity Generation and Nuclear Generation by Country in 2012, Ranked by Percentage Nuclear, GWH

Country	Nuclear Generation (GWh)	Total Generation (GWh)	% Nuclear
France	427,702	576,470	74%
Slovakia	15,025	28,780	52%
Belgium	47,944	97,154	49%
Ukraine	91,575	198,833	46%
Hungary	15,761	38,699	41%
Switzerland	26,878	66,468	40%
Sweden	59,221	149,136	40%
Bulgaria	15,256	44,467	34%
Czech Republic	28,568	87,800	33%
Finland	23,273	74,036	31%

South Korea	158,633	535,551	30%
Spain	65,000	298,620	22%
Romania	11,752	60,510	19%
USA	823,010	4,316,210	19%
Taiwan	41,571	247,047	17%
Russia	185,842	1,111,527	17%
United Kingdom	62,545	387,541	16%
Canada	96,057	645,120	15%
Germany	81,544	583,489	14%
Argentina	13,709	136,274	10%
Pakistan	5,007	106,579	5%
South Africa	12,099	279,652	4%
Netherlands	4,182	113,704	4%
Mexico	10,089	282,317	4%
Japan	28,764	980,433	3%
Brazil	12,957	506,134	3%
India	21,621	1,108,951	2%
China	87,731	4,994,752	2%

Sources: IAEA; Worthington Sawtelle LLC

8.3 Share of Nuclear Electricity Generation by Region in 2011, Ranked by percentage

Table 71 Nuclear Electricity Generation by Region in 2011, Ranked by %

Region	Nuclear % Contribution	Thermal % Contribution	Hydro % Contribution	Renewables % Contribution	Total % Contribution
North America	18.8	63	15.6	2.6	100

Latin America	2.2	39.5	57.4	0.9	100
Western Europe	25.7	51.3	16.8	6.3	100
Eastern Europe	18.7	65.6	15.5	0.2	100
Africa	2	80.9	16.5	0.5	100
Middle East and South Asia	1.8	87.3	10.9	0.02	100
Southeast Asia and the Pacific		88.4	9.3	2.3	100
Far East	6.9	78	13.9	1.1	100
Total	12.3	68.2	17.4	2.1	100

Source: US Department of Energy

8.4 Distribution of Operating Reactor Types By Region (as of 6/2012)

Table 72 Distribution of Operating Reactor Types By Region (as of 6/2012)

	PWR		BWR		GCR		PHVR		LWGR		FBR	
	GW	%	GW	%	GW	%	GW	%	GW	%	GW	%
North America	67.4	27%	34.0	46%	-	0%	12.6	54%	-	0%	-	0%
Latin America	1.9	1%	1.3	2%	-	0%	0.9	4%	-	0%	-	0%
Western Europe	91.8	37%	13.9	19%	8.0	100%	-	0%	-	0%	-	0%
Eastern Europe	36.4	15%	-	0%	-	0%	1.3	6%	10.2	100%	0.6	97%
Africa	1.8	1%	-	0%	-	0%	-	0%	-	0%	-	0%
Middle East and South Asia	1.5	1%	0.3	0%	-	0%	4.3	18%	-	0%	-	0%
Southeast Asia and the Pacific	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Far East	47.6	19%	24.9	33%	-	0%	4,.1	18%	-	0%	.02	3%
Total	248.4	100%	74.5	1%	8.0	100%	23.1	1%	10.2	100%	0.6	100%

Sources: IAEA; Worthington Sawtelle LLC

8.5 Distribution of Operating Reactor Types by Country (as of 6/2012)

Table 73 Distribution of Operating Reactor Types by Country (as of 6/2012)

	PWR		BWR		GCR		PHVR		LWGR		FBR	
	No.	MWe	No.	MWe	No.	MWe	No.	MWe	No.	MWe	No.	MWe
Argentina	-	-	-	-	-	-	2	.9	-	-	-	-
Armenia	1	0.4	-	-	-	-	-	-	-	-	-	-
Belgium	7	5.9	-	-	-	-	-	-	-	-	-	-
Brazil	2	1.9	-	-	-	-	-	-	-	-	-	-
Bulgaria	2	1.9	-	-	-	-	-	-	-	-	-	-
Canada	-	-	-	-	-	-	18	12.6	-	-	-	-
China	13	10.5	-	-	-	-	2	1.3	-	-	1	-
Czech Republic	6	3.8	-	-	-	-	-	-	-	-	-	-
Finland	2	1.0	2	1.8	-	-	-	-	-	-	-	-
France	58	63.1	-	0.0	-	-	-	-	-	-	-	-
Germany	7	9.5	2	2.6	-	-	-	-	-	-	-	-
Hungary	4	1.9	-	-	-	-	-	-	-	-	-	-
India	-	0.0	2	0.3	-	-	18	4.1	-	-	-	-
Iran	1	0.9	-	-	-	-	-	-	-	-	-	-
Japan	24	19.3	26	24.9	-	-	-	-	-	-	-	-
Mexico	-	0.0	2	1.3	-	-	-	-	-	-	-	-
Netherlands	1	0.5	-	-	-	-	-	-	-	-	-	-
Pakistan	2	0.6	-	-	-	-	1	0.1	-	-	-	-
Romania	-	-	-	-	-	-	2	1.3	-	-	-	-
Russia	17	12.9	-	-	-	-	-	-	15	10.2	1	0.6

Slovakia	4	1.8	-	-	-	-	-	-	-	-	-	-
Slovenia	1	0.7	-	-	-	-	-	-	-	-	-	-
South Africa	2	1.8	-	-	-	-	-	-	-	-	-	-
Spain	6	6.1	2	1.5	-	-	-	-	-	-	-	-
South Korea	19	17.9	-	-	-	-	4	2.8	-	-	-	-
Sweden	3	2.8	7	6.5	-	-	-	-	-	-	-	-
Switzerland	3	1.7	2	1.6	-	-	-	-	-	-	-	-
U.K.	1	1.2	-	-	15	8.1	-	-	-	-	-	-
Ukraine	15	13.1	-	-	-	-	-	-	-	-	-	-
U.S.	69	67.4	35	34.1	-	-	-	-	-	-	-	-
WORLDWIDE	272	250.3	84	77.7	15	8.1	47	23.1	15	10.2	2	0.6

Sources: Worthington Sawtelle LLC; IAEA

9 APPENDIX F KEY PARTICIPANTS

9.1 AREVA

Ownership	Public; AREVA.PA
Location	33 rue la Fayette PARIS, 75442 France
Internet Address	www.areva.com
Market Cap	€ 5.46 B
2011 Revenue	€ 8,872 B

Areva is a France-based company that offers technological solutions for nuclear and renewable forms of power generation. It is organized into five business groups: Mining; Front End; Reactors and Services; Back End; and Renewable Business Group. The names of the groups follow the nuclear fuel cycle: Mining involves uranium mining, Areva produces 16% of the world's uranium; Front End includes UF6 conversion and enrichment; Reactors and Services produce finished fuel as well as major reactor components and design; and Back End is involved in reprocessing and waste management. Reactors and Services constitute 37% of Areva revenue. Renewable Energies include solar, wind, bioenergy and hydrogen power.

The major shareholder of the Company is Commissariat a l'Energie Atomique with 73.03% stake. The company principally operates in France, Europe, North and South America and Asia-Pacific. The company's manufacturing facilities are located in around 43 countries, and it has a sales network in over 100 countries. Areva is headquartered in Paris, France.

Commentary: AREVA has been struggling with its EPR reactor sales. The two EPRs under construction, Olkiluoto 3 in Finland and Flamanville 3 in France, have been plagued by cost overruns and schedule delays. AREVA was excluded from bidding in the Czech Republic and Finland. AREVA missed dividends in 2011 and 2012.

9.2 ATMEA

Ownership	Joint Venture Areva and Mitsubishi Heavy Industries
Location	Tour AREVA - 92084 Paris La Défense Cedex 9 – France France
Internet Address	www.atmea-sas.com
Market Cap	n/a
2011 Revenue	n/a

ATMEA is a joint venture between Areva and Mitsubishi Heavy Industries. Through ATMEA the companies provide the GEN III+ reactor system called ATMEA1, a 1,100 MW 3 loop PWR. ATMEA refers to this design as "mid-sized."

Commentary: The French regulatory authority evaluated the ATMEA1 as if it had applied for an operating license and was given a positive opinion in 2012. Argentina, Brazil and Turkey may be considering the reactor, but at present, there are no firm orders for a plant.

9.3 Atomic Energy of Canada

Ownership	Private
Location	2251 Speakman Dr. Mississauga, L5K 1B2 Canada
Internet Address	http://www.aecl.ca
Market Cap	n/a
2011 Revenue	n/a

Established in 1952, Atomic Energy of Canada Limited (AECL) split in 2011. Known for designing and developing the CANDU nuclear power reactor, the company designed and built nuclear reactors and provided services such as construction management, waste management, decommissioning, and life-extension projects related to CANDU reactors worldwide. SNC-Lavalin bought the commercial reactor division of AECL in 2011. The Canadian government retained the company's laboratory operations, which includes two facilities for nuclear technology research and development. (D&B)

9.4 Babcock & Wilcox Nuclear Operations Group

Ownership	Public NYSE:BWC
Location	13024 Ballantyne Corporate Place, Suite 700 Charlotte, NC 28277
Internet Address	http://www.babcock.com
Market Cap	$ 3.2 billion
2012 Revenue	$ 3.5 billion

The Babcock & Wilcox Company (B&W) supplies power generation systems. The Company provides a range of products and services to customers in the power and other steam-using industries, including electric utilities and other power generators, industrial customers in various other industries, and the United States Government. The product portfolio of the company includes auxiliary equipment, commercial nuclear plant components, boilers, modular nuclear reactors, boiler replacement parts and environmental equipment. B&W operates four business units, namely, Power Generation, Nuclear Operations, Technical Services and Nuclear Energy.

The Nuclear Operations business unit engineers, designs and manufactures precision naval nuclear components and reactors for the U.S. Department of Energy (DOE)/National Nuclear Security Administration's (NNSA) Naval Nuclear Propulsion Program.

The Technical Services business unit provides various services to the Government, including uranium processing, environmental site restoration services and management and operating services for various Government-owned facilities.

The Nuclear Energy business unit supplies commercial nuclear steam generators and components to nuclear utility customers. In addition, this segment offers a range of services for steam generators and balance of plant equipment, as well as nondestructive examination and tooling/repair solutions for other plant systems and components.

9.5 Cameco Corporation

Ownership	Public NYSE:CCJ, TSX:CCO
Location	2121-11th Street West Saskatoon SK S7M 1J3 Canada

Internet Address	http://www.cameco.com
Market Cap	$ 8.6 billion
2012 Revenue	$ 2.3 billion

Cameco is one of the world's largest uranium producer. It is the largest producer of uranium in the U.S. and has a controlling interest in the world's largest high grade ore reserves. In addition to mining, Cameco provides refining and conversion services and fabricates fuel for CANDU reactors. In January 2013, it acquired NUKEM Energy GmbH, a large nuclear fuel trader. Cameco also generates electricity as a 31% owner of the Bruce Power Limited Partnership, amounting to 3,260 MW from the Bruce B NPPs in Canada.

9.6 CB&I (Acquired The Shaw Group Inc.)

Ownership	Public NYSE: SHAW
Location	4171 Essen Lane Baton Rouge, LA 70809
Internet Address	http://www.shawgrp.com
Market Cap	$ 3.19 billion
2012 Revenue	$ 6.01 billion

CB&I acquired the Shaw Group Inc. in February 2013. Shaw provided engineering, procurement, construction, maintenance, fabrication, manufacturing, consulting, remediation and facilities management services to a global public and private client base. It was the leading private nuclear engineering and construction company in the world. At present, it is building four AP1000 units in China; and all of the units in construction in the U.S.: Vogtle 3 and 4; and V.C. Summer 2 and 3. It has strategic relationships with Westinghouse for the AP1000 and with Toshiba for the ABWR.

9.7 China Guangdong Nuclear Power Group

Ownership	State Owned
Location	Science Building, No 1001 Shangbuzhong Road Shenzhen, 518028 China
Internet Address	http://www.cgnpc.com.cn

Market Cap	n/a
2012 Revenue	n/a

China Guangdong Nuclear Power Group (CGNPG) owns and operates nuclear power stations in China. It also engages in the construction of nuclear power projects, and development of clean energy, including wind power and hydropower. CGNPG operates as a subsidiary of State-Owned Assets Supervision & Administration Commission of the State Council. It developed the CPR-1000, an indigenous PWR. CGNPG has collaborated with Areva in the construction of two EPRs in China.

9.8 China National Nuclear Corporation

Ownership	State Owned
Location	No.1 Nanasanxiang, Sanlihe, Beijing 100822 China
Internet Address	http://www.cnnc.com.cn
Market Cap	n/a
2012 Revenue	n/a

China National Nuclear Corporation (CNNC) is the Chinese analogue to Russia's Rosatom. It is a state corporation responsible for all thing nuclear, including moth military and commercial systems. The company also manufactures and markets isotopes, radioactive sources and their products, besides manufacturing of natural uranium, and other associated minerals. In addition, it produces and supplies nuclear fuels such as uranium exploration and mining. Further, the company provides research and development, production, marketing and technical services to nuclear instrumentation and environmental products. CNNC operates its business through over 100 subsidiary companies. CNNC is headquartered in Beijing, China. Figure 50 lists the NPPs operated or being constructed by CNNP.

Figure 50 CNNP NNP Operating and Under Construction

	NPP	Type	MWe
Operating NPPs			
	Qinshan 1	PWR	320
	Qinshan II	PWR	1,950

	Qinshan III	HWR	1,438
	Tianwan	PWR	2,120
	Daya Bay	PWR	1,960
	Ling Ao	PWR	2,000
Under construction			
	Expansion Qinshan II	PWR	650
	Fuqing	PWR	6,480
	Expansion Qinshan I	PWR	2,160
	Sanmen	PWR	2,500
	Changjiang	PWR	1,300
	Taohuajiang	PWR	2,500
	Tianwan	PWR	4,120

9.9 Electricite de France S.A.

Ownership	Public EPA:EDF
Location	22-30 avenue de Wagram, cedex 08 Paris, 75382 France
Internet Address	http://www.edf.com
Market Cap	$25.37 billion
2012 Revenue	$97.27 billion (consensus)

Electricite de France S.A. (EDF) is engaged in the generation, transmission and distribution of electricity, and the supply of natural gas. EDF is involved in various business activities including production, transportation and distribution, energy selling and trading. EDF generates electricity from nuclear, fossil-fired, hydroelectric, wind, and other renewable energy sources. EDF operates in France, Germany, the U.K. and Italy. A little over 70% of its customers are in France. It supplies electricity, gas and associated services to about 38.1 million customers globally, including approximately 27.7 million customers in France.

9.10 Gen 4 Energy (formerly Hyperion Power Generation)

Ownership	Private
Location	P.O. Box 44069 Denver, CO 80201
Internet Address	http://www.gen4energy.com
Market Cap	n/a
2012 Revenue	n/a

Formerly Hyperion Power Generation Inc., Gen4 Energy is a private company developing the Gen4 Module based on intellectual property licensed from Los Alamos National Laboratory. The Gen4 Module differs considerably from other SMRs in its deployment concept. The modules are factory sealed and installed underground at the end user's site. After 7 - 10 years of operation, the unit is returned to the factory. The 70 MWt/ 25 MWe Modules are most likely to operate in remote locations that are currently served by large diesel generators.

9.11 GE Hitachi Nuclear Energy and Hitachi-GE Nuclear Energy

Ownership	LLC
Locations	US: 3901 Castle Hayne Rd. Wilmington, NC, 28402 Japan: Akihabara Daibiru Building 18-13, Soto-Kanda 1-chome Chiyoda-ku Tokyo, 101-8608
Internet Addresses	http://www.ge-energy.com/nuclear http://www.hitachi-hgne.co.jp

Market Cap	n/a
2012 Revenue	n/a

Since 2007, GE and Hitachi have operated their nuclear divisions under a joint venture for the development and marketing of their Gen III ABWR and its variants. The joint venture has two names and two headquarters. Hitachi-GE Nuclear Energy Ltd (HGNE) is headquartered in Japan and majority owned by Hitachi and GE Hitachi Nuclear Energy (GEH) in the U.S. with the majority partner being GE. In addition to the ABWR, the joint venture provides R&D, design, manufacturing, construction, system maintenance services and nuclear fuel for existing BWRs. Early in 2013, HGNE acquired Horizon Nuclear Power, a joint venture of RWE and E.On which intends to construct approximately 6 GW of NPPs at existing nuclear sites in the UK.

In addition, GEH has submitted the Gen. III+ ESBWR to Finland's Teollisuuden Voima (TVO) for their Olkiluoto Nuclear Power Plant, Unit 4.

9.12 General Atomics

Ownership	Private
Locations	3550 General Atomics Ct. San Diego, CA 92121-1122
Internet Addresses	http://www.ga.com
Market Cap	n/a
2012 Revenue	n/a

General Atomics (GA) is a resource for a number of high technology systems. The company has been the primary developer of modular helium-cooled nuclear power reactor systems (HTGR), and its TRIGA® research reactors have operated around the world for over 45 years. The two areas where GA is most involved with commercial nuclear power are the development of an SMR and nuclear fuel. GA is developing the GT-MHR gas turbine modular helium reactor. Concerning fuel, GA has a subsidiary in the uranium conversion business as well as several uranium-mining interests.

9.13 Generation mPower LLC

Ownership	Joint Venture Bechtel, B&W
Location	11525 N. Community House Road Suite 600 Charlotte, NC 28277
Internet Address	http://www.generationmpower.com
Market Cap	n/a
2012 Revenue	n/a

Generation mPower LLC is a joint venture between B&W and Bechtel. Generation mPower is developing the mPower reactor, a small modular reactor design with the flexibility to provide between one to five 180 MW module units. See Section 4.2.1.

9.14 Holtec International, Inc

Ownership	Private
Locations	1001 North US Highway 1 Suite 204 Jupiter, FL 33477-4480
Internet Addresses	http://www.smrllc.com
Market Cap	n/a
2012 Revenue	n/a

Holtec International provides technologies to manage spent nuclear fuel, and as a provider of capital equipment and services to commercial power plants. Through its subsidiary, SMR, LLC, it is developing the Holtec Inherently Safe Modular Underground Reactor (HI-SMUR) design. Its first product is called the SMR-160. The company expects an operable version by 2018.

9.15 IHI Corporation

Ownership	Public TYO:7013

Location	Toyosu IHI Bldg., 3-1-1, Toyosu, Koto-ku Tokyo, TKY 135-8710 Japan
Internet Address	http://www.ihi.co.jp
Market Cap	$3.83 billion
2012 Revenue	$11.22 billion

IHI Corporation provides design, manufacture, sale, repairs and maintenance services for a variety of heavy industries and aerospace. IHI is one of the primary suppliers of major reactor components, including primary containment vessels, reactor pressure vessels, and radioactive waste vitrification systems. IHI also stores vitrified waste for domestic utilities.

9.16 Korea Electric Power Corporation

Ownership	Public NYSE: KEP
Location	167, Samseong-Dong, Gangnam-Gu Seoul, 135791 South Korea
Internet Address	http://www.kepco.co.kr
Market Cap	$18.22 billion
2012 Revenue	$51.18 billion

Korea Electric Power Corporation (KEPCO) is South Korea's national electric utility and is somewhat analogous to U.S. electric utility holding companies. KEPCO operates the Korean transmission and distribution grid as well as nuclear, hydro and thermal generation plants. In addition to the conventional electric utility operations, KEPCO has a number of subsidiaries focused on nuclear power: Korea Hydro & Nuclear Power Company, Ltd. (KHNP), KEPCO Engineering and Construction Company, Inc. (KEPCO E&C), and KEPKO Nuclear Fuel (KNF). KHNP operates 21 GW of NPPs in Korea with another 9.4 GW in construction. KEPCO E&C has built 14 NPPs and is under contract to provide 4 units to the U.A.E. KNF provides all of the fuel to the KHNP fleet. KHNP, in collaboration with the government and other agencies, developed the APR-1400, an indigenous PWR that is the current national standard nuclear power plant. KEPCO is also developing the SMART reactor, a PWR type SMR.

Commentary: In addition to domestic construction, KEPCO has become a strong contender in the export market. The U.A.E. order is significant.

9.17 Mitsubishi Heavy Industries

Ownership	Public TOY:7011
Location	Mitsubishi Juko Bldg. 2-16-5, Konan, Minato-ku TOKYO, TKY 108-8215 Japan
Internet Address	http://www.mhi.co.jp
Market Cap	$18.20 billion
2012 Revenue	$32.11 billion

Mitsubishi Heavy Industries, Ltd. is a Japan-based manufacturing company with primary businesses in marine vessels, aerospace, structures, and power. Its nuclear business is organized within the Nuclear Energy Systems headquarters, with divisions focused on the design and development of their PWR, nuclear fuel, nuclear fuel cycle system components and advanced reactor plants (FBR, HTGR, fusion). MHI has domestic and overseas nuclear subsidiaries: Mitsubishi FBR Systems, Inc.; Mitsubishi Nuclear Fuel Co., Ltd.; Mitsubishi Nuclear Energy Systems, Inc. (USA); and the ATMEA joint venture with AREVA in France.

MHI is developing the Advanced Pressurized Water Reactor (APWR) with Japanese, European and US versions; a FBR; and the ATMEA 1 reactor design jointly with AREVA.

9.18 NuScale Power

Ownership	Private
Location	6650 SW Redwood Lane Suite 210 Portland, OR 97224
Internet Address	http://www.nuscalepower.com
Market Cap	n/a
2012 Revenue	n/a

NuScale Power, Inc. (NuScale) is commercializing a 45 MWe LWR SMR module. A minimum of 6 modules comprise a unit; up to 12 modules can be deployed as a single unit. Each module has its own containment vessel and reactor system, as well as its own turbo generator. NuScale is targeting cogeneration and process steam/heat applications as well as electricity generation.

Commentary: NuScale has had difficulties in raising capital, however early in 2012, Fluor Corporation took a controlling interest. The company was not selected for a grant in the first round of DOE SMR funding and is waiting to reapply.

9.19 Pebble Bed Modular Reactor Ltd.

Pebble Bed Modular Reactor Ltd (PBMR) is currently in a "Care and Maintenance" state until mid-2013 when investors will determine the next course of action. In the meantime, PBMR has minimal employees and all work is suspended. Until the suspicion occurred in 2010, PBMR had been developing a helium cooled high temperature reactor system with online fueling and graphite moderation. The fuel consists of billiard ball sized "pebbles" that contain graphite and uranium oxide. The target module had a capacity of 165 MWe, however the company's new direction may seek a smaller design focused on process heat and other applications, rather than electricity.

9.20 Russian State Nuclear Organizations

Although terminology and trappings give Russian nuclear power organizations a Western corporate "look," at their core they are the inheritors of the state monopolies that existed in the Soviet Union. In 2007 and 2008 many state corporations were reorganized into Joint Stock Corporations (JSC). Figure 51 provides a rough organizational chart of the Russian JSCs involved in commercial nuclear power.

Figure 51 Organizational Structure Russian State Corporations and Joint Stock Corporations

<table>
<tr><td colspan="6">State Nuclear Energy Corporation Rosatom</td></tr>
<tr><td colspan="5">Commercial Nuclear Power</td><td>Other</td></tr>
<tr><td colspan="6">Atomic Energy Power Corporation JSC (AtomEnergoProm) (AEP)</td></tr>
<tr><td>AtomEnergoMash JSE</td><td>Rosenergoatom Concern JSC</td><td>Atomredmetzoloto (ARMZ) Uranium Holding JSC</td><td>Techsnabexport (TENEX)</td><td>TVEL JSC</td><td>Nizhny Novogrod, Moscow and St. Petersburg NPP JSCs</td></tr>
</table>

Source: Worthington Sawtelle LLC

9.20.1 Rosatom

Rosatom is the holding corporation for all things nuclear in Russia. Its missions, in addition to commercial nuclear power, include nuclear defense, national laboratories and the Russian nuclear icebreaker fleet. Rosatom controls over 250 companies and entities on behalf of the state. The government is considering privatization of the commercial divisions but this has not happened yet.

9.20.2 AtomEnergoProm

Ownership	State Owned
Location	JSC Atomenergoprom Bolshaya Ordynka Str., 24 119017, Moscow Russian Federation
Internet Address	http://www.atomenergoprom.ru
Market Cap	n/a
2011 Revenue	$ 12.49 billion

AtomEnergoProm (AEP) provides uranium production, engineering, design, reactor construction, power generation and research. It covers all elements of the fuel cycle with the exception of reprocessing and spent fuel storage.

Figure 51 identifies the AEP subsidiaries:

- TVEL JSC which produces and supplies nuclear fuel to Russian NPPs and abroad, including to the EU and the CIS. Has a 17% share of the global nuclear fuel market
- TENEX JSC, which provides enrichment services and exports nuclear materials, including enriched uranium, to foreign countries. Has a 40% share of the global enrichment market
- ARMZ Uranium Holding JSE (formerly Atomredmetzlolto) which is engaged through a number of subsidiaries in the extraction of uranium and other precious metals from the territory of the Russian Federation and Kazakhstan and plans to expand its activities abroad.
- Rosenergoatom Concern JSC, which is the operator of all Russian NPPs
- Atomenergomash JSC, which is the holding company for a significant number of enterprises that specialize in manufacturing of machinery and equipment for the nuclear and power energy industries, including turbines, steam generators, and pipelines
- NPP JSCs include a number of separate JSCs that both operate specific NPPs and participate in the operation of some export NPPs.

9.21 Toshiba

Ownership	Public TYO:6502
Location	Toshiba Bldg. 1-1-1, Shibaura, Minato-ku TOKYO, TKY 105-8001 Japan
Internet Address	http://www.toshiba.co.jp
Market Cap	$ 18.63 billion
2011 Revenue	$ 66.8 billion

Toshiba Corporation (Toshiba) is a leading manufacturer and marketer of electrical and electronic products. It provides digital consumer products, electronic devices and components, power systems, industrial and social infrastructure systems, and home appliances. Toshiba also designs, manufactures and sells nuclear power generation systems, thermal power generation systems and hydroelectric power generation systems.

Toshiba is the number one NPP supplier in Japan with a 34% market share, all BWRs. Toshiba acquired a 20% interest in Westinghouse, allowing it to offer PWR market products as well. The company is now producing the ABWR, with two units operating in Japan and several slated in the international market. It is also developing its "4S" product, a SMR that consists of a sodium cooled fast reactor with the capacity of 45 MWe.

9.22 URENCO

Ownership	Limited Corporation: 1/3 shares held by UK government, 1/3 by Netherlands government; 1/3 by German utility consortium Uranit
Location	URENCO Court, Sefton Park, Bells Hill, Stoke Poges, Buckinghamshire, SL2 4JS, UK
Internet Address	http://www.urenco.com
Market Cap	n/a
2011 Revenue	$ 1.73 billion

URENCO provides uranium enrichment services using its own proprietary centrifuge technology; URENCO has a 29% share of the enrichment market. It provides those services through four plants in the U.K., Germany, the Netherlands and the U.S. It also owns 50% of Enrichment Technology Company Limited, a joint venture with AREVA.

9.23 Westinghouse Electric Company LLC

Ownership	Toshiba subsidiary
Location	4350 Northern Pike Monroeville, PA 15146-2886 USA
Internet Address	http://www.westinghousenuclear.com
Market Cap	n/a
2011 Revenue	n/a

Westinghouse Electric is the surviving business unit of the original Westinghouse Corporation. The company now is exclusively nuclear focused and provides fuel, services, technology, plant design, and equipment for the commercial nuclear electric power industry. It operates four product lines: Nuclear Automation, which provides instrumentation and control systems to operating plants; Nuclear Fuel, which produces finished fuel assemblies for PWRs, BWRs, VVERs, and AGRs; Nuclear Power Plants focused on new generation PWRs and component manufacturing; and Nuclear Services that assist operating NPP staff. Westinghouse Electric estimates that almost 50% of nuclear power plants around the world and about 60% of US plants are based on the company's technology.

9.24 Key Firms No Longer Participating

Over the last 3 years, a number of firms that had traditionally played major roles in commercial nuclear power have either been acquired or dropped out of the business. These include:

- British Nuclear Fuels
- Framatome
- RWE AG
- Siemens

10 ABBREVIATIONS

ABB-CE	Asea Brown Boveri - Combustion Engineering
ABWR	Advanced Boiling Water Reactor
ACR	Advanced CANDU Reactor
ACRS	Accelerated Cost Recovery System
AEA	Atomic Energy Act
AEC	U.S. Atomic Energy Commission
AECL	Atomic Energy Canada, Limited
AEMC	Alternative Emergency Management Centre
AEO	Annual Energy Outlook
AFR	Advanced Fast Reactor
AFUDC	Allowance for funds used during construction
AGR	Advanced Gas Cooled Reactor
AHTR	Advanced High Temperature Reactor
ALWR	Advanced Light Water Reactor
AMIGA	All Modular Industry Growth Assessment Modeling System
ANL	Argonne National Laboratory
ANP	Advanced Nuclear Power
APWR	Advanced Pressurized Water Reactor
ASE	AtomStroyExport

ASM	Annual Survey of Manufactures
BNFL	British Nuclear Fuels, Ltd.
BOE	Barrel of oil equivalent
Btu	British thermal unit
BWR	Boiling Water Reactor
c/kWh	Cents/kilowatt-hour
CAAA	Clean Air Act Amendments
CAGR	Compound Annual Growth Rate
CANDU	Canada Deuterium Uranium
CAPM	Capital asset pricing model
CCAPM	Consumption-based Capital Asset Pricing Model
CCGT	Combined Cycle Gas Turbine
CEA	Commissariat a l'Energie Atomique
CF	Capacity Factor
CFB	Circulating Fluidized Bed
CFR	Code of Federal Regulations
CHP	Combined Heat-and-Power
CNSC	Canadian Nuclear Safety Commission
CO2	Carbon Dioxide
COGEMA	COGEMA Nuclear Fuels
COL	Construction and Operating License
CPI-U	Urban Consumer Price Index

CRDM	Control rod drive mechanism
CTBT	Comprehensive Test Ban Treaty
D&D	Decommissioning and decontamination
DOE	U.S. Department of Energy
EDF	Electricite de France S.A.
EIA	Energy Information Administration
ENEA	European Nuclear Energy Agency
ENSI	Swiss Federal Nuclear Safety Inspectorate
ENSREG	European Nuclear Safety Regulators Group
EPA	U.S. Environmental Protection Agency
EPR	European Pressurized Reactor
ERDA	Energy Research and Development Authority
ESBWR	European Simplified Boiling Water Reactor
ESC	Emergency Support Centre
EURATOM	European Atomic Energy Community
F-ANP	Framatome Advanced Nuclear Power
FBR	Fast Breeder Reactor
FED	Fuel Element Debris
FERC	Federal Energy Regulatory Commission
FNR	Fast Neutron Reactor
FRAM	Framatome Advanced Nuclear Power
GA	General Atomics

GCR	Gas Cooled Reactor
GDP	Gross Domestic Product
GE	General Electric
GTCC	Gas Turbine Combined Cycle
GT-MHR	Gas-Turbine Modular Helium Reactor
GW	Gigawatt
GWh	Gigawatt hour
HLW	High-level waste
HRSG	Heat Recovery Steam Generator
HTGR	High Temperature Gas Reactor
HWLWR	Heavy-Water-Moderated, Light-Water-Cooled
IAEA	International Atomic Energy Agency
IDC	Interest during construction
IEA	International Energy Agency
ILW	Intermediate level waste
IRIS	International Reactor Innovative and Secure
IRR	Internal rate of return
JAEA	Japan Atomic Energy Agency
JAERI	Japan Atomic Energy Research Institute
kg	Kilogram
kgHM	Kilograms of heavy metal
KgU	Kilogram of uranium

kW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelized cost of electricity
LLW	Low level waste
LMCR	Liquid Metal Cooled Reactor
LMFBR	Liquid Metal Fast Breeder Reactor
LWGCR	Light Water Gas Cooled Reactor
LWGR	Light Water Cooled Graphite Reactor
LWR	Light-water reactor
MACRS	Modified Accelerated Cost Recovery System
METI	Ministry of Economy, Trade and Industry
MHR	Modular helium reactor
MITI	Ministry of International Trade and Industry
MMBtu	Thousand Thousand British Thermal Units
MOX	Mixed-oxide
MT	Metric ton
Mtu	Metric ton of uranium
MW	Megawatt
MWh	Megawatt hour
NEA	Nuclear Energy Agency
NEI	Nuclear Energy Institute
NFWA	Nuclear Fuel Waste Act

NISA	Nuclear and Industrial Safety Agency
NNSA	National Nuclear Safety Administration
NOX	Nitrogen oxide
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
O&M	Operation and Maintenance
OECD	Organization for Economic Cooperation and Development
PBMR	Pebble Bed Modular Reactor
PDP	Preliminary Decommissioning Plan
PHWR	Pressurized Heavy Water Reactor
PLEX	Plant Life Extension
PRIS	Power Reactor Information System Database
PRISM	Power Reactor Innovative Small Module
PUREX	Plutonium uranium extraction – Plutonium uranium oxidation
PWR	Pressurized water reactor
R&D	Research and development
RBMK	Reaktor Bolshoy Moshchnosti Kanalniy
SBWR	Simplified Boiling Water Reactor
SMR	Small Modular Reactor
SNF	Spent nuclear fuel
SO2	Sulfur dioxide
SPF	Spent Pool Fuel

SWU	Separative work units
TEPCO	Tokyo Electric Power Company
TMI	Three Mile Island
UK	United Kingdom
UKAEA	United Kingdom Atomic Energy Authority
UO2	Uranium Oxide
US	United States
VHTR	Very High Temperature Reactor
VVER	Voda-Vodyanoi Energetichesky Reaktor
W	Watt
WAC	Weighted average costs
WACC	Weighted average cost of capital
WAGR	Windscale's Advanced Gas cooled Reactors
WEO	World Energy Outlook
WETO	World Energy, Technology, and Climate Policy Outlook
Wh	Watt hours
WNA	World Nuclear Association
WWER	Water Cooled Water Moderated Power Reactor