



# Nuclear Power Economics and Project Structuring

2017 Edition

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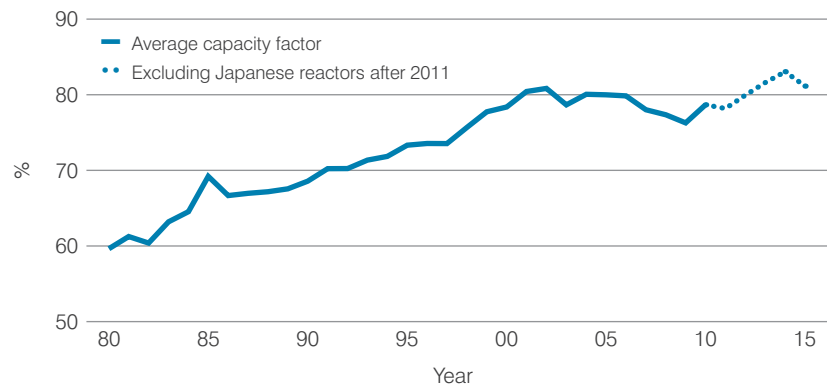
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# Executive Summary

Nuclear power is an economic source of electricity generation, combining the advantages of security, reliability, virtually zero greenhouse gas emissions and cost competitiveness. Existing plants function well with a high degree of predictability. The operating costs of these plants are usually very competitive, with a low risk of significant operating cost inflation. The capacity factors of existing plants are high (over 90% in the US). Nuclear power plants provide electricity when it is needed. Plants are now expected to operate for 60 years and even longer in future.

Global nuclear capacity factor



Source: World Nuclear Association analysis based on IAEA PRIS data

The International Energy Agency (IEA) sees the global demand for electricity growing at 1.9% per year in the period to 2040. Given this demand environment, coupled with the desire to reduce the greenhouse gas emissions from the generation of electricity, the IEA projects growth of an annualised 2.3% in nuclear generation over that period<sup>1</sup>.

Nuclear competes well with rival generation technologies as is indicated by the assessment of the Organisation for Economic Cooperation and Development (OECD) - Nuclear Energy Agency (NEA) & IEA<sup>2</sup>, although the level of competitiveness does vary at different discount rates and between countries. In the pivotal Chinese market, nuclear has a lower levelised cost of generating electricity (LCOE) than any other technology barring hydro.

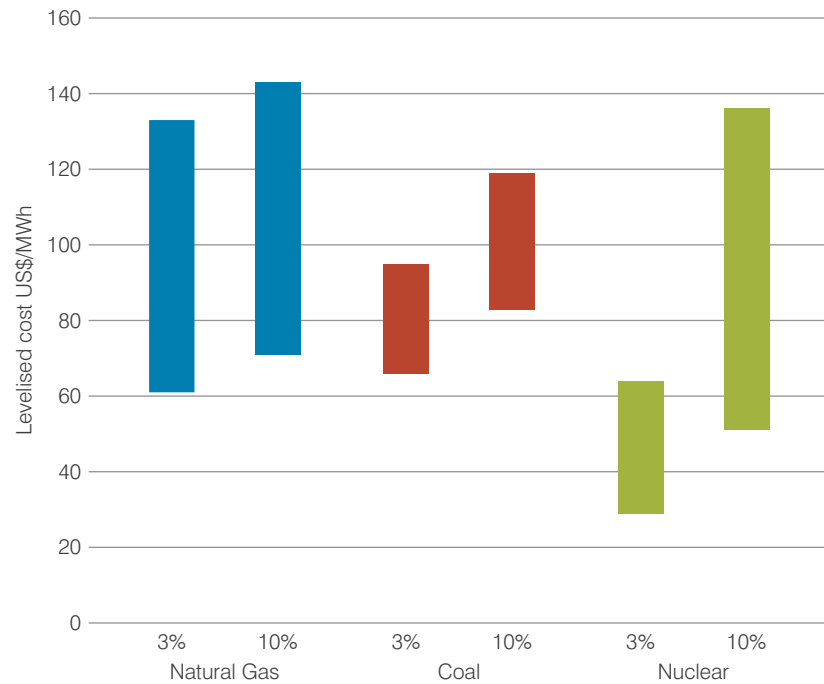
In some electricity markets, especially those that are deregulated, subsidised intermittent renewable generation and gas-fired generation not penalised by carbon costs are creating economic difficulties for all baseload generators, including nuclear. Where the system and external costs of competitor technologies are added to the plant-level costs, the competitiveness of nuclear is enhanced. In order for these advantages of nuclear to be fully realised, policymakers need to address fundamental market design problems. In some countries, deregulated markets are being partially re-regulated in order to place monetary value on the qualities that nuclear power brings (reliability, security, zero emissions).

The economics of new nuclear plants are heavily influenced by their capital cost, which accounts for at least 60% of their levelised cost of electricity. Interest charges and the construction period are important variables for determining the overall cost of capital. The escalation of nuclear capital costs

<sup>1</sup> World Energy Outlook 2016, International Energy Agency. Both growth rates are for the 'New Policies Scenario'.

<sup>2</sup> Projected Costs of Generating Electricity 2015 Edition, OECD-NEA&IEA, 2015

Levelised cost of generating baseload electricity by technology in OECD countries 2015 (US\$/MWh, 3% and 10% discount rates)



Source: *Projected Costs of Generating Electricity 2015 Edition, OECD-NEA & IEA*

in some countries, more apparent than real given the paucity of new reactor construction in OECD countries and the introduction of new designs, has peaked in the opinion of the IEA<sup>3</sup>. In countries where continuous development programmes have been maintained, capital costs have been contained and, in the case of South Korea, even reduced. Over the last fifteen years global median construction periods have fallen. Once a nuclear plant has been constructed, the production cost of electricity is low and predictably stable.

Economic risks relate to a range of factors including: the regulation of electricity markets and the existence of competitor technologies that are subsidised or fail to account for external costs; nuclear safety regulation; project construction performance; operational performance; and political risk. Some of these risks can be managed by the reactor engineering, procurement and construction contractors or the utility but others are outside the control of the industry. In practice, current nuclear investment is undertaken in broadly regulated markets largely via utility balance sheet financing where the operator can offset the risks of any given generating technology against those of other assets in their portfolio. Most electricity markets are regulated and characterised by dominant state-owned companies.

<sup>3</sup> Projected Costs of Generating Electricity 2015 Edition (p19), International Energy Agency and OECD-Nuclear Energy Agency

# 1

## Introduction

This report updates the previous report of the same name published in 2012, which itself drew on work in earlier reports. The principal changes to this report concern: additional material on nuclear capital costs, in particular evidence that capital cost inflation has peaked and is in any case not a worldwide phenomenon; the impacts of competitor technologies, in particular renewables and gas-fired generation; and the challenges that deregulated electricity markets pose for nuclear. A new section on the systems costs of intermittent generation has been included.

All the information presented in the report has been taken from the publications of intergovernmental and governmental agencies, independent authors and universities.

There are two main aims of this report. Firstly, to highlight that new nuclear build is justified in many countries on the strength of today's economic criteria and, secondly, to identify the key risks associated with a nuclear power project and how these may be managed to support a business case for nuclear investment.

Many countries recognize the substantial role which nuclear power has played in satisfying various policy objectives, including energy security of supply, reducing import dependence and reducing greenhouse gas or polluting emissions. Nevertheless, as such considerations are far from being fully accounted for in liberalized or deregulated power markets, nuclear plants must demonstrate their viability in these markets on commercial criteria as well as their lifecycle advantages. Efforts are being made by policymakers in a number of countries to place a

monetary value on these other policy objectives in a way that can support nuclear power.

The research and development work undertaken in the early stages of nuclear power development was a challenging project for government research organizations as well as the industrial sector. The optimum technical solutions were progressively uncovered through multiple and various demonstration programmes developed in the 1950s and 1960s under government funding and, at the same time, by increasingly scaling up the reactor ratings to compete more easily with fossil fuels. Designs were mainly motivated by the search for higher thermal efficiency, the ability to stay online continuously and better utilization of uranium resources. The breakthrough in the commercialization of nuclear power was reached when unit ratings exceeded several hundreds of MWe in the mid-1960s.

Starting in the late 1980s, a number of governments moved away from direct regulation in electricity markets (e.g. government utilities or investor-owned utilities subject to rate-of-return controls) to various types of deregulated electricity industry approaches that typically include a competitive market-based generation sector. There are significant differences in the level and nature of regulation between countries but most remain characterised by high levels of regulation, either explicitly or implicitly. Electricity market liberalization itself comes in many guises, but the nuclear power industry recognizes that nuclear power projects must demonstrate that they are commercially viable projects that will attract investors. With nuclear energy's high capital cost and long development and

construction period, investors focus on ways in which risks can be managed and risk allocations optimized. The business case for nuclear ultimately depends on the structure of risk allocation between operators, investors, governments, suppliers and customers.

Although new nuclear power plants require large capital investment, they are hardly unique by the standards of the wider energy industry, where oil platforms and natural gas liquefaction facilities cost many billions of dollars. Projects of similar magnitude can be found in the building of new roads, bridges and other elements of infrastructure. Many of the risk-control and project management techniques developed for these projects can also be applied to building nuclear power stations.

Risks that are specific to nuclear plants are those surrounding the management of radioactive waste and used fuel and the liability for nuclear accidents. As with many other industrial risks, public authorities must be involved in setting the regulatory framework. The combined goal for policymakers seeking to incentivise nuclear must be public safety and a stable policy environment necessary for investment.

To support new build projects must be structured to reduce and share risks amongst key stakeholders in a way that is both equitable and that encourages each project participant to fulfil its responsibilities.

The information in this report is presented as follows:

Section 2 highlights the good economic performance of current nuclear plants.

Section 3 demonstrates the need for substantial new electricity generating capacity worldwide.

Section 4 examines the ability of new nuclear plants to compete.

Section 5 identifies the key risks of nuclear projects and how they may be mitigated.

Section 6 considers project structuring and the different ways of allocating risks.

Section 7 highlights the role of government in ensuring adequate electricity supply.

Section 8 examines the role of financing for major electricity infrastructure.



# 2 Economics of Current Plants

Low-cost baseload electricity supply has been a critical enabler of economic and social development and nuclear power has played a key role in delivering such supply for decades in many countries. The economics of nuclear are characterised by low and stable operating costs, resulting from the low proportion of fuel cost in the total cost structure, which have enabled nuclear plants to supply reliable, competitive and low carbon baseload power. Once built and commissioned, and assuming a good operational performance, nuclear power plants should be able to carry out this indispensable role for the long term.

## 2.1 Plant performance

With high fixed costs and low running costs, average electricity costs for nuclear plants fall substantially with increased output. It is therefore vital for nuclear operators to achieve high plant capacity factors<sup>4</sup>. Nuclear plants aim to operate continuously to achieve very low marginal and average costs.

With growing baseload electricity demand, capacity factors of nuclear plants around the world have increased by 10% since 1990, from 70% to 80%. In some countries, the

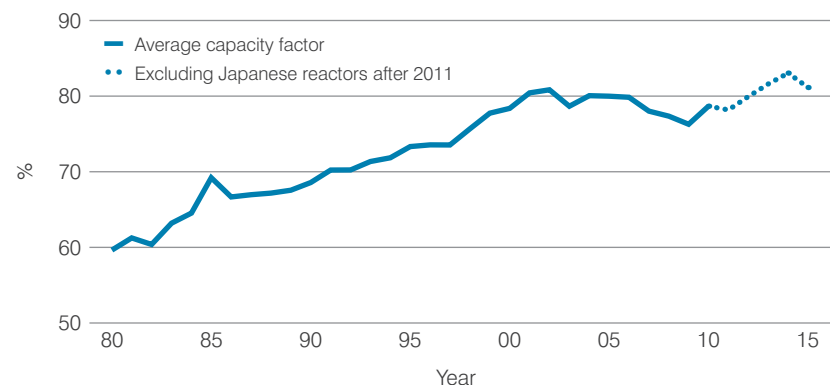
improvement is even more dramatic – for example, in the United States from 66% to 90%. Levels of 90% and above have also been achieved by plants in Europe and Asia for many years. Lower levels can be partly explained in France by the high share of nuclear power in the electricity mix and its use in load following.

The impact of higher capacity factors can be seen in the stability of the nuclear share of world electricity generation from the late 1980s. This was maintained at 16-17% until the early 2000s, despite few new plant openings, but rapid electricity demand growth in the developing world since then has meant that the share has now fallen to 11%.

## 2.2 Generating costs

Whilst there are many country-specific factors, it is possible to make some general statements about the trend of fuel and operations and maintenance (O&M) costs of nuclear plants: nuclear fuel costs have fallen over time due to lower uranium and enrichment prices together with new fuel designs allowing higher burn-ups, while O&M costs tend to be somewhat higher than for other thermal modes of generation.

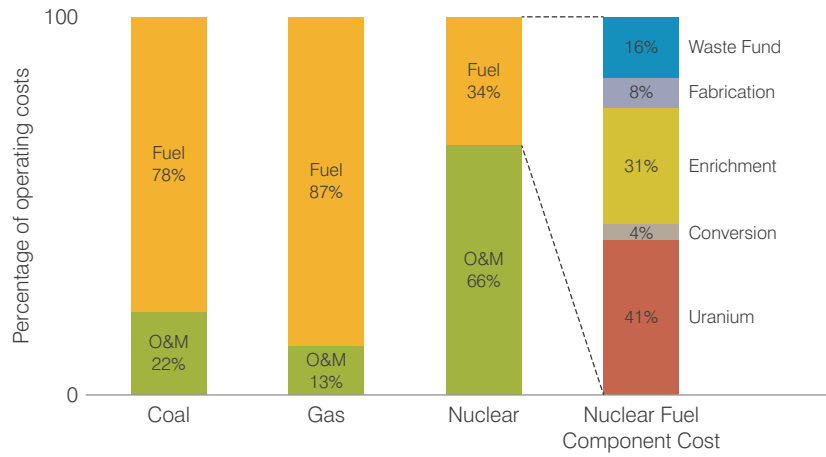
Figure 1: Global nuclear capacity factor



Source: World Nuclear Association analysis based on IAEA PRIS data

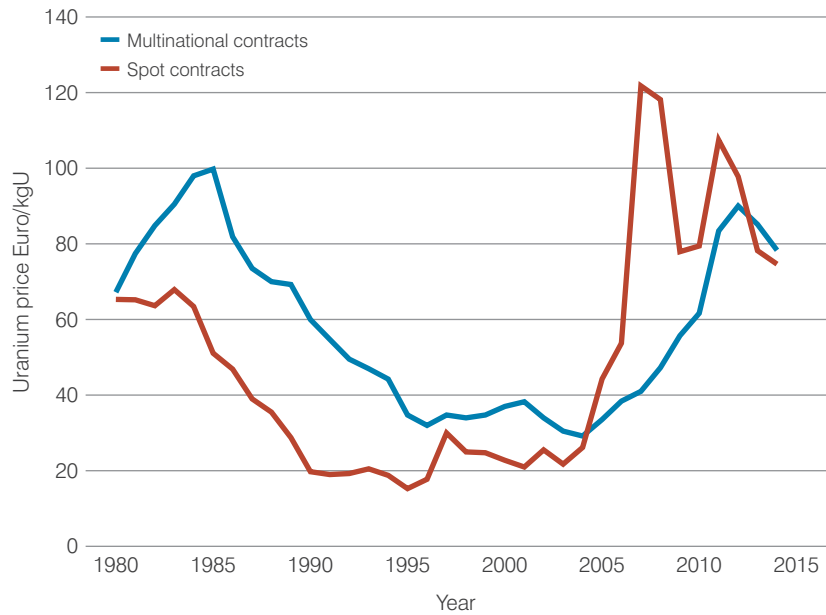
<sup>4</sup> The capacity factor is the ratio of the actual energy produced by a power plant in a given period, to the hypothetical maximum possible, i.e. running full time at rated power.

Figure 2: Breakdown of operating costs for nuclear, coal and gas generation



Source: Nuclear Energy Institute

Figure 3: EU uranium oxide prices 1980-2014



Source: Euratom Supply Agency

Nuclear fuel costs in the US have fallen from 1.46 cents per kWh in the mid-1980s to only 0.76 cents per kWh in 2014, which has included a mandatory element for used fuel management of 0.1 cents per kWh, paid into a central governmental fund. As can be seen in Figure 3, uranium prices can be volatile, but their impact on electricity costs is relatively minor as the uranium

cost is only a small fraction of the total operating cost (around 14%). In the case of both coal and gas plants, fuel prices fell to all-time lows in real terms in the late 1990s, as additional low cost reserves were brought into production. The discovery and exploitation of large quantities of unconventional shale gas has pushed electricity prices down further in the US.

Table 1. Average US nuclear production costs, 1985-2014, 2011 cents per kWh

	1985	1990	1995	2000	2005	2010	2014
O&M costs	2.21	2.37	1.96	1.59	1.44	1.57	1.64
Fuel costs	1.46	1.15	0.84	0.63	0.51	0.68	0.76
Total	3.67	3.52	2.80	2.22	1.95	2.25	2.40

Source: Federal Energy Regulatory Commission, Nuclear Energy Institute

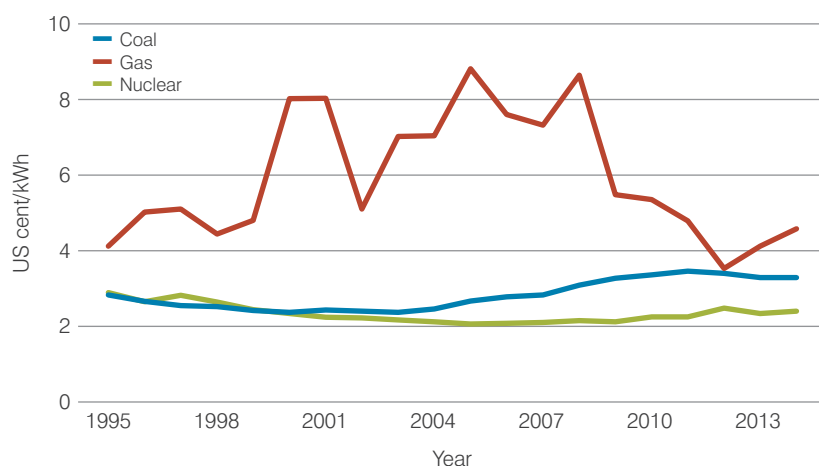
The fuel costs of operating nuclear plants are low and can only be beaten by plants that generate electricity without the need for fuel, such as hydro and other renewable technologies. In the US, average nuclear production costs<sup>5</sup> were 2.40 cents per kWh in 2014, the lowest of any thermal generation technology in that country. However, nuclear operating costs vary by plant and some nuclear plants in the US have not been able to cover these costs in the face of both very low cost gas, which has depressed power prices, and the increased revenue volatility resulting from intermittent renewable generation. This situation so far has been unusual, so in the EU for example, production costs remain much lower for nuclear generation than for coal and gas plants. However, the continued increase of heavily subsidised renewable generation in the EU threatens to

undermine the economics of nuclear in that continent too. In some power networks, for example the PJM<sup>6</sup> area in the US and in the UK, the difficulties caused by intermittent generation are recognised and the value of reliable power generation is rewarded by the development of capacity markets.

The trend in nuclear production costs was strongly downwards in the US in real terms from the mid-1980s until 2005 but has since then started to increase. The split between O&M and fuel costs is shown in Table 1.

O&M costs include both fixed (occurring irrespective of the level of plant operation) and variable elements. In Europe, nuclear production costs of as low as 1 Euro cent per kWh have been achieved in the past in both Finland and Sweden. The balance between O&M,

Figure 4: US electricity production costs by fuel type 1995-2014



Source: Federal Energy Regulatory Commission, Nuclear Energy Institute

<sup>5</sup> Production costs, also known as operating costs, include fuel and O&M costs.

<sup>6</sup> The PJM transmission area of the north and east of the USA is the largest electricity wholesale market in the world

fuel and used fuel (including waste management) costs depends very much on the age of the plant, with a tendency for O&M to rise as plants get older but for used fuel charges to reduce as the accumulated fund dedicated to this becomes mature. In Germany, used fuel charges tend to be higher so generating costs are usually around 1.4 Euro cents per kWh.

Nuclear operating costs could change further in certain ways:

- The decline in the price of uranium oxide concentrate ( $U_3O_8$ ) will probably be reversed at some point with the future expected demand increases, thereby encouraging new mine investment. Fuel service costs, which account for more than half the total fuel cost, could be cut slightly further thanks to technological progress (e.g. higher burn-up fuel) as well as through the implementation of innovations (e.g. in enrichment and used fuel management).
- O&M costs are particularly influenced by regulatory requirements, which may vary (depending on circumstances) from augmented in-service inspection and additional fire protection features, to enhanced operator training and reinforced security measures. Increased requirements have resulted from the safety reassessments following the Fukushima accident in 2011.

## 2.3 Capacity uprates

Uprating the power output of nuclear reactors is recognized as a highly economic source of additional generating capacity. The refurbishment of the plant turbine generator combined with utilizing the benefits of initial margins in reactor designs, digital instrumentation and control technologies and investment in other enhanced generating capacity can increase plant output

by up to 15-20%. There are many examples of this throughout the world, but it has been a particular focus in Sweden, the United States and East European countries. In the United States, up to 3.1 GWe of additional capacity was approved via this route between 2005 and 2014. Capacity uprates reduce generating costs by spreading the fixed O&M costs over a higher output.

## 2.4 Licence extensions

In those cases where plant licences are limited in time, owners are obtaining extensions from their regulatory authorities where they can justify longer operational lives for their plants. This process is most visible in the United States where 81<sup>7</sup> of the 100 units have already been granted a 20-year extension to their operating licences to operate until 60 years and others are in the process of applying. The NRC is currently preparing to consider licence extensions to 80 years.

The licence extension process has been more predictable and less expensive than many commentators originally anticipated. For companies in the private sector, extending the design lifetime of plants may also allow them to spread decommissioning charges over a longer period than originally planned and further improve profitability. Nevertheless, the substantial capital expenditure associated with longer operational lifetimes may still force closure on some current nuclear plants that cannot justify the upfront costs involved – especially for the smaller, older and inherently less efficient units. But in general, extension of the operational lifetimes of nuclear plants is economically attractive, so long as the political environment is supportive. For example, in Canada, Bruce Power is extending the operational lifetimes of

<sup>7</sup> As at October 2016

six of its reactors by 30-35 years at a cost of \$13 billion, which compares favourably with the cost of alternative generation possibilities.

In France, a figure for the 58 nuclear units of up to €10 billion in additional costs has been announced to deploy post-Fukushima modifications and comply with the requirements of the safety authority. However, these costs have to be seen in the context of the need to invest heavily anyway in areas such as upgraded IT systems and the maintenance of heavy components required to extend the operating lifetimes of these units beyond 40 years. The total cost of this work is estimated at €50 billion, which includes the additional €10 billion, and will have only a minimal impact on the levelised cost of nuclear electricity over the next 20 years of operation. Extending the operating lifetimes of the existing reactors has been judged by the national audit body as the most economical way to continue the long history of low power prices in France.

## 2.5 Political risk

A significant threat to the costs of the current operating fleet of reactors in some countries is coming from the imposition of additional taxes on nuclear generation, arguably to penalise the perceived excessive profits supposedly earned by their owners. For example, in 2012 there were nuclear-specific taxes of €5/MWh in Belgium, €6.7/MWh in Sweden<sup>8</sup> and €145/gof fissile fuel (equivalent to €15/MWh) in Germany. The effect of these taxes has been to advance the closure dates of reactors in Germany (Grafenrheinfeld), Spain (Garona) and Sweden (Oskarshamn

1&2 and Ringhals 1&2). In countries where the threat of such additional nuclear-specific taxes is significant, this will negatively affect investor appetite for new nuclear plants and even for operating lifetime extensions.

Political risk can take a number of forms apart from nuclear taxation. For example, in Japan the restart of the reactors currently offline following the 2011 Fukushima accident is subject to decisions by the Japanese courts; in France the premature retirement planned for the Fessenheim reactors has resulted from negotiations between political parties and in Germany the decision to advance the phase-out of nuclear soon after the Fukushima accident was reported to be the result of an electoral calculation by the governing party.

## 2.6 Conclusions

The overall picture for current nuclear plants is that they are operating more efficiently than in the past and unit operating costs are low relative to those of alternative generating technologies. More output is being achieved from each reactor through improved performance and capacity uprates; their operation should continue for many years in the future, backed by the necessary investment in refurbishment. These improvements have now become routine and will be integrated into the construction of new nuclear plants.

The political risk facing the economic functioning of nuclear in a number of countries has increased with the imposition of nuclear-specific taxes that in some cases have deprived operators of the economic incentive to continue to operate existing plants.

<sup>8</sup> An agreement has been reached by the main political parties in Sweden to phase out this tax. The effect of this agreement on the expected closure dates of Oskarshamn 1&2 and Ringhals 1&2 is unclear as of October 2016.

# 3 Market Potential for Electricity Generation to 2035

Global electricity production and consumption increased at about 2.6% per annum over the period 1990-2013 but many forecasters see this rate of increase falling in the future. For example, the International Energy Agency's<sup>9</sup> (IEA) New Policies Scenario projects global electricity demand to increase by 1.9% per annum in the period 2014-2040. Non-OECD countries are responsible for almost all this growth. In China for example, electricity consumption should have increased 80% by 2040. In most OECD countries, policies aimed at lowering demand growth rates are being implemented as are those that will shift the balance of supply towards those technologies deemed to be favourable from an environmental viewpoint.

Within the electricity sector, a large amount of investment in new generating capacity will be required by 2040 in order to satisfy both the projected 64% increase of demand<sup>10</sup> and the need to replace a large number of plants that will be retired over this period. The economic challenge for utilities of building new nuclear plants is much lower in the face of a rapidly growing rather than a static or declining electricity demand; in the latter case, new plants have to displace existing plants whose capital costs are often fully amortised and can therefore remain profitable even at low electricity prices.

## 3.1 Electricity sector investment requirements

According to the IEA<sup>11</sup>, investment in power generating plants of all types in the period 2014-2035 will cost a cumulative \$9.5 trillion in the New Policies Scenario. Nuclear is projected to account for \$1061 billion of this

total, which represents investment in about 300 GWe of new capacity, split \$389 billion in the OECD countries and \$672 billion in the non-OECD countries. It should be noted that in arriving at these estimates the assumed investment cost of new nuclear plants in the US, EU and China rises by 10-40%. Given that the IEA assumes most of this investment will take place in regulated markets, government policy will play a critical role in attracting finance.

## 3.2 The potential position of nuclear power – the International Energy Agency view

A consequence of so much of the new generating capacity being fossil-fired in the New Policies Scenario is that world carbon emissions from the electricity sector are set to carry on increasing in the period to 2040. The 450 Scenario has lower electricity demand growth and also substantial technology shifting in favour of low carbon technologies such as nuclear; the scenario projects 642 GWe of nuclear capacity worldwide in 2030 and 820 GWe in 2040. The IEA scenarios derive from a model that amongst other things assumes that the costs of renewable power sources tend to fall as the technologies mature, whereas the costs of nuclear power, which is already a mature technology, continue to rise. Both of these assumptions are questionable (see Figure 5 and the discussion in Chapter 4).

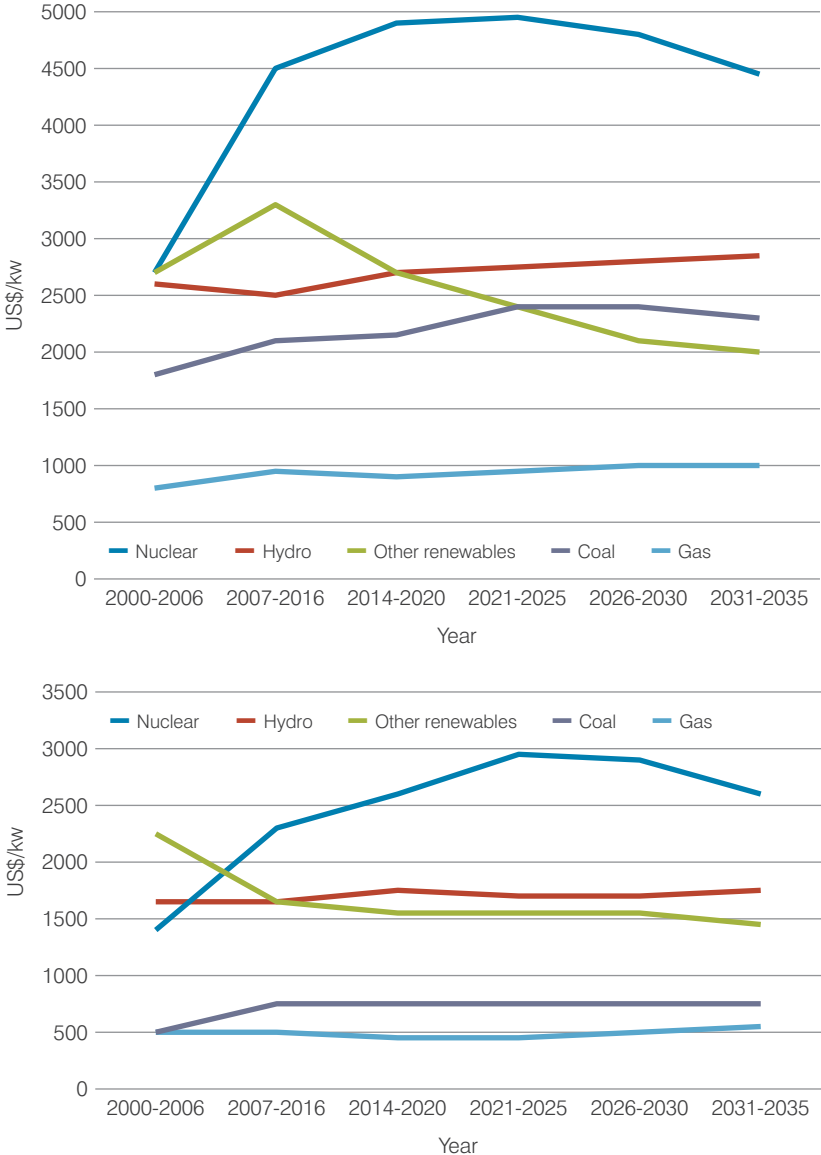
The IEA scenarios effectively drop out of a wider energy model of the world, building in all the likely generation technologies. One development is that the IEA, which was previously over-pessimistic about

<sup>9</sup> *World Energy Outlook 2016*, International Energy Agency

<sup>10</sup> As projected by the IEA for its New Policies Scenario in the *World Energy Outlook 2016*.

<sup>11</sup> *World Energy Investment Outlook*, International Energy Agency, 2015

Figure 5: Average annual unit investment cost in power plants by type in the New Policies Scenario, OECD countries (top) and China (below)



Source: International Energy Agency, World Energy Investment Outlook, 2015

Table 2. IEA nuclear capacity scenarios for 2030, GWe gross

IEA 2016	New Policies	520
	Current Policies	488
	450	642

Source: IEA (2016)

current reactors shutting down, now recognizes that they are generally performing very well in economic terms and operating periods are generally being extended, unless there are political impositions on this process (as in Germany).

Projected to 2050, the IEA's 2 Degree Scenario<sup>12</sup> (an extension of its 450 Scenario which is described in the World Energy Outlook) includes a nuclear energy component of 930 GWe (sufficient to meet 17% of world electricity demand). Given that this scenario relies in part on an ambitious increase in capacity from renewable energy sources and fossil-fuelled power plants with carbon capture and storage, and that either of these generating segments could fall short, the World Nuclear Association is promoting a target whereby 25% of electricity is generated by nuclear. To reach this level by 2050 would require 1000 GWe of new nuclear capacity.

Whilst this goal is certainly ambitious, it can be delivered if the nuclear construction performance that was achieved in the 1970s and 1980s is repeated.<sup>13</sup>

### 3.3 Conclusions

Even when ignoring all environmental considerations, it is clear that the extent of the requirement for new generating capacity affords nuclear an opportunity for continued good growth prospects. Should governments implement policies to incorporate the external costs of fossil fuel burning and allocate system costs to those generators that incur them, the economic benefits of nuclear power would become more visible to potential investors. The key to grasping this opportunity is undoubtedly keeping the economics attractive, both with the current stock of reactors, where the case has already been made strongly, and now with new nuclear build programmes.

<sup>12</sup> *Energy Technology Perspectives 2015*, International Energy Agency, and *Technology Roadmap Nuclear Energy 2015 Edition*, Nuclear Energy Agency and International Atomic Energy Agency

<sup>13</sup> *Energy Harmony on a Major Scale*, *Nuclear Engineering International*, 26 April 2016



# 4

## Economics of New Plant Construction

### 4.1 Capital costs

The overall economics of new nuclear plants are dominated by their capital costs. In the assessment of new capacity, the studies quoted below show that capital costs including accrued interest account for around 65-85% of the levelised cost of a new nuclear plant<sup>14</sup>. For combined cycle gas turbine (CCGT) plants, usually around 20% of the levelised costs are accounted for by plant capital requirements, with most of the remainder being fuel requirements. For renewable electricity projects, the capital cost element can be as high as 90% because there is no fuel cost to using wind or sunlight as energy sources.

The importance of these very different cost schedules rises with the rate of interest levied. When interest rates are high, projects with high initial capital costs, such as nuclear, are disadvantaged in comparative financial appraisals. However, interest rates in OECD countries have been in decline since the 1980s and today's very low rates are expected to persist for some time; indeed, some economists argue that these countries have entered an era of low interest rates<sup>15</sup>. Once capital-intensive power plants are completed, the capital costs and accrued interest must be recovered through a long operating lifetime with fuel and O&M costs well below the prevailing electricity price. This has been the general experience with nuclear plants.

Capital costs are incurred while the generating plant is under construction and include expenditure on the necessary equipment, engineering and labour. These are often quoted as 'overnight' costs, which are exclusive of interest accruing during the construction period<sup>16</sup>. They include engineering, procurement and construction (EPC) costs, owners' costs and various contingencies.

Once the plant is completed and electricity sales begin, the plant owner begins to repay the full investment cost, comprising the sum of the overnight costs and accrued interest charges. The price charged must cover not only these costs, but also annual fuel costs and expenditure on operation and maintenance (O&M) of the plant. A periodic charge for the eventual decommissioning of the plant should also be made, provided over the economic lifetime of the plant, however, this is likely to take place some 40 to 60 years after plant commissioning.

About 80% of overnight costs are EPC costs, with about 70% of these consisting of direct (physical plant equipment with labour and materials to assemble them) and 30% indirect (supervisory engineering and support labour costs with some materials) costs. The remaining 20% of overnight costs are contingencies and owners' costs (essentially the cost of testing systems and training staff). In addition, first-of-a-kind (FOAK) costs are a fixed cost of a particular design of reactor and can amount to very significant investments. The way in which these are added to overnight capital costs depends on how the vendor wishes to allocate these across its reactor sales.

### 4.2 Capital cost escalation

With relatively few nuclear plants constructed in North America and Western Europe over the past two decades, the amount of information on the costs of building modern nuclear plants is somewhat limited. An important source of information comes from the OECD's Nuclear Energy Agency (NEA) and the IEA, who periodically publish a joint report entitled *Projected Costs of Generating Electricity*, the most recent of which

<sup>14</sup> This broad range is taken from *Synthesis on the Economics of Nuclear Power*, William D'haeseleer, European Commission, November 2013. There is a discussion of the levelised cost methodology in the Appendix.

<sup>15</sup> For example, Laurence Summers, Bold reform is the only answer to secular stagnation, *Financial Times*, 7 Sept 2014

<sup>16</sup> For convenience, it is assumed that the plant is built literally overnight so that the capital costs can be separated from the financing costs.

Table 3. Capital cost estimates for a new nuclear reactor, \$/kWe

Country	Technology	Overnight cost A		Investment cost B	
		1998	2015	1998	2015
<b>Europe</b>					
Finland	BWR	2 256		2 672	
	PWR (EPR)		4 896		6 959
France	PWR	1 636		2 280	
	PWR (EPR)		5 067		7 202
<b>East Asia</b>					
Japan	BWR	2 521		3 146	
	ABWR		3 883		5 519
South Korea	PWR	1 637		2 260	
	ALWR		2 021		2 580
<b>North America</b>					
USA	PWR	1 441	4 100	2 065	5 828

A. Overnight cost includes owner's costs pre-construction and during construction and EPC costs.

B. Overnight cost plus imputed interest charges during construction at 10% a year.

Source: IEA, 2001, *Nuclear Power in the OECD*, OECD-NEA & IEA. *Projected Costs of Generating Electricity 2015 Edition*, OECD-NEA & IEA

appeared in September 2015. In this publication, the level of nuclear capital costs varies considerably by country – see Table 4 below which selects only those countries with new or recent nuclear programmes and may be compared with estimated costs in 1998 – and it is apparent that nuclear capital costs have escalated over time.

Insight into nuclear capital costs can also be gained from the NEA & IEA historical series of levelised cost estimates taken from previous editions of *Projected Costs of Generating Electricity* and which use the standard NEA & IEA assumptions. It is encouraging to note that, in view of the dominant influence of capital cost on the levelised cost of nuclear power, the series indicate that capital costs in some cases may have peaked or be close to peaking. Figures 6 and 7 show this data at both the 5% and 10% discount rates for a sample of countries that are currently constructing nuclear power

plants and for which the capital cost estimates should therefore be relatively well founded.

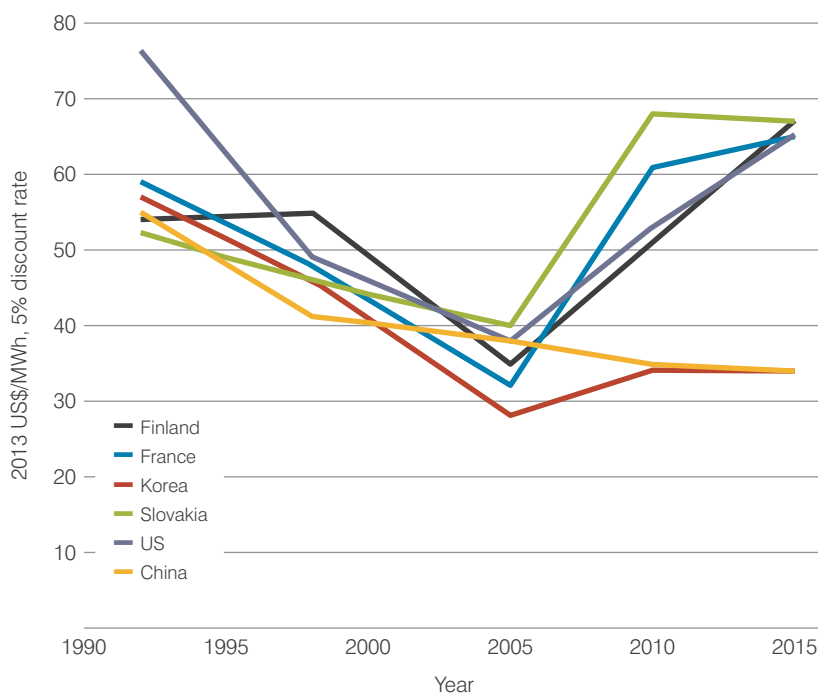
The French nuclear programme provides some further useful data on capital costs. The *Cour des Comptes*<sup>17</sup> has said that the costs of building nuclear power plants has increased over time from €1170/kWe (at 2010 prices) when the first of the currently operating 58 PWRs was built at Fessenheim (commissioned in 1978), to €2060/kWe when Chooz 1 and 2 were built in 2000 and a projected €3700/kW for the Flamanville EPR. It can be argued that a lot of this escalation relates to the much smaller magnitude of the programme by 2000 (compared with when the French were commissioning 4-6 new PWRs per year in the 1980s) and the failure to achieve series economies. The French programme also arguably shows that industrial organization and standardization of a series of reactors allowed construction costs, construction time and operating and

<sup>17</sup> *Les Coûts de la Filière Electronucléaire*, Cour des Comptes, 2012

maintenance costs to be brought under control. The total overnight investment cost of the French PWR programme amounted to less than €85 billion at 2010 prices. When

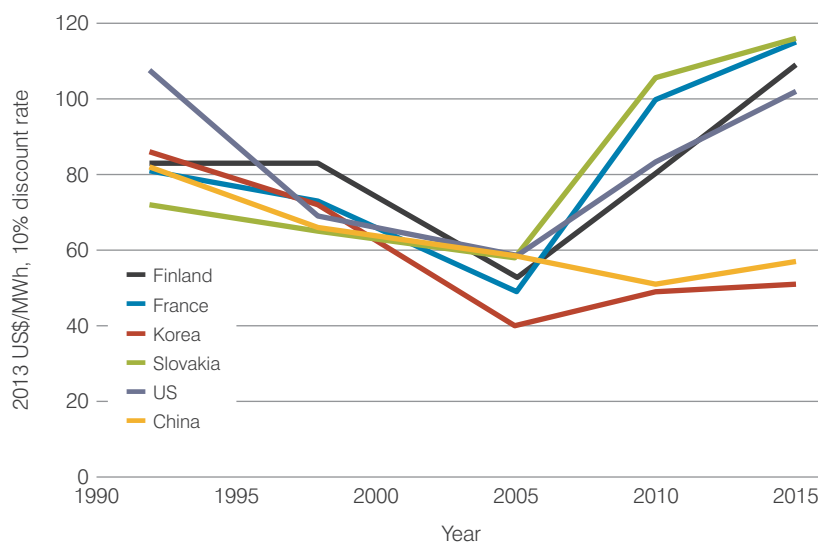
divided by the total installed capacity (63 GW), the average overnight cost is €1335/kW. This is much in line with the costs that were then provided by the manufacturers.

Figure 6: Historical Nuclear LCOEs (2013 US\$/MWh, 5% discount rate)



Source: IEA/NEA Projected Costs of Generating Electricity 2015 edition

Figure 7: Historical Nuclear LCOEs (2013 US\$/MWh, 10% discount rate)



Source: IEA/NEA Projected Costs of Generating Electricity 2015 edition

Table 4. Overnight Capital Cost trends for historical reactor programmes

Country	Construction start	Annualized rate of change in overnight capital cost
USA	1954-1968, 18 demonstration reactors	-14%
	1964-1967, 14 turnkey reactors	-13%
	1967-1972, 48 reactors completed pre-TMI	+23%
	1968-1978, 51 reactors completed post-TMI	+5 to +10%
France	1957-1966, 7 gas-cooled reactors	-17%
	1971-1991, 59 light-water reactors	+2 to +4%
Canada	1957-1974, 6 reactors	-8%
	1971-1986, 18 reactors	+4%
West Germany	1958-1973, 8 reactors	-6%
	1973-1983, 18 reactors	+12%
Japan	1960-1971, 11 imported reactors	-15%
	1970-1980, 13 foreign designs	+8%
	1980-2007, 30 domestic reactors	-1 to +1%
India	1964-1972, 5 imported reactors	-7%
	1971-1980, 5 domestic reactors	+5%
	1990-2003, 6 domestic reactors+ 2 imported	-1%
South Korea	1972-1993, 9 foreign designs	-2%
	1989-2008, 19 domestic reactors	-1%

Source: Lovering, Yip and Nordhaus, *op. cit.*

Most recently, Lovering, Yip and Nordhaus<sup>18</sup> have compared the historical nuclear cost experience in seven countries. It is evident that there is a wide range of experiences. The US has exhibited the most extreme cost inflation but with a very wide variation; for the US reactors in the lowest cost quartile there was very little cost inflation. There was high cost inflation in Germany and to a lesser extent in Canada but in India, France and Japan there was very little cost inflation. In South Korea, as indicated above, costs fell over time. The authors conclude that a range of different cost-drivers have been in play, many of them country-specific. The study gives some support for a cautious optimism that the gradual globalisation of the nuclear

supply chain could see a reduction of nuclear capital costs. Table 5 presents a summary of the results.

A number of possibilities have been identified<sup>19</sup> to reduce capital costs. For example,

- Replicating several reactors of one design on one site can bring major unit cost reductions.
- Standardization of reactors and construction in series will yield substantial savings over the series.
- Learning-by-doing is regarded as potentially a significant way of reducing capital costs, both through replication at the factory for components and at the construction site for installation.
- Larger unit capacities can provide economies of scale.

<sup>18</sup> *Historical construction costs of global nuclear power reactors*, J.Lovering, A.Yip, T.Nordhaus, *Energy Policy*, 91 (2016) 371-382

<sup>19</sup> *Reduction of Capital Costs of Nuclear Plants*, OECD-NEA, 2000.

<sup>20</sup> *The Economic Future of Nuclear Power*, University of Chicago, 2004

- Simpler designs, possibly incorporating passive safety systems, can also yield savings as can improved construction methods.
- A predictable and consistent licensing process should result in substantial savings. The key is to get the new plant up to safety and design requirements and running as quickly as possible, avoiding unexpected costs and starting at the earliest date to generate revenues.

It seems clear that the economics of nuclear power are much improved if a number of standard models can be ordered. The economies of series production then come into play and the fixed overhead costs of design and permitting involved in the supply of nuclear grade components and systems can be spread over a number of units. Possibly of equal importance is the reduction of construction and permitting risk that is associated with building a number of standardised units which allows greater predictability and reduced timelines for the development of additional plants.

The recent experience in Asia, particularly China and South Korea, has certainly reinforced the idea that series construction and standardisation can reap significant benefits in lowering capital costs. In both of these countries there has been a continuing programme of construction over 1998-2015 and it is of note that the escalation of costs shown in Table 4 and Figures 6 and 7 for Europe and North America were found not to be applicable to China and South Korea. For example, the ratio of French to Korean overnight costs increased from 1:1 in 1998 to 1:2.5 in 2015, a period in

which 11 Korean reactors were commissioned but only one in France. Given that this period was characterised by rising commodity prices and increased employee pay rates in Korea and China, the likely cost moderating influence of series economies is apparent.

### 4.3 Interest charges and the construction period

The construction time of a nuclear power plant is usually taken as the duration between the pouring of the first concrete and grid connection. In advance of construction, a substantial amount of time and effort is involved in planning and gaining approvals and licensing for the facility. Construction interest costs can be an important element of total capital costs but this depends on the rate of interest and the construction period. For a five-year construction period, a University of Chicago study (2004)<sup>20</sup> shows that the interest payments during construction can be as much as 30% of the overall expenditure. This increases to 40% if applied to a seven-year construction schedule, demonstrating the importance of completing the plant in line with the original schedule. The industry, however, believes that the construction period could be as low as four years. Where investors add a risk premium to the interest charges applied to nuclear plants, the impact on the financing charges will be substantial. The industry has to demonstrate that this premium is unwarranted, on the basis of consistent achievement of building plants on schedule and on budget.

There is evidence that this is starting to happen as Figure 8 shows. The median time taken to construct nuclear power plants has fallen in the last 15 years; it is the predominance of construction in East Asia and

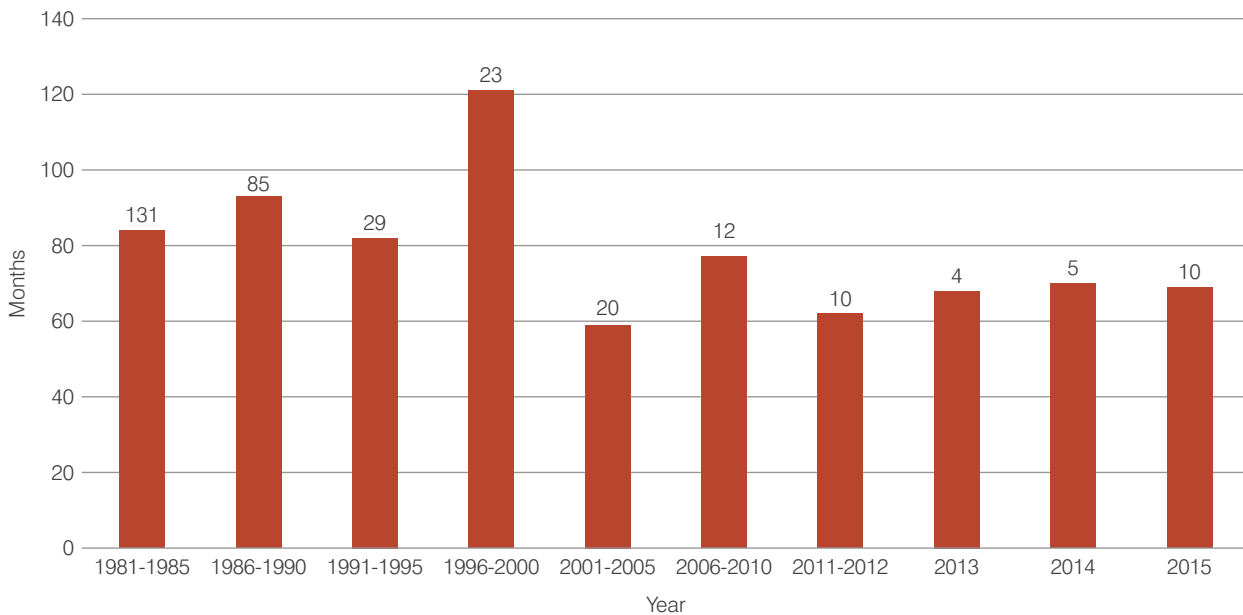
their successful adherence to initial construction schedules that largely accounts for this improved global performance. The key appears to lie in the replication of standardised reactor designs at a series of sites, and even more so at the same site. Figure 9 shows the construction time in months taken for the series of CPR-1000 reactors built between 2005-2016 in China and Figure 10 shows the construction performance for the series of P4 reactors built in France between 1977-1993. Whilst the French experience shows some upward drift in construction period, the record is not as bad as portrayed by critics of the industry.

### 4.4 Small modular reactors

Small modular reactors (SMRs) are characterised by electrical capacity of less than 300 MWe and designs that allow for modular construction. In recent years there has been a revival of interest in SMRs in the light of the limited economies of scale realised for large reactors. SMRs promise faster construction and quicker delivery of series economies that could offset their higher per kWe capital costs and thereby deliver levelised costs that are in line with those for larger reactors. Savings could come from the following considerations:

- Construction should be more rapid as a result of the use of factory produced units that can be transported relatively easily to the site and 'plugged in' to other units leading to lower site costs.
- More rapid construction should result in lower interest costs during the construction period.
- Quality control should be improved as a result of factory construction thereby leading to less construction, permitting and operating risk.

Figure 8: Global median reactor construction periods since 1981 and numbers of grid connections in each period



Source: IAEA, Power Reactor Information System

- The production of larger numbers of reactors should allow series economies to be delivered more quickly and certainly, so the learning-by-doing cost reductions would be realised more rapidly.
- Lower absolute plant capital requirements that could result in lower utility leverage and thus lower premia on utility debt.

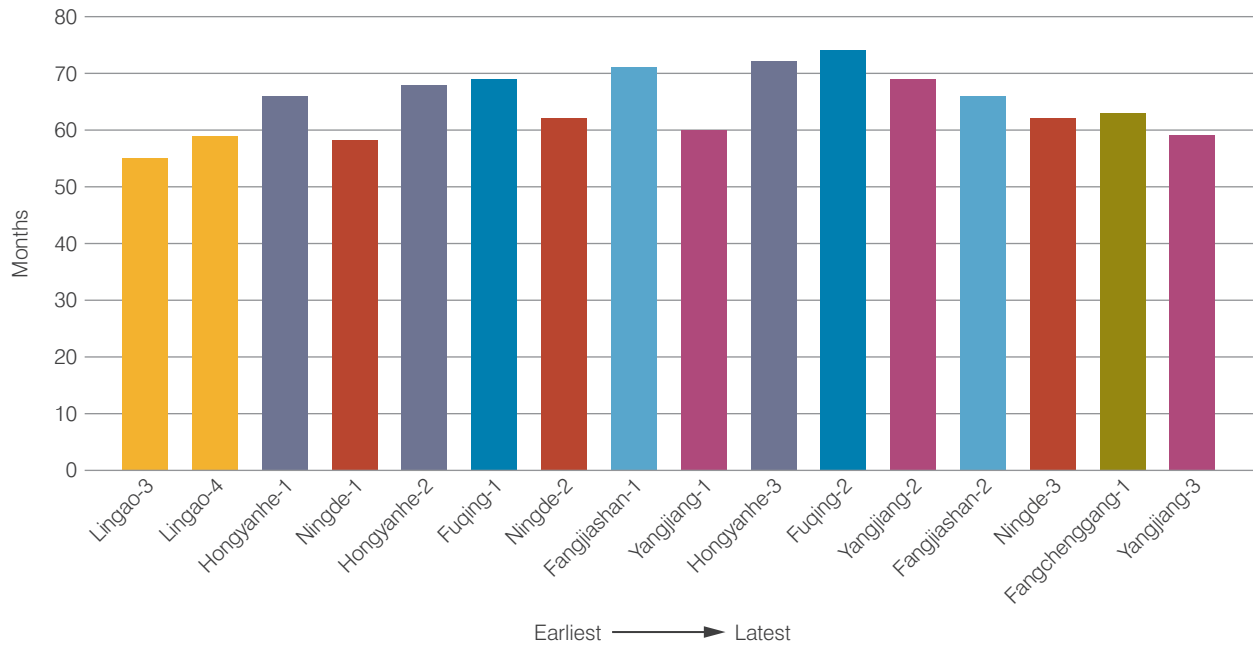
The last consideration is particularly significant as the financing of large reactors is a major challenge for all but the biggest utilities, especially in more deregulated markets. The high volume of finance required for large reactors, to cover an investment cost that can be in excess of \$6 billion in the US and EU, often represents a significant proportion of the utility's market capitalisation. The risks associated with nuclear construction are thereby translated into risks to the credit worthiness of the utility as a whole. The debt ratio of the utility might well be increased leading to a

downgrading of its credit rating and consequently a higher cost of capital to the utility. Geoffrey Rothwell<sup>21</sup> has suggested a possible saving on the cost of capital raised for a n<sup>th</sup>-of-a-kind (NOAK) SMR of 2.4% per year versus a FOAK large Gen III reactor. Should savings in the cost of capital of this order be realised, he estimates that SMRs could compete well with larger reactors on the levelised cost of generation.

In most OECD countries, electricity demand growth is expected to be low or even negative over the coming decades. The risk to a utility entailed by an SMR investment in such a market is very much lower than for a large reactor. Moreover, the SMR site is likely to allow subsequent additions of capacity in a manner more closely calibrated to demand increases whilst simultaneously delivering further series economies resulting from the construction of multiple reactors on a single site.

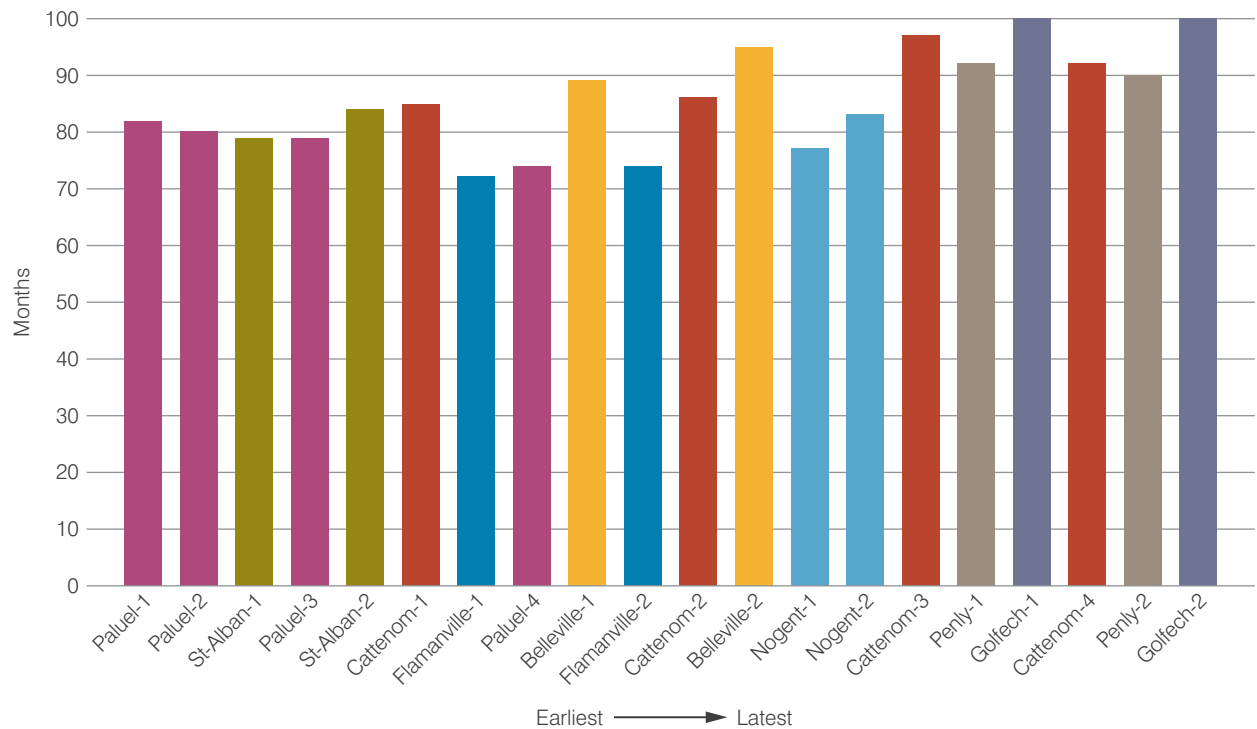
<sup>21</sup> *Economics of Nuclear Power*, G.Rothwell, 2016. He provides an illustration (p123) that if the utility present value was \$20 billion then an investment of \$12 billion for two large FOAK reactors would result in a cost of capital of 6.9% versus 4.5% for an investment of \$4 billion in two NOAK SMRs.

Figure 9: China: CPR-1000 construction performance in months 2005-2016



Same coloured bars = reactors constructed on the same site  
 Source: World Nuclear Association Database

Figure 10: France: P4 construction performance in months 1984-1993



Same coloured bars = reactors constructed on the same site  
 Source: World Nuclear Association Database

The characteristics of SMRs might also lead to revenue enhancement as a result of:

- Greater opportunities arising to use process heat and to co-generate resulting from the ability to site reactors closer to communities or commercial activities (SMRs feature a higher level of passive safety than large reactors).
- Greater ability to flex generation to match the demand volatility that is expected from the increased use of intermittent renewables.

To date, SMRs are under construction in Russia, China and Argentina and are currently envisaged to be employed in isolated locations, such as the Northern regions of Russia, and for co-production, such as water desalination in Saudi Arabia.

## 4.5 Operating costs

The operating costs of nuclear plants are typically low and the subject has been covered in Chapter 2 of this report. It should be noted that, when evaluating nuclear plants using new designs, fuel use should be more economical than for older plants, for example by allowing higher burnups.

Nuclear fuel costs include charges for used fuel management and disposal. These are well-identified and validated, providing a good level of predictability of long term costs<sup>22</sup>. Financial contributions are usually made over the economic lifetime of the plant towards plant dismantling and eventual site restoration. Given that plants are expected to have long operating lifetimes, the contributions are not significant (usually less than 1% of the total levelised costs).

As noted in Chapter 2, O&M costs vary between countries but the prospect is for continuing

improvements in plant operating practices as lessons from best practice are taken up more broadly. Indeed, the deregulation of electricity markets has arguably helped in generalising best practices in reducing O&M costs throughout the industry which together with higher capacity factors has improved the competitiveness of many plants.

## 4.6 Evaluations of nuclear competitiveness

As nuclear plants have relatively high capital costs but low operating costs, it is important to the overall economics of nuclear that plants operate at very high load factors, supplying the demand for baseload electricity. Although renewable energy sources are likely to take an increasing share of incremental electricity supply in many markets, it is still expected that most incremental and replacement generating investments to satisfy the baseload demand will use fossil fuels (coal or gas) or nuclear.

There have been many studies carried out which assess the relative electricity generating costs for new plants utilizing different technologies. The OECD-NEA & IEA publishes the *Projected Costs of Generating Electricity*, a standardised levelised cost assessment of a wide range of generating technologies in different countries, at roughly five-year intervals (the last edition in 2015).

*Projected Costs of Generating Electricity 2015 Edition*, highlights the continued competitiveness of nuclear in many countries since the previous report in 2010 and the general improvement since the 1998 report. This is generally due to the improved operating performances of nuclear plants and to higher fossil fuel price expectations. A summary of the results (see Figure 11) shows

<sup>22</sup> *The Economics of the Nuclear Fuel Cycle*, OECD-NEA, 1994.



Table 5. Levelised Costs of Electricity, US\$/MWh, 10% discount rate

Technology	Country / Regional Data	Levelised Cost (US\$/MWh 2013)
Nuclear	USA	102
	Europe	109-136
	China	49-64
	South Korea	51
Hydroelectric	USA	87-194
	Europe	40-388
	China	28
Onshore Wind	USA	52-79
	Europe	85-151
	China	72-82
	South Korea	179
Offshore Wind	USA	167-188
	Europe	170-261
	South Korea	327
Solar Photovoltaic	USA	103-199
	Europe	123-362
	South Korea	176-269
Gas	USA	71
	Europe	101-263
	China	95
	South Korea	122-130
Coal	USA	104
	Europe	83-114
	China	82
	South Korea	86-89

Source: OECD-NEA & IEA, *Projected Costs of Generating Electricity 2015 Edition*

that, even at a 10% discount rate, nuclear is the cheapest option in many countries. For all countries, the report assumes a cost of carbon of \$30 per tonne; it also projects the costs to five years in the future, a particularly important consideration for renewables where the capital costs of wind and solar are assumed to continue falling. The 2015 report introduces estimates based on a 3% discount rate which shows nuclear to be unambiguously the lowest cost baseload generation technology. This rate can be seen as representative

of the cost of capital in a number of countries where state-owned enterprises can borrow on similar terms to government.

The key messages of the 2015 report are:

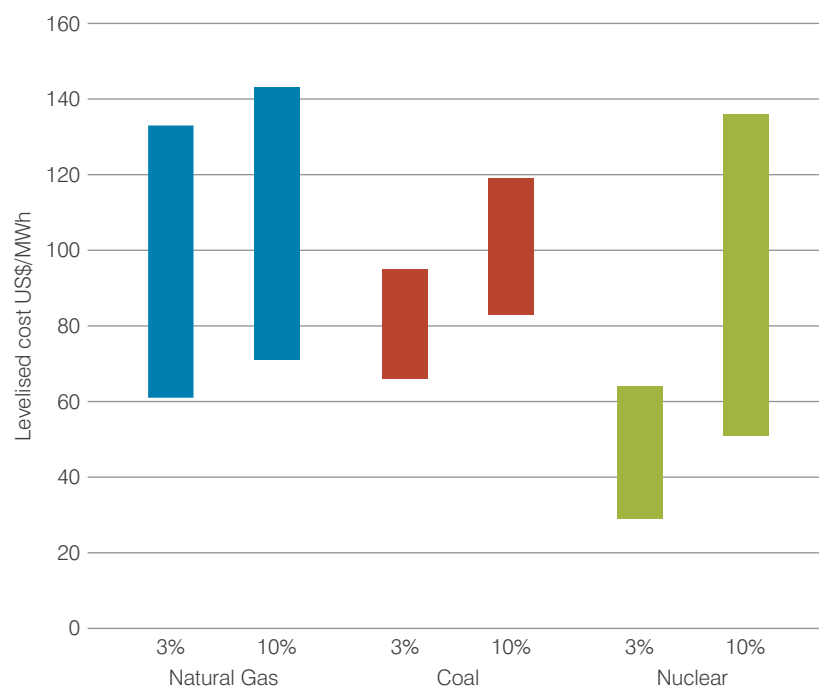
- The role of government to provide a predictable and durable regulatory environment, with visibility and credibility for the investors and to help ensure the competitiveness of low-carbon technologies, via the internalization of CO<sub>2</sub> permit costs by fossil fuel fired generators.

- The absence of a global conclusion as to whether nuclear is the best option. In all circumstances an assessment of the specific conditions is required. Nuclear discounted at 3% is very competitive, but less so if it is discounted at 10%.

Other points include:

- The costs of nuclear, gas and coal to less than \$150/ MWh (excluding special cases).
- Where gas is cheap (as in the US today) it is hard for nuclear to

Figure 11: Levelised cost of generating baseload electricity by technology in OECD countries 2015 (US\$/MWh, 3% and 10% discount rates)



Source: *Projected Costs of Generating Electricity 2015 Edition*, OECD-NEA & IEA

<sup>23</sup> LCOE plant costs have been taken from *Projected Costs of Generating Electricity 2015 Edition*. System costs have been taken from Nuclear Energy and Renewables, NEA, 2012. A 30% generation penetration level for onshore wind, offshore wind and solar PV has been assumed in the NEA estimates of system costs, which include backup costs, balancing costs, grid connection, extension and reinforcement costs. A discount rate of 7% is used throughout, which is consistent with the plant level LCOE estimates given in the 2015 edition of the *Projected Costs of Generating Electricity*. The 2015 study applies a \$30/t CO<sub>2</sub> price on fossil fuel use and uses 2013 US\$ values and exchange rates.

<sup>24</sup> The impact of intermittent renewables on other generators has often been overlooked in the literature reviewing system costs. A recent exception is *Integration Costs Revisited – An Economic Framework for Wind and Solar Variability*, L.Hirth, F.Ueckerdt, O.Edenhofer, *Renewable Energy* 74, 925-939. The authors estimate the ‘utilisation effect’ (capacity factor) on thermal generators; at 40% intermittent penetration the utilisation rate of thermal generators falls to 47%. The cost of the lower level of thermal utilisation is estimated as €49/MWh.

<sup>25</sup> *Report of the ExternE Project*, European Commission, 2001. Human activities like electricity generation or transport cause substantial environmental and human health damages, which vary widely depending on how and where electricity was generated. The damages caused are for the most part not integrated into the pricing system. Environmental policy calls these damage costs externalities or external costs. Public policy should aim to ensure that prices reflect total costs of an activity, incorporating the cost of damages caused by employing taxes, subsidies, or other economic instruments. This internalization of external costs is intended as a strategy to rebalance the social and environmental dimension with the purely economic one, accordingly leading to greater environmental sustainability.

compete. Continuation of low gas prices is, however, far from certain – low prices will induce significant demand increases and curtailment of supply plans.

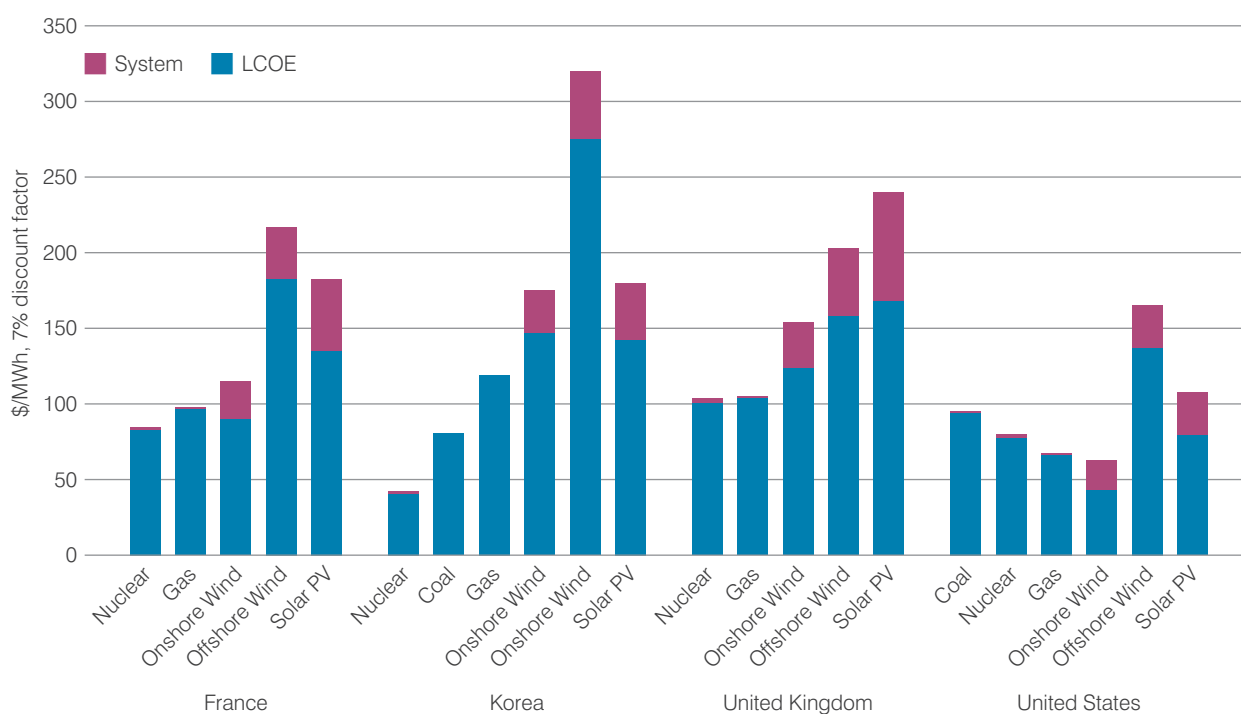
- At good sites, the cost of large hydro is very low (<\$50/ MWh) but the most suitable sites have largely already been developed.
- The rapid decline of solar costs to quite competitive levels; however, as with wind power, the system costs of intermittency have not been included. This point deserves some elaboration.

#### 4.7 Reliability of supply and environmental performance

In order to provide reliable electricity supply, provision must be made for backup generation at times when generating plant is not operating. Provision must also be made to

transmit the electricity from where it is generated to where it is needed. The costs incurred in providing backup and transmission/distribution facilities are known as system costs and these costs vary greatly between different generating technologies. For nuclear and fossil fuel generators, systems costs relate mainly to the need for reserve capacity to cover periodic outages, whether planned or unplanned. The system costs associated with intermittent renewable generation relate to their inability to generate electricity without the required weather conditions and their generally dispersed locations distant from centres of demand; these systems costs are far higher for renewables than they are for dispatchable generators. The system costs of renewables increase as their penetration rises, which is the objective of policymakers in a number of countries. Adding the

Figure 12: Comparative LCOEs and system costs by generating technology in four countries (\$/MWh, 7% discount factor, 2014 and 2012)



Source: *Projected Costs of Generating Electricity 2015 Edition*, OECD-NEA & IEA; *Nuclear Energy and Renewables*, OECD-NEA (2012)

systems costs of renewables to their plant-level costs greatly increases the overall costs of reliable supply. The future competitiveness of intermittent renewables depends very much on the resolution of a number of current uncertainties which could moderate their systems costs, including the success of 'smart' demand management, the volatility-reducing effects of increased interconnection and above all the development of electrical storage solutions at reasonable cost. Figure 12 shows the impact of some estimated system costs<sup>23</sup> on the overall levelised costs in four important nuclear countries.

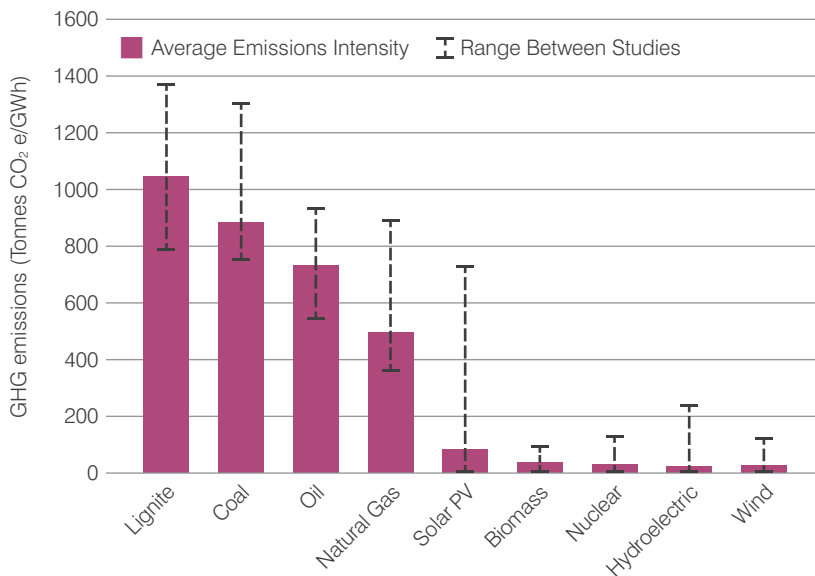
The overall cost competitiveness of nuclear on the other hand and as measured on a levelised basis (see Figure 12), is much enhanced by its modest system costs. However, the impact of intermittent electricity supply on wholesale markets has a profound effect on the economics

of baseload generators, including nuclear, that is not captured in the levelised cost estimates given in studies such as the *Projected Costs of Generating Electricity*. The negligible marginal operating costs and priority grid access of wind and solar mean that, when climatic conditions allow generation from these sources, they undercut all other electricity producers. At high levels of renewable generation, e.g. as implied by the EU's 30% renewable penetration target, the nuclear load factor is reduced and the volatility of wholesale prices is greatly increased whilst the average wholesale price level falls. The increased penetration of intermittent renewables thereby reduces the financial viability of nuclear generation (and other baseload generators)<sup>24</sup>. The integration of intermittent renewables with conventional baseload generation is a major challenge facing policymakers in the EU and

certain states in the USA and until this challenge is resolved, e.g., by the introduction of long-term capacity markets or power purchase agreements, investment in baseload generation capacity in these markets is likely to remain insufficient.

The environmental and social impacts of different generating technologies also vary greatly. These impacts are referred to as external costs, which are those that are not expressed in monetary terms and incurred by the plant operator but that impact on third parties, e.g., the health of the local population. The nuclear levelised costs noted above incorporate all the major external costs of operating a nuclear plant, whereas fossil fuel modes of generating electricity have traditionally not incorporated their substantial environmental effects, as shown in the ExternE report<sup>25</sup> (European Commission 2001).

Figure 13: Lifecycle greenhouse gas emissions intensity of electricity generation methods



Source: Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources, World Nuclear Association, 2011

As fossil fuel generators begin to incur real costs associated with their impact on the climate, through carbon taxes or emissions trading regimes, the competitiveness of new nuclear plants will improve. This is particularly so where the comparison is being made with coal-fired plants (because they are so carbon-intensive) but it also applies, to a lesser extent, to gas-fired plants.

The likely extent of charges for carbon emissions has become an important factor in the economic evaluation of new nuclear plants, particularly in the EU where an emissions trading regime has been introduced but which is yet to reflect the true costs of carbon emissions. Nevertheless, "about 40 national and over 20 sub-national jurisdictions are putting a price on carbon. Together these carbon pricing instruments cover ... about 12% of annual global greenhouse gas emissions."<sup>26</sup>

Carbon prices on these markets have stayed relatively low since their inception, lower than the

\$30/tCO<sub>2</sub> taken into account by authors of the *Projected Costs of Generating Electricity 2015 Edition* study. In Europe, since 2013, the European Union Allowance price is stagnating around €5-9/tCO<sub>2</sub>. Other factors may have played a role in the observed emissions reductions worldwide including the impact of policies and subsidies supporting renewable energies, the depressed economical context in recent years and energy efficiency improvements. The European Union is considering a reform of the Emissions Trading System to ensure more stable and higher permit prices needed to support the delivery of the EU's 1990-2030 greenhouse gas emissions reduction target of 40%.

The World Nuclear Association has issued a report<sup>27</sup> comparing estimates from a range of sources for greenhouse gas emissions from various generating technologies indicating that nuclear power plants are amongst the lowest of any power generation technology.

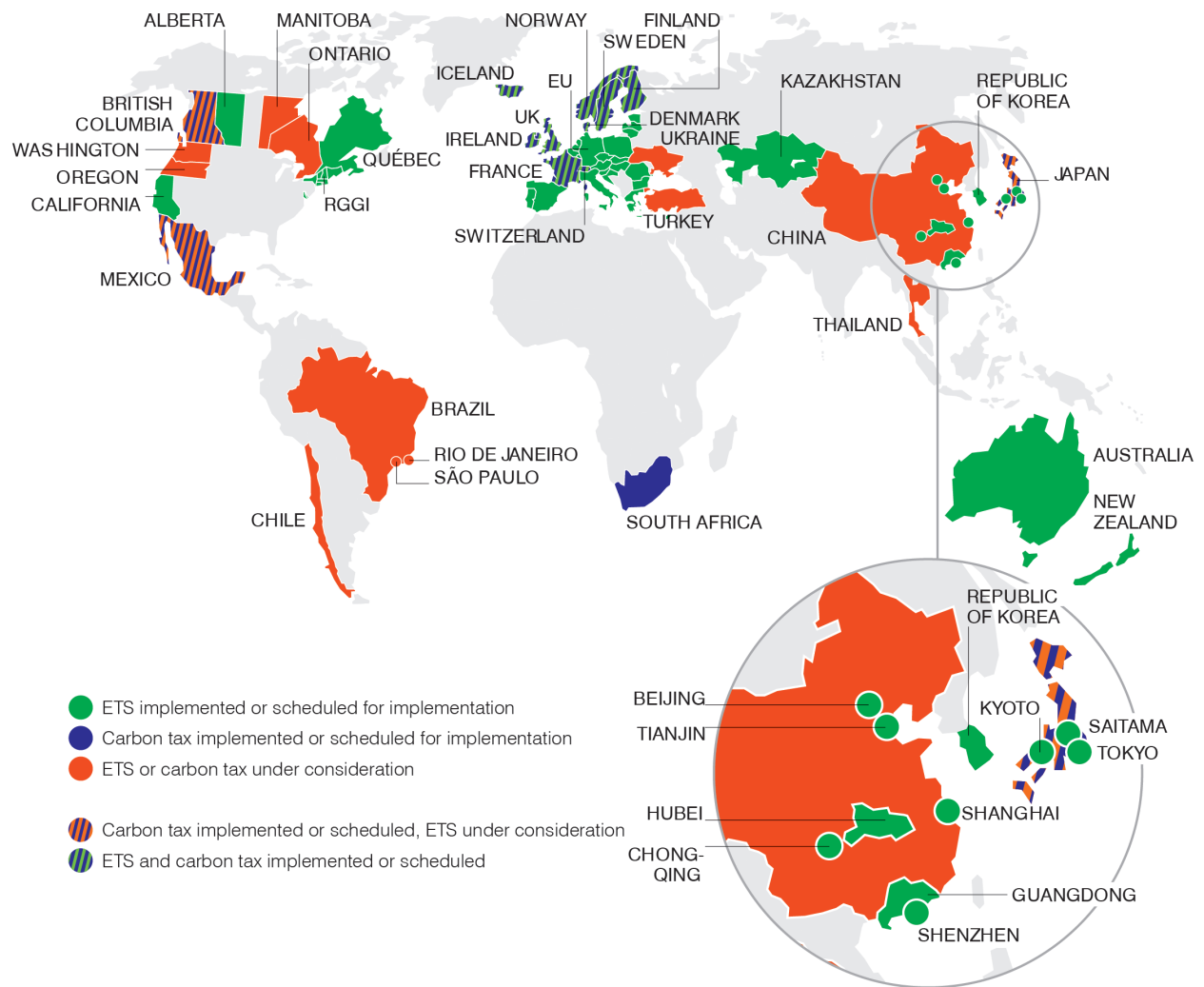
## 4.8 Electricity market regulation

The nature of the electricity market regulation governing a nuclear plant's operation is very relevant to a utility's choice of generation technology. Electrical power generation, including nuclear, was largely developed by public bodies in a regulatory environment that facilitated long-term investment. In some countries, nuclear plants were built primarily to ensure national security of supply, although competitively priced electricity with a stable cost was clearly also very important. Even today, reducing the dependence on imported fossil fuels with uncertain price prospects remains important in many countries. The expected long-term stability in costs was also an important consideration favouring nuclear and it remains a

<sup>26</sup> *State and Trends in Carbon Pricing*, World Bank Group, Washington DC, 2014

<sup>27</sup> *Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources*, World Nuclear Association, 2011.

Figure 14: Worldwide carbon pricing jurisdictions



Source: World Bank Group, *State and Trends in Carbon Pricing, 2014*

strong argument today. Government-owned or rate-of-return regulated utilities have an overall economic objective of meeting demand at an agreed (i.e. high) level of reliability at a low long-term cost of electricity, which usually results in a portfolio of generation types, fuels and locations. In such a system there is no significant wholesale market setting prices for the nuclear generator. Critically, the system allows the total costs of all units in the portfolio, including nuclear, to be recovered. This 'traditional model' of electricity supply had the

virtue of delivering a high level of supply reliability but at an economic cost (potentially as a result of over-investment) that has persuaded many countries to liberalise or deregulate the power market.

The move to a market-based electricity industry approach changes the above state of affairs. Short-term electricity market spot prices (and expectations of future spot prices) are expected to provide economic signals for power plant investments. Spot prices are intended to reflect the

marginal cost of electricity in each trading period. The market operator selects the lowest price bids received from generators in order to meet demand for each trading period and the price of the last bid sets the wholesale spot price for that period. A generating unit will be dispatched in this system by a market operator based on short run marginal cost (i.e. the change in costs resulting from small and temporary changes in plant output), sometimes referred to as 'avoidable' costs. For a nuclear power plant such short run costs

are very low compared with other thermal generators as most plant costs relate to 'unavoidable' or fixed costs, namely operations and maintenance costs (O&M), some fuel costs (including costs for the management and disposal of used fuel), recovery of construction costs, and accrual of plant decommissioning costs. In an electricity market based on short run marginal costs, a nuclear plant is likely to be dispatched almost all of the time and the difference between the wholesale market price and zero represents revenue.

In the market-based electricity supply systems of the past, marginal producers had been relatively high operating cost fossil fuel plants. The prices achieved in such systems were sufficient to cover the fixed costs of nuclear albeit with a great degree of uncertainty relating to the amount of revenue that would be earned. Since the start of the new millennium this expectation has been upset by two developments. First, the exploitation of unconventional gas in some markets (mostly North America) has lowered the cost of gas-fired electricity, which in some locations has resulted in very low wholesale electricity prices. Second, the promotion of renewables with similarly almost zero marginal costs has in some locations and at some times also reduced wholesale prices.<sup>28</sup> These two developments have for some nuclear plants greatly reduced revenues. Where such competing technologies exist in deregulated markets, as the US experience shows, it can be difficult for nuclear power plants to be financially viable although it is possible to design support arrangements that recognise the benefits that nuclear power brings to overcome these challenges (e.g., long-term power contracts, capacity payments, and carbon pricing).

<sup>28</sup> Low wholesale prices do not however equate to low prices for consumers; the variability of new renewables has to be managed either by back-up generation, additional grid capacity or by storage, the costs of which will be passed on to consumers.

## 4.9 Conclusions

Nuclear energy competitiveness depends mainly on the capital required to build the plant (and implicitly the construction time) together with the service charge on that capital (which is proxied in levelised cost calculations by the discount rate). If a discount rate of 5-8% is used, then nuclear is usually competitive with other generating technologies assuming overnight capital costs in the typical ranges apparent today for a number of countries. This cost advantage could increase with a reduction of nuclear capital costs, which can be expected once the FOAK costs for the currently new reactor designs are absorbed, learning-by-doing has spread and construction time reduced. It is to be expected that, once a number of plants of the same design are successfully completed on time, finance will be forthcoming for subsequent units on more favourable terms.

When system costs are added to the plant levelised costs of different generation technologies, nuclear energy's competitiveness as a low carbon energy source is increased further. However, the impacts of subsidised intermittent renewables and 'un-carbon costed' gas are depressing wholesale prices in deregulated markets and the advantages of nuclear will not be realised fully until these fundamental market design problems are addressed by policymakers.

New nuclear plants generate electricity at predictable, low and stable costs for 60 years of operating life and in all likelihood even longer in the future. Their system and external costs in normal operation are also both low. Investment in nuclear should therefore be attractive to industrialised countries which require significant baseload amounts of low cost power over the long term.

# 5

## Risks of Nuclear Projects

Structuring a nuclear new-build project for success requires the identification and understanding of the various risks associated with a project of such magnitude and complexity. Some risks are quite similar to those in any power investment project; others are unique to nuclear. In developing a project, a utility will undertake a comprehensive risk assessment, which will be reviewed and updated as the project progresses.

Nuclear projects are capital intensive, with long project schedules and involving hundreds of contractors and suppliers. They have significant fixed operating and maintenance costs and low fuel costs. They exist in a rigorous regulatory environment where the regulator actively patrols plant operations and has authority to impact unit construction and operation. Nuclear plants are also subject to public scrutiny and concern. In normal operation, nuclear plants are environmentally friendly but public concerns often focus on the questions of long-term management of nuclear waste and potential consequences of very low probability safety events. The large number of stakeholders and their interactions creates complexity, posing a major project management challenge.

Table 5 lists risks that are associated with a nuclear project. Table 6, in Section 6, shows how these risks may be mitigated.

Construction schedules for nuclear projects are notably long. This can influence the allocation of cost-inflation risk in relevant construction contracts. It can also impact on the negotiation of power purchase agreements (PPAs), if these are a requirement before construction commences.

In preparing its risk assessment a utility may assess the probability

of the event occurring and the consequent impact. Measures to manage or monitor the risk can be identified and a further assessment made of the residual probability and impact. These methods are not unique to nuclear power projects and are discussed below:

### 5.1 Electricity market regulation and revenue predictability

The prospects for nuclear power are greatly affected by the type of market regulation encountered. For any operator in a deregulated market, revenue unpredictability is a key risk. The uncertainty affecting future electricity prices and indeed whether the nuclear operator will be able to secure customers for its output have an important bearing on revenue predictability. The private investor will be particularly concerned about risks in the first two decades in the life of a plant, when there is likely to remain a large volume of outstanding debt related to the plant. The possibility of revenues falling below costs (including the cost of debt finance) for a significant period will lead the providers of capital to demand a high risk premium. In some cases, electricity prices below even operating costs have been a reality for nuclear plant operators and have for example resulted in the premature closure of the Kewaunee and Vermont Yankee plants in the USA. Revenue risks in some deregulated markets have been heightened with the development of new sources of low cost natural gas and the promotion of renewables with extremely low operating costs. The long-term economic advantages of nuclear power are also greatly eroded by the relatively high discount rates applied to the assessment of power projects. The high capital intensity

Table 6. Nuclear power project risk

	Development	Construction	Operation	Decommissioning
Technical	Regulatory assessment	Safety	Safety	Safety
	Site suitability	Design completion/changes	Plant performance	Design completion/changes
	Environmental impact	Regulatory assessment/approvals	Skilled and experienced workforce	Regulatory assessment/approvals
	Planning approvals	Vendor and contractor performance	Nuclear event elsewhere	Contractor performance
		Equipment supply chain	Nuclear event	Equipment supply chain
		Skilled and experienced workforce	Beyond design basis events	Skilled and experienced workforce
		Construction quality	Fuel supply chain	Transport routes to/from site
		Transport routes to site		Availability of waste management routes and disposal
		Industrial relations		
	Business Case	Economics	Design changes	Electricity markets
Demand forecast		Delay	Trading and price	Decommissioning fund performance
Used fuel and radioactive waste disposal			Capacity factor	
			Carbon price	
			Fuel costs	
			Capital additions	
Societal and Political			Early closure	
			Cost of waste and used fuel disposal	
		General public support and local approval		
		Policy supporting the need for nuclear power		
		Decommissioning and waste management policies and implementation		
	Carbon pricing mechanism			
	Environmental policy			

and long development/construction period of a nuclear power project are offset by an operating lifetime that may be 60 years or longer; however, nuclear project cashflows after about 30 years of operation have little net present value using a commercial discount rate at the time a financial investment decision is made.

In contrast, regulated markets are characterised by a far higher degree of revenue predictability, whether rates are set by a regulatory body or by a utility with sufficient pricing power to set rates to cover

the average cost of its operations. Thus in regulated electricity supply systems where new generating technologies are introduced, the utility is able to control the impact on existing plants and may be able to pass opportunity costs onto consumers. The potential access of new generation technologies to these markets is as a result controlled in a way that it cannot be in deregulated markets. Nuclear operators in regulated markets are able to assure investors of a more certain return on their capital and consequently are able to obtain finance on better

terms. Most regulated markets are typified by large state-owned utilities that are able to borrow with effectively a sovereign guarantee. The economics of nuclear plants in such markets are therefore greatly enhanced.

## 5.2 Nuclear safety regulation

Safety is of utmost importance in nuclear operations. Regulatory concerns can delay or halt nuclear plant construction or operation. While public protection



is an essential governmental responsibility, that goal must be pursued, to the maximum extent possible, through a regulatory environment that provides sufficient predictability to elicit the investment necessary to bring the benefits of nuclear technology to the public. The nuclear industry has recognized that it can contribute to stability and smoothness in the regulatory process by achieving greater constancy in reactor designs. Ultimately, the public interest is served by regulatory certainty combined with smooth procedures.

The regulatory licensing process can be broken into several stages. The first is reactor design certification. The second is site approval, which is usually made easier on sites with previously constructed reactors. Next come licences for construction and operation. Additionally, in most countries local planning approvals and environmental assessments are needed both by law and as a means of achieving and demonstrating public acceptance.

US experience provides a good example of strengthening regulatory certainty in the new-build process. The Nuclear Regulatory Commission (NRC) has established a licensing framework that provides for pre-approval of a prospective site for a new plant, certification of reactor designs well ahead of any construction, and the issuance of a single licence to build and operate a new plant using a certified design and a pre-approved site – a combined construction and operating licence (COL).

The new approach moves all design, technical, regulatory, and licensing issues to the front of the licensing process so that before construction begins and any significant capital spending occurs, safety and

environmental issues can be fully addressed. The new licensing framework aims to assure potential investors that their investment in a new nuclear plant will not be jeopardized as long as construction adheres to the approved design and standards. Delays caused by public intervention in the past are now prevented by strictly defined time-frames for public hearings and consultations. It bears emphasis that adequate staffing of regulatory agencies is important for timely decisions.

### 5.3 Project delivery

New-build risks include costly delays due to problems with designs, supply of equipment and materials, personnel, construction and commissioning. These risks, not unique to nuclear, can be allocated amongst the plant owner-operator, the plant engineering, procurement and construction (EPC) contractors, the plant vendor and financiers. Contracts can provide for a fixed delivery price, with penalties for delays and incentives for completion ahead of schedule or below budget, but the complexity of a project means that contracts must also provide for mechanisms to resolve difficulties as they arise.

A new generation of reactors has been designed to reduce project risks. Building these reactors using pre-fabrication, pre-assembly and modularization along with 3-D modelling, open-top construction and other advanced construction techniques can further control risks. The new reactor designs take advantage of the significant R&D, construction and operating experience available in what can now be called a mature technology.

The nuclear industry (the reactor vendors and utilities) works in cooperation with national and

international regulatory and safety bodies with the aim of harmonizing regulatory and utility requirements for reactor designs throughout the world. Such harmonization would lower costs for manufacturing, construction, maintenance, and refuelling outages. Standardized designs can be mass-produced and with economies of scale.

It has been recognised that those who build first-of-a-kind (FOAK) reactors bear the burden of one-time risks and provide followers with valuable information and experience. To reward this benefit, the US government has introduced FOAK incentives that include loan guarantees, investment tax credits and insurance against regulatory delays.

Countries that are introducing nuclear power for the first time are already subject to considerable start-up burdens. They are therefore well-advised to adopt proven designs that have already passed the FOAK stage and have accumulated some operational experience.

Because nuclear projects are especially capital-intensive, effective project management is essential if risks are to be managed, costs contained, and schedules met. In this fundamental respect, nuclear new-build projects are little different from any other major construction project; they demand top management personnel applying proven techniques.

### 5.4 Operations

While nuclear operations clearly involve a variety of risks, it should be noted that existing nuclear plants are being run very professionally in some 30 countries around the world – creating a strong foundation for the operation of new reactors in those nations as well as other

countries now preparing to initiate nuclear power programmes. Nuclear operations have benefited from skill improvement programmes, the advice of nuclear regulators, and the sharing of information and technical assistance through international professional associations (notably, the World Association of Nuclear Operators). Enhanced maintenance and support services now guarantee performance for up to 60 years, so future operational risks are likely to be deemed less significant than in the past. Nevertheless, a number of operational nuclear power plants have experienced prolonged (i.e. longer than a year) outages for a variety of reasons. During such a prolonged outage, the nuclear power plant earns no revenue and is likely to have higher than normal costs, as efforts are made to return the plant to operation. The negative impact of a prolonged outage for a merchant nuclear plant will result in a severely negative impact on returns to investors and such outages may not be insurable.

The risk of poor operational performance can be controlled by the employment of a well-trained and experienced workforce, applying a carefully planned and implemented maintenance regime. Ongoing support from vendors is also important in controlling any technological risk associated with new designs.

With regard to the replacement of plant equipment, the business case for new build may require that the project includes a contingency fund for some capital expenditure through the operating lifetime of the plant in addition to predicted replacements identified in the vendor's design. With regard to fuel, the utility must also consider its fuel procurement strategy to control any cost or supply-chain risks.

Finally, plant security concerns from natural events (e.g. floods, earthquakes or severe climatic conditions) are covered in new plant evaluations. Protection against terrorist attacks clearly requires collaboration and support from government authorities.

## 5.5 Decommissioning and waste management

End-of-life risks relate to plant decommissioning and dismantling, and radioactive waste and used fuel management. Used fuel costs are in many countries regarded as part of the overall fuel cost, with an ongoing charge levied to take account of management. It depends, however, on the establishment of an appropriate national political framework.

Decommissioning costs are usually covered by annual charges levied on electricity consumers to cover the ultimate cost, fixed by national rules, similar to used fuel. However, a range of possibilities exist, for example, in France nuclear operators are required to establish funds covering decommissioning and waste management from the beginning of a plant's operation<sup>29</sup>.

## 5.6 Accident insurance

The cost of accident insurance contributes to the total cost of a nuclear power plant, as it does to the cost of other potentially high impact industrial facilities such as hydro dams, and oil and chemical facilities. A severe nuclear accident with health and environmental consequences beyond the plant boundary is a very low probability event, albeit one with high costs should it happen. It should be noted that most of these costs arise from the effects of government-mandated precautions, e.g. evacuation of potentially

<sup>29</sup> *Costs of Decommissioning Nuclear Power Plants*, OECD-NEA, 2016

affected populations, rather than directly inflicted injuries to health and environment.

Plant owners must carry insurance to cover most operating risks. Liability for severe accidents is defined by international conventions (notably, the Vienna and Paris Conventions as well as the Convention on Supplementary Compensation for Nuclear Damage) and/or by national legislation (such as the Price-Anderson Nuclear Industries Indemnity Act in the United States). In contrast to many other industrial sectors, these frameworks precisely define and cap the liability borne by the operator, with the possibility for public authorities to accept responsibility for liabilities in excess of the cap. They also have the advantage of requiring that strict and exclusive liability rests with the plant operator (i.e. regardless of fault and to be borne by the operator alone) which greatly simplifies the options for claimants in claiming for damages. Insurance is reportedly available on commercial terms to cover damages of between \$10-15 billion at a cost of 0.1-0.2 ¢/kWh<sup>30</sup>.

Japan was not party to any international convention relating to liability and compensation for damage caused by a nuclear accident at the time of the March 2011 accident at the Fukushima Daiichi plant; it is now a contracting party to the Convention on Supplementary Compensation for Nuclear Damage. Soon after the accident, the government brokered

an institutional solution to raising funds to meet compensation claims. The Nuclear Damage Compensation Facilitation Corporation is financed by Japanese nuclear plant operators plus access to government bonds with a value of up to \$86 billion (as of December 2013) and is responsible for making payments to those affected by the accident as well as acting as an insurer to the industry.

## 5.7 Political

Governmental commitment to the need for nuclear power is a prerequisite to any nuclear construction, but that commitment cannot obviate all risks of laws and regulations governing electricity markets and taxation being modified.

Another aspect of political risk is that public acceptance can shift, perhaps undermining a project's viability during or after construction. Barring unforeseen and extreme events, however, utilities are in a strong position to minimise this risk by drawing upon the industry's considerable experience in dealing with questions of public concern. In most countries, the industry has succeeded in gradually building public support for nuclear power, by demonstrating strong operating performance. The industry's excellent safety record is the basis on which policymakers have been able to point to nuclear energy as an important response to the imperatives of energy security and environmental protection.

<sup>30</sup> *Liability for Nuclear Damage*, World Nuclear Association Information Library. The figure is in line with an estimate provided in a survey of information on nuclear economics by William D'haeseleer (*Synthesis on the Economics of Nuclear Power*, European Commission, 2013). He suggests probability-weighted unit damage costs arising from a nuclear accident of 0.1 ¢/kWh.

# 6

## Project Structure and Risk Allocation

The essential aim of project structuring is to achieve an efficient application of capital and resources. Project risks should be assigned to the party most capable of handling their control.

The structure of a new nuclear power project will be influenced greatly by the market in each particular country or region. A project in a deregulated market will be structured differently to one in a regulated market. In a regulated market, investments may be made following regulatory scrutiny of a plan which, once agreed, allows costs to be passed through to the consumer.

There is no single way to structure a nuclear project; a number of project models can succeed. The essential characteristic is a suitable sharing of risks and benefits. However, just as standardisation of design can lower both the cost and risk of new plants, so can standardized business structures. It is expected that the number of different approaches will be reduced as more experience is gained and projects repeat structures that work well.

Although project structures may vary, and can be complex in some markets, there will be similar parties involved and the allocation of risks will always be a key factor in assessing whether the business case for a nuclear power station can be assembled. Simply transferring a risk does not make it disappear. The receiving party must demonstrate that it can control the risk if uncertainty is to be lowered to acceptable levels.

The prime participants in a nuclear project are:

- Government – responsible for overall energy policy and, in some cases, financing.
- Financiers – investors in debt or equity required to finance the project.
- Market – formed by electricity customers wanting electricity at a competitive price.
- Utility (generator) – which is ultimately responsible for developing and running the complete project.
- EPC contractors – companies which are responsible to the owner for delivery according to schedule and budget.
- Vendors – which are responsible for supplying equipment and technology to either the owner, the EPC contractor or as part of a joint venture or consortium, according to schedule and budget.
- Regulatory authorities – which are responsible for addressing all matters related to protecting public safety and the environment, from the design stage to plant operation and fuel management.

Table 7 overleaf shows ways in which the risks of nuclear projects listed in Table 6 can be monitored and controlled.

### 6.1 Development

During the phase of project development when government effectively controls the permitting and approvals process, the risk of the design being rejected or the project being delayed is likely to be carried by the utility and potential reactor vendors. Using internationally-accepted designs, preferably already built elsewhere, can help to control risks of rejection or delay, but substantial sums of money can be committed, and be at risk, even before the first concrete is poured.

### 6.2 Stakeholder involvement

Stakeholder participation is a key to allaying concerns about waste management and the safety and security of nuclear installations.

Table 7. Risk control and monitoring in nuclear power projects

	Development	Construction	Operation	Decommissioning
Technical	Internationally-accepted designs Building on existing nuclear sites	Develop sound contractual arrangements for involved parties Invest in supply chain infrastructure Good training programmes Invest in transport infrastructure Previous construction experience Strong project management	Involvement in organisations such as the World Association of Nuclear Operators Good training programmes Invest in new nuclear fuel facilities 'Fleet' approach to reactor management Invest continuously in plant maintenance and improvement	Decide on decommissioning strategy as early as possible Invest in workforce training
	Seek investment from major power users Build business case on various demand scenarios Investigate opportunities for revenue stabilisation	Stick to standardized designs Use an appropriate mix of permanent and contract staff	Develop sound long-term power contracts or otherwise develop revenue stabilisation options (e.g., capacity markets) Develop a balanced portfolio of fuel contracts in line with utility risk management policies Nuclear knowledge management	Contribute to well-defined fund as required
Business Case				
Societal and Political	Public debates and hearings Regular opinion polling Gain cross-party political support Emphasise environmental advantages of nuclear Develop waste management policy with government			

Public hearings and debate are sound means for improving dialogue and ultimately saving time. Providing information to the public and its representatives is essential to building trust with the wider community. Such information also serves a documentary function, putting on record what has been proposed and approved, to avoid the possibility of recurrent argument.

### 6.3 Construction

During the construction phase, the various risks can be covered by

contractual arrangements among the utility, EPC contractor and vendors. Here there is a range of possibilities. For example, in a turnkey project the EPC contractor assumes almost all risks of cost overruns. Financial penalties and rewards are common for parts of the construction contract relating to timing and quality. As an alternative, utilities can assume greater risk in exchange, perhaps, for the opportunity to benefit from a lower overall cost. EPC contractors and vendors will seek to limit their exposure and ultimately a portion of the risk

will reside with the utility. Because the expense of nuclear plants will have an impact on company balance sheets, forming consortia to share risks may often be a good solution.

### 6.4 Operation

Once a plant is running, the utility will control most of the risks – specifically, for safe operation and for maintaining control of O&M costs. The utility can manage its fuel and O&M costs by entering into long-term deals with suppliers and contracting out key services such as plant outages.

During operations, there are obvious benefits to using reactors of standardised design and of running a series of reactors in a 'fleet' approach. Sharing the fixed costs and a common supply chain – and taking advantage of knowledge and experience at similar plants – plainly enhances both economic and safety performance.

Operators can gain performance benefit and also security from regulatory penalty by responding actively and cooperatively to advice from regulatory and safety authorities. Such responsiveness, coupled to transparency in plants operations, contributes to public trust and acceptance. For example, in the areas surrounding French nuclear plants, local information commissions meet regularly, bringing together utility officials from the operator and stakeholder representatives.

The threat of revenue volatility and reduced capacity factors resulting from low cost gas-fired and intermittent renewable generators are outside the direct control of nuclear operators. The solutions to these threats in terms of carbon pricing and lower renewables subsidies require action by policymakers.

## 6.5 Decommissioning and waste management

Plant decommissioning, as well as the management of waste and used fuel, must be the responsibility of the industry, operating within a sound regulatory framework. Public authorities must, however, bear ultimate policy responsibility for ensuring that facilities for the management, storage and disposal of long-lived wastes are provided. This requires the establishment of segregated funds to cover radioactive waste disposal expenses.

# 7 | The Role of Government

Nuclear power requires governmental support in the form of policies that affirm its value and which establish a framework for its operations. Inevitably, issues surrounding radiation and possible weapons proliferation create public interest, to which governments should respond. The effectiveness of the government response in satisfying public concerns affects the political and public context surrounding nuclear projects. Where nuclear issues remain controversial, uncertainty carries a significant premium in the business case for new nuclear power stations.

As a starting point, government should commit to nuclear power as a part of national energy strategy and, in countries facing a likelihood of change in governing party, this should include a considerable degree of cross-party consensus. Clearly there cannot be absolute guarantees that government policy will not change, but there needs to be at least an agreement that nuclear power is recognised as a long-term commitment.

A government supporting nuclear power can be reasonably expected to undertake the following:

## Energy policy

As a reference point and guide for all stakeholders, government should define a long-term energy policy addressing the major challenges of energy supply, security of supply and environmental protection.

## Regulatory and local planning system

Government oversight authorities must apply standards in such a way as to meet the objectives of protecting public safety and security while facilitating the gain from the production of nuclear power. Good

regulation is proportionate to the risk it seeks to control and should be consistent across industries. International standards are to be preferred to avoid the imposition of unnecessary burdens on trade and the transfer of technology. To enhance efficiency and lower costs, construction and operating licences can be issued together. The local planning process should concentrate on local issues, ensuring full deliberation within a time-limited framework.

## Safety regulation of operations

Public safety is a prime responsibility of government, which should take account of the evidence regarding the risk of harm, including the advice from international organizations and agencies, such as the World Health Organization and the International Commission on Radiological Protection.

## Radioactive waste and used fuel management

Government must accept and act on its responsibility to coordinate a comprehensive plan for the long-term storage of radioactive waste and used fuel, while coming to terms with the issues of reprocessing and geological repositories. While plant operators should be expected to contribute their share of the costs, governments must lead on this sensitive but fundamental issue, which involves all users of radiological and nuclear materials (such as hospitals). In some cases, governments will need to work with other countries to develop shared storage and disposal facilities.

## Decommissioning

Government policy must ensure that each plant operator makes financial provision for decommissioning, using a segregated fund.

### **Nuclear liability**

Government must have a clear and consistent policy and legal framework defining the respective insurance responsibilities of government and nuclear operators.

### **Power market**

Government must ensure an efficient and reliable energy market, both currently and in the future, and which provides some excess of capacity to meet growth and unexpected demand. To achieve this, the market regime should be designed to encourage long-term investment. In order to encourage nuclear development in deregulated systems, government may need to provide some means of revenue assurance over a significant period, such as the strike prices fixed for 35 years that have been offered to the operator of the Hinkley Point C plant in the UK.

### **Climate change**

Any government pursuing a serious policy on the mitigation of greenhouse gases must support measures to penalize carbon emissions. A policy that penalizes carbon inherently strengthens the competitive position of nuclear power. An example of institutionalised carbon penalties is the European emissions trading scheme, a regional system of greenhouse gas tradable quotas, within a sequenced framework of reductions in emissions necessary to avoid runaway global warming and ocean acidification. An alternative is direct carbon taxes, which might be seen as preferable in view of the low level of permit prices associated with the EU's emissions trading scheme. Whichever approach is adopted, nuclear should be treated as an important low-carbon technology.



# 8

## Financing

All discussion of nuclear financing must inevitably focus on one essential principle: a good project structure will attract financing at the lowest possible cost. Equity providers – investors willing to take risk in exchange for the prospect of higher return – have a different tolerance for risk to providers of debt. With more complex project structures, investors may perceive there to be more risk, increasing what they will require in expected return or requiring a higher proportion of equity. The optimal management of risk should allow a higher proportion of relatively low cost debt finance.

In assessing whether they will provide debt financing, banks and other lending institutions will evaluate a project's creditworthiness. In the case of project finance, they will look for a strong set of creditworthy contracts. Most often, the borrower will be a large utility; here the lender will look for a strong balance sheet, an established cashflow and will also weigh the borrower's experience in building and operating a fleet of nuclear and other units. Lenders do not take risk other than the credit risk of a borrower and require a level of certainty that their loan will be repaid on a given date.

In the 1970s and 1980s, many investors, notably in the USA, lost money on nuclear and coal plant investments when market liberalisation ended the ability to pass on all costs to customers and left a legacy of stranded costs (i.e. those unlikely ever to be repaid by subsequent operating profits). Then, in the late 1990s and early 2000s, electricity trading arrangements in many markets changed fundamentally, leaving some financiers cautious about the entire energy sector.

Within complex structures, financial institutions can be innovative and

creative in managing and distributing risk but they cannot reduce the economic risks facing nuclear power plants. Nonetheless, there are very large sums of money seeking profitable investments and for nuclear projects to gain financing, it requires only that projects be structured so as to demonstrate clearly that they are creditworthy.

### 8.1 Electricity markets and financing

The structuring of the nuclear project – and how it is financed, particularly the relative amounts of debt and equity – depends heavily on the model of plant ownership and nature of the power market. Both are crucial to the allocation of risks between project participants. As has already been described, electricity markets vary in the degree of regulation and the level of regulation greatly affects the financial options available to the project. In regulated markets, utilities with well-capitalised balance sheets and the ability to pass on regulatory-approved costs will be able to access large volumes of debt finance. In contrast, merchant utilities in deregulated markets will need to issue a much higher share of relatively expensive equity. In practice, government support is likely to be a feature of nuclear financing through mechanisms such as investment or offtake/price support agreements via state-owned or controlled entities (such as utilities or banks) and guarantees for private loans.

Specific financing routes for nuclear projects include:

#### Balance sheet financing by utilities

Many utilities, especially in regulated areas, are integrated electricity

service providers with strong balance sheets that enable them to finance even large capital costs, such as nuclear power plants. Most utilities have a significant element of state ownership and almost all nuclear reactors under construction have been financed via this traditional method, supplemented by loans in some cases from state-owned finance companies, and it is likely to remain the dominant model for the foreseeable future.

### Project finance

Debt investors lend to a single-purpose entity, whose only asset is the new power plant and whose only revenue is future power sales. This structure has advantages for sponsors as projects are highly leveraged. Whilst equity will be required during the pre-construction phase, the sponsors will need to contribute the greater part of their equity investment only at a later stage, while their other assets are protected. The main difficulty is attracting debt financing at reasonable rates and the track record for project finance in nuclear has disappointed. In the USA, it was hoped that government loan guarantees could enable this financing route but the failure of the Calvert Cliffs 3 project indicated that loan guarantees in themselves were insufficient.

### Concession arrangements

Concessions are a variety of project finance that might involve a government-run competition for a company (or more likely a consortium) to build, finance and operate a specified number of nuclear plants in return for which there would be arrangements to ring-fence revenues for a period of time at an agreed tariff. An example of such a partnership is the 'build-own-operate-transfer' concept behind

the investment by Rosatom in the Akkuyu plant in Turkey which features a fixed price deal for 70% of the power produced over 15 years and an eventual sale of equity to Turkish companies. Alternatively, the project equity could remain with Rosatom for an extended period in which case the model would be 'build-own-operate'. In practice, this structure is a niche possibility for nuclear.

### Power user investment

In this model, which was adopted for the fifth Finnish reactor under construction at Olkiluoto, the equity is largely contributed by a consortium of local energy-intensive industries and local utilities. The owners will take the output of the plant at cost, amortizing the debt portion from the market. If the plant operates well, the owners will receive relatively cheap electricity over a long period, avoiding the risks of having to buy or sell power on the open market. This financing route depends on there being a sufficient number or scale of energy-intensive industries willing to participate in the financing.

### Vendor finance

Reactor vendors may choose to invest equity in a nuclear plant. Clearly, the vendor has a strong interest in the project progressing and will be in a good position to help resolve any development problems concerning the reactor. Vendor balance sheets are limited and any offering is likely to meet only part of the financial requirement. Once the reactor has been constructed and is operating satisfactorily, the vendor will most likely seek to refinance and sell its stake.

## 8.2 Cost of capital

The capital intensity of nuclear projects means that the cost of capital strongly influences total generation cost and competitiveness

against alternative technologies. Despite an increased ability to mitigate many risks, the historical experience of delays in plant construction has resulted in the perceived need for a significant risk premium on lending for new nuclear as compared to other technologies. Nuclear projects usually also require a higher initial equity share, adding to the cost of capital. These differences can be crippling to project economics. Risk perception initiates a vicious circle, whereby adverse risk perception leads to more costly financing, which makes the project look even riskier in financial terms. This circle can only be overcome by improved plant construction performance.

The cost of capital is variable, with merchant generating plants attracting a higher risk premium, which inhibits large nuclear projects. In contrast, large, well-established and vertically integrated electricity utilities with strong balance sheets have ready access to relatively cheap borrowing on a large scale and can also withstand a high gearing (debt to equity) ratio. This is most likely to be the best model for new nuclear power projects.

Alternatively, where large power customers invest in the nuclear plant and agree to take the output under long-term arrangements (as in the case of the Olkiluoto 3 project, where there is no risk premium), or in the US regulated market, the cost of capital should be relatively low as many market risks to the utility are mitigated.

Reducing the risk perception – and the consequent risk premium – is essential to future nuclear projects. This gain can be expected to occur over time as early projects, such as those being developed in the USA, demonstrate a clear break

with the past and show that risks can be mitigated by sound project structures. These initial successes should also induce greater public confidence, support and acceptance, leading to a virtuous circle of declining risk perception for future projects.

In the context of volatile electricity markets, certain inherent features of nuclear energy should contribute to the lowering of risk perception, as compared to alternative technologies. These include:

- Cost stability during the operational phase, resulting from the low share of fuel in overall operating costs.
- Fuel supply security.
- High capacity factors.
- Potentially large upside benefit from efforts to decarbonise the power sector.

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# Appendix

## The Levelised Cost Methodology and the Evaluation of Competitiveness in Regulated and Deregulated Markets

The economics of generating electricity should be evaluated in a consistent manner across the various possible technologies. It is important to distinguish the key elements in the cost structure of a nuclear power plant and compare these with the costs of other modes of electricity generation. National and local circumstances and conditions are crucial in these evaluations.

The standard procedure used in investment decisions is to 'levelise' the costs over the life of the plant and divide by the amount of electricity produced to give a cost per kWh. Given that the value of money decreases over time i.e. its 'time value', it is necessary to apply a discount rate to present the costs on a common basis, in order to allow economic comparisons<sup>31</sup>. The discount rate is sometimes set by a public authority as a target rate of return on capital, but in a deregulated market it is effectively the rate of return required on the project by financial markets – in other words, the cost of capital (a risk-weighted average of the interest rate on any loan capital and the required return on equity, known as WACC<sup>32</sup>). The levelised cost of electricity (LCOE) is equivalent to the electricity price needed to cover both the operating and annualized capital costs of the plant and is used as a marker for economic viability.

Whilst this procedure works well for investment decisions in regulated markets, in deregulated markets calculation of the LCOE is only a first approximation for determining economic viability. The variability of electricity prices and difficulty of forecasting such prices, especially in the face of the spread of low-cost gas and intermittent renewables as well as new techniques of demand-management, means that there is no certainty in deregulated markets that the LCOE will be covered by revenues. Although a limited forward market for electricity exists, the long timescale over which a nuclear power plant will operate means that future revenues are very uncertain.

<sup>31</sup> These are often referred to as discounted cash flow (DCF) or net present value (NPV) methodologies.

<sup>32</sup> Weighted Average Cost of Capital





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