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Nuclear Power Economics and Project Structuring

World Nuclear Association

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1 Introduction

The aims of this report are twofold. Firstly, to highlight that new nuclear build is fully justified 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. It is written to promote a better understanding of these complex topics by the educated layperson, which may encourage subsequent wider discussion.

From the national viewpoint, 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 power markets, nuclear plants must demonstrate their viability on normal commercial criteria as well as their life cycle advantages.

The research and development work that was 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, lower system pressure, the ability to stay on line 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.

Since the late 1980s, on the electricity power supply side, governments have steadily moved away from direct regulation in energy markets to concentrate on establishing the framework for a competitive supply system. There are significant differences in regulatory regimes with some countries retaining a substantial regulated element. Electricity market liberalization itself comes in many guises, but the industry today recognizes that all plants must demonstrate that they are cost-effective and that this must be achieved while still maintaining very high safety and environmental standards. Safety and the best economic operation tend, in any case, to go hand in hand.

With nuclear energy's higher capital cost and longer development and construction period, investors will focus on how risks can be managed and risk allocations optimized. The business case for nuclear will ultimately depend on the structure of risk allocation between operators, investors, suppliers and customers.

Although new nuclear power plants require large capital investment, they are hardly unique by the standards of the overall energy industry, where oil platforms and liquefied natural gas (LNG) 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 are equally applicable 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 must be public safety and the stable policy environment necessary for investment.

To support new-build projects, projects must be structured to 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 in the following sections –

Section 2 Highlights the excellent 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 major electricity infrastructure.

Section 9 Offers concluding remarks.

2 Economics of Current Plants

2.1 INTRODUCTION

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 of nuclear and it remains a strong argument today.

As the world is moving towards liberalized power markets, an electricity generating station should remain on line if generating (or marginal) costs are competitive with those of alternatives. These are sometimes also referred to as short run or "avoidable costs" as they are specific to the continued operation of an existing plant and are commonly broken down into operations and maintenance (O&M) and fuel costs (which should include an element for management and disposal of the used fuel). Previous costs of construction and plant decommissioning costs are not included – the former are effectively sunk, while the latter have to be paid once the plant is completed and operating – neither are specific to future operation of the plant. Capital costs may or may not be amortized in the accounting books of the plant owner, but this should not affect the decision on whether a plant continues to operate.

2.2 PLANT PERFORMANCES

With high fixed costs and low running costs, average electricity costs for nuclear plants fall substantially with increased output. It is vital for nuclear operators to achieve high plant availability and capacity factors[1], while strictly adhering to safety standards. Nuclear plants operate around the clock to achieve very low marginal and average costs.

Under growing base load electricity demand, capacity factors (sometimes called load factors) of nuclear plants around the world have increased by ten percentage points since 1990, from 70% to 80%. In particular countries, the improvement is even more dramatic – for example, in the United States from 66% to 90%. Levels of 90% and above have been achieved by many 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 semi base load and load following.

The impact of higher capacity factors can be seen in the stability of nuclear's share in world electricity generation from the late 1980s until comparatively recently. This was maintained at 16-17%, despite few new plant openings, but rapid electricity demand growth in the developing world has meant that the share has now fallen to 14%. Nevertheless, nuclear generating capacity has been rising at only 1% per annum since 1990, but nuclear electricity production by 2-3% per annum.

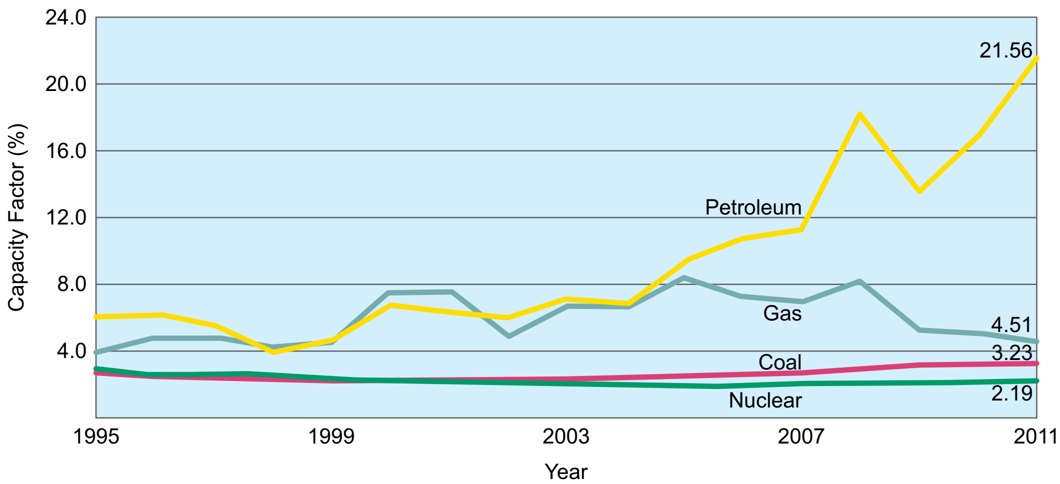
[1] Capacity factor is the ratio of the actual energy produced by a power plant in a given period, to the hypothetical maximum possible, i.e. running full time at rated power.

2.3 GENERATING COSTS

There are many country-specific factors but it is possible to make some general statements about the trend of fuel and operations and maintenance (O&M) costs of nuclear plants over time, compared with competing technologies. OECD[2]/NEA[3] studies from 1983-2009 (OECD-NEA & IEA (2010) and earlier) show relative stability in the overall generating cost of nuclear power plants. This has resulted essentially from two different factors: Nuclear fuel costs have fallen over time due to lower uranium and enrichment prices together with new fuel designs allowing higher burnups, while O&M costs tend to be somewhat higher than for other thermal modes of generation, but have now stabilized.

Nuclear fuel costs in the United States have fallen from 1.46 cents per kWh in the mid-1980s to only 0.68 cents per kWh today. This includes a mandatory element for used fuel management of 0.01 cents per kWh, paid into a central governmental fund. Uranium prices have risen since 2003, but the impact on electricity costs is relatively minor as the uranium cost is only a small fraction of the total kWh cost (around 5%). 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. In the new millennium, an upward tendency in these prices has become apparent, although technical developments in gas plants, particularly the introduction of high thermal efficiency combined cycle gas turbines (CCGTs) and the discovery of large quantities of unconventional shale gas, have limited the rise of operating costs per unit of electricity, at least for now and the near future.

Overall 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 United States, average nuclear production costs were 2.19 cents per kWh in 2011, the lowest of any generation technology in this country (Figure 1). In France as well, O&M and fuel costs remain much lower for nuclear generation than for coal and gas plants.



Note: Production costs = Operations & Maintenance + Fuel. Production costs exclude capital cost since this varies greatly among utilities and states.
Source: Nuclear Energy Institute

Figure 1: US electricity production costs 1995-2011, 2011 cents per kWh

The trend in nuclear production costs has been strongly downwards in the US in real terms since the mid-1980s and the split between O&M and fuel costs is shown in Table 1.

2 OECD = Organisation for Economic Co-operation and Development
3 NEA = Nuclear Energy Agency, an agency of the OECD

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

	1985	1990	1995	2000	2005	2011
O&M costs	2.21	2.37	1.96	1.59	1.44	1.51
Fuel costs	1.46	1.15	0.84	0.63	0.51	0.68
Total	**3.67**	**3.52**	**2.80**	**2.22**	**1.95**	**2.19**

Source: FERC[4]

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, fuel and spent 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 spent fuel charges to reduce as the accumulated fund dedicated to this becomes mature. In Germany, spent fuel charges tend to be higher so generating costs are usually around 1.4 Euro cents per kWh.

At such levels, nuclear power plants have been performing very well on a sustained basis and are the most competitive non-hydro technology on operating cost grounds.

Nuclear operating costs can be reduced further in certain ways. However, it cannot be assumed that uranium prices will decline once again – indeed, they are likely to remain at a higher level for some time, thereby encouraging new mine investment. Fuel service costs, already low, could be cut slightly further thanks to technological progress (e.g. higher burnup fuel) as well as through the implementation of innovations (e.g. in enrichment and spent fuel management), insofar as far as these can be implemented in full compliance with safety requirements and public acceptance. 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.

2.4 CAPACITY UP-RATES

Up-rating the power output of nuclear reactors is recognized as a highly economic source of additional generating capacity. The refurbishment of the plant turbo generator combined with utilizing the benefits of initial margins in reactor designs and digital instrumentation and control technologies can increase plant output significantly, by up to 15-20%. There are many examples of this throughout the world, but it is a particular focus in Sweden, the United States and East European countries. In Sweden, all of the remaining reactors will most likely be up-rated, while in United States, up to 3 GWe could be added to nuclear capacity via this route between 2011 and 2015. Capacity up-rates are particularly important in spreading fixed O&M costs over a higher output and have been important in cutting generating costs per kWh.

2.5 LICENCE EXTENSIONS

In those cases where plant licences are limited in time, owners are seeking and obtaining extensions from their regulatory authorities where they can justify longer operational lives for their plants. Such owners

[4] FERC = Federal Energy Regulatory Commission (USA)

are then prepared to make substantial capital investments in the plants. This process is most visible in the United States as over half the 104 units have already been granted a 20-year life extension and many others are in the process of applying. This started with a small number of plants, but is now expected to spread to most operating units in the country. The relicensing process has been more predictable and less expensive than many commentators originally anticipated. For companies in the private sector, extending the lifetime of plants may also allow them to spread decommissioning charges over an extended lifetime and further improve profitability. Nevertheless, it is accepted that requirements to undertake substantial capital expenditure, possibly for safety reasons, may still force closure on some current nuclear plants which cannot justify the sums involved, especially the smaller, older and inherently less efficient units.

2.6 MARKET IN EXISTING NUCLEAR PLANTS

The attraction of existing nuclear power stations in a liberalized market has been demonstrated in the United States. Ownership consolidation of nuclear plants has been a powerful force in recent years, with the larger groups Exelon, Entergy, Dominion and FPL buying plants from owners with only one or two reactors and thus less committed to nuclear. It is expected that this will continue in the future, with all US nuclear plants eventually operated by a smaller number of large companies. These plants have substantial asset values and those available have attracted several bidders, while prices have generally risen. This has been a positive feature for the industry, as it suggests confidence in achieving continued low cost operation. It also has advantages in raising capital for any new units.

2.7 CONCLUSIONS

The overall picture with current nuclear plants is very clear. They are operating more efficiently and operating costs are generally low relative to those of alternative generating technologies. More output is being achieved with each reactor through improved availability / capacity up-rates and operation will 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 Fukushima accident is unlikely to alter these general conclusions. The additional capital expenditure necessary to meet regulatory requirements following the reactor "stress tests" and other evaluations will not have any significant impact on the costs of nuclear generation. In the United States, it is believed that the additional, costs will fall below those imposed by the post 9/11 additional security requirements and a figure of only $100 million across the entire US nuclear fleet of 104 units has been quoted. In France, a higher figure for the 58 nuclear units, of up to 10 billion Euros in additional post-Fukushima costs, has been announced. However, this has to be seen in the context of the need to invest heavily anyway in extending the operating life of these units beyond 40 years. The cost of this pre-Fukushima was quoted at 30 billion Euros (spread over many years) and the additional 10 billion Euros will have only a minimal impact on the cost of nuclear electricity over the next 20 years of operations. Extending the operating lives of the existing reactors has been judged by the national audit body the Cour des Comptes (2012) as the most economical way to extend the long history of low power prices in France.

A bigger 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 "super profits" earned by their owners. This has been a factor in Germany and Sweden and now also in Finland.

3 Market Potential for Electricity Generation to 2035

3.1 INTRODUCTION

Global primary energy production and consumption have recently been growing at around 2% per annum and most projections see this continuing, but at a slower rate in the period to 2035. For example, the New Policies Scenario in IEA[5] (2011) projects that global primary energy demand will increase by 38% in the period 2009-2035 (1.3% per annum), reaching 17 billion tonnes of oil equivalent.

The growth rate of electricity demand will exceed this, based on recent trends that favour the delivery of energy in this way. The environmental consequences of the exploitation of energy resources on this scale are now very much a subject of public debate. Policies aimed at lowering demand growth rates are under active consideration as are those that will shift the balance of supply towards those technologies deemed to be favourable from an environmental viewpoint, i.e. generating no or lower carbon emissions. These are considered by the IEA in their 450 Scenario, whereby the concentration of greenhouse gases in the atmosphere is constrained to 450 parts per million of carbon dioxide equivalent.

Within the electricity sector, a huge amount of investment in new generating capacity will be required by 2035 in order to satisfy both a doubling of demand and the need to replace a large number of plants that will be retired over this period.

3.2 ELECTRICITY SECTOR INVESTMENT REQUIREMENTS

According to the IEA (WEO 2011, New Policies Scenario), investment in electricity generation before 2035 will cost a cumulative $17 trillion and in their New Policies Scenario, power generation will increase from 20,043 TWh in 2009 to about 36,250 TWh in 2035. With plant retirements, a total of 5,900 GW of new build is required, costing some $10 trillion. The remaining $7 trillion will be needed for investment in transmission and distribution.

The IEA report does not break down the 5,900 GW of new capacity into that required for base load generation and that aimed at covering peaks. It has, however, noted that the reserve margins tend to reduce with liberalized power markets and there are therefore some doubts about the ability of liberalized regimes to ensure adequate cover.

3.3 THE POTENTIAL POSITION OF NUCLEAR POWER – IEA VIEW

The IEA has gradually taken a more optimistic view of the future of nuclear power as more governments have shown support, reflected in their policies. For example, in its 2011 World Energy Outlook (WEO), its New Policies Scenario shows a higher level of expected new nuclear build that previous Reference Scenarios in earlier reports, with world nuclear generating capacity rising from 370 GWe in 2011 to 591 GWe in 2030 and 633 GWe in 2035.

[5] IEA = International Energy Agency

A consequence of so much of the new generating capacity being fossil-fired in these two scenarios is that world carbon emissions from the electricity sector are set to carry on increasing steeply in the period to 2030. The 450 Scenario has lower electricity demand growth and also substantial technology shifting in favour of low carbon technologies such as nuclear and shows 758 GWe of nuclear capacity worldwide in 2030 and 865 GWe in 2035. 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, do not. Both of these assumptions are questionable.

In the aftermath of the Fukushima accident, the IEA has also developed a Low Nuclear case, in its 2011 WEO. This reflects possible policy changes towards nuclear and also any ancillary economic impacts and shows world nuclear generating capacity at 340 GWe in 2030 and 335 GWe in 2035.

3.4 THE POTENTIAL POSITION OF NUCLEAR POWER – WNA[6] VIEW

WNA (2011a) shows three substantially different scenarios for nuclear to 2030. These are summarized in Table 2 and can be compared with the IEA views.

Table 2: WNA Nuclear Generating Capacity Scenarios, GWe

	2011	2015	2020	2025	2030
Reference	364	411	471	554	614
Lower	364	387	411	378	308
Upper	364	417	518	661	790

Source: WNA (2011a)

The WNA scenarios are prepared on a country-by-country basis but are developed by reference to a common set of generic assumptions for each scenario on, for example, the relative economics of nuclear compared with alternative generating technologies; the impact of measures introduced to stem greenhouse gas emissions, such as carbon taxes or emissions trading regimes; the state of public acceptance of nuclear power projects. For example, the reference case in WNA (2011) assumes that nuclear's economic position and public acceptance continue the slow but steady improvements achieved since 2000 (irrespective of the Fukushima accident in most countries) and shows nuclear generating capacity rising by 250 GWe to 2030. The upper scenario, on the other hand, assumes nuclear energy's economic position and public acceptance improve substantially from today and generating capacity more than doubles by 2030. There are relatively few retirements as most reactors achieve operating licence extensions. There is approximately 500 GW of new nuclear build, spread across many of the countries with current reactors but with particularly strong building programmes in China and India. This therefore constitutes a substantial revival of nuclear power. The lower scenario makes much more pessimistic assumptions and has very little new build beyond reactors currently under construction and a slow phase out beginning in the 2020s as many reactors around the world reach 40 years old.

[6] WNA = World Nuclear Association

Table 3: IEA and WNA nuclear capacity scenarios for 2030, GWe

IEA 2011	New Policies	591
	Low Nuclear	340
	450	758

WNA 2011	Reference	614
	Lower	307
	Upper	790

Source: WNA (2011a) and IEA (2011)

Table 3 shows that there is a good correspondence between the IEA's New Policies Scenario and the WNA Reference Scenario. The IEA 450 Scenario is similar to the WNA Upper Scenario, but not so optimistic on new reactor construction in the 2020s. On the other hand, the IEA Low Nuclear case is not as pessimistic as the WNA's Lower Scenario, which has very little new plant construction and accelerated closure of reactors in some countries.

The IEA scenarios effectively drop out of a wider energy model of the world, building in all the possible generation technologies, while the WNA's are more judgmental, building on WNA members' specific knowledge of particular countries. Nevertheless, the thinking behind both is similar. One recent development is that the IEA was previously over-pessimistic about current reactors shutting down, but they now recognize that they are generally performing very well in economic terms and operating periods are generally being extended, unless there are political impositions in this process (as in Germany).

3.5 CONCLUSIONS

Even when ignoring all environmental considerations, it is clear that the extent of the requirement for new generating capacity to 2035 affords nuclear a great opportunity for a sharp revival. Incoming policies to incorporate the external costs of fossil fuel burning are allowing the benefits of nuclear power from an environmental standpoint to become visible to potential investors. The key to grasping this opportunity is undoubtedly making the economics attractive, both with the current stock of reactors, where the case has already been strongly made, and now with new nuclear build programmes.

4 Economics of New Plant Construction

4.1 INTRODUCTION

As far as new electricity generating plants are concerned, the basic economic question can be presented quite simply. Are the lower and stable fuel costs of a nuclear plant compared with local competition from alternative generating modes sufficiently attractive to offset the higher initial capital costs?

The economics of generating electricity should ideally 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 nevertheless crucial in these evaluations. Both the magnitude and the timing of costs are variable for different technologies and are very location-dependent.

This is particularly important when evaluating the relative competitiveness of new generating capacity. With significant costs and revenues occurring at different times in the operating lives of all modes of electricity generation, a discount rate has to be chosen to bring ("levelize") these to a common basis, in order to allow economic comparisons[7]. This discount rate is sometimes set by a public authority as a target rate of return on capital, but in a liberalized market it is effectively the rate of return required on the project by financial markets – in other words, the cost of capital (a weighted average of the interest rate on any loan capital and the required return on equity). The levelized cost of electricity (LCOE) is the price needed to cover both the operating and annualized capital costs of the plant and is used as a marker for economic viability.

The balance of costs varies for different generating technologies. In the assessment of new capacity, recent studies quoted below show that capital costs including accrued interest account for around 60% of the levelized cost of electricity (LCOE) of a new nuclear plant. With Combined Cycle Gas Turbine (CCGT) plants, usually only around 20% of the costs are investment, with most of the remainder fuel. For renewable electricity projects, the capital cost element can be as high as 90%.

Fuel costs, even after accounting for the full costs of spent fuel and radioactive waste management, are the main economic advantage of nuclear plants against fossil fuel generating modes. Fuel costs for new nuclear plants (including spent fuel management) account for only around 20% of the LCOE whereas for CCGTs, it is typically 75%. The uranium concentrate component should be no more than 5%. New nuclear plant designs will use fuel much more economically, with higher burnups, meaning this is unlikely to rise significantly. The cost of electricity from nuclear power plants is therefore largely insensitive to changes in costs of uranium fuel, contrary to the situation in gas and coal plants. Fossil fuel prices, especially gas, are uncertain in the medium and longer term and project evaluations for power plants must incorporate considerable fuel price volatility.

International studies show that O&M costs are variable for nuclear plants, depending heavily on national regulatory practices, the efficiency of plant operators and on factors such as plant size and age. They tend, however, to be stable in any country over time (but can benefit from moving to higher capacity factors)

[7] These are often referred to as discounted cash flow (DCF) or net present value (NPV) methodologies.

and on average account for 20% of the LCOE. There have been continuous improvements made in plant operating practices since the TMI accident in 1979 and the Chernobyl accident in 1986. More recently, liberalization of electricity markets has arguably helped in introducing best practices in reducing O&M costs throughout the industry.

Provision is usually made for nuclear plant decommissioning costs by making financial contributions over the economic life of the plant towards plant dismantling and eventual site restoration. Given that plants are expected to have long lives, the contributions are not significant (usually less than 1% of the total) in the context of the competitiveness of either current or future nuclear plants.

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 financial appraisals. Once capital-intensive power plants are completed, the capital costs and accrued interest must be recovered through a long operating life with fuel and O&M costs well below the prevailing electricity price. This has been the general experience with nuclear plants.

It should be noted that these costs taken altogether 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[8] (European Commission 2001). Nuclear fuel costs include charges for spent fuel management and disposal. These are well-identified and validated, providing a good level of predictability of longer term costs (OECD-NEA 1994).

4.2 CAPITAL COSTS

With relatively few new nuclear plants constructed in the past decade, the amount of information on the costs of building modern nuclear plants is inevitably somewhat limited, but the many studies that have been made available do their best to derive reasonable estimates.

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. They include engineering-procurement-construction (EPC) costs, owners' costs and various contingencies. Once the plant is completed and electricity sales begin, the plant owner begins to repay the sum of the overnight 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. In the case of nuclear plants, fuel costs will include an allowance for the management and disposal of the spent fuel. A periodic charge for the decommissioning of the plant should also be made, provided over the economic life of the plant, to pay for the eventual cost. However, this is likely to take place some 40 to 60 years after plant commissioning.

[8] 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. Doing so is a clear objective for the European Union, for example, as expressed in the Fifth Framework Programme of the European Commission and in the Göteborg Protocol of 2001.

OECD-NEA and the IEA published in March 2010 a report "Costs of Generating Electricity." The report uses data provided by national authorities (and from industry associations Eurelectric and EPRI) in the autumn of 2009, and normalizes the calculation of the cost in US$ per kWh conversion at current exchange rates through 2008 and by using three common parameters: the discount rate, lifetime and cost of CO2. Nevertheless the capital and other costs are taken as local data. The obvious interest of the report is to compare costs between countries and different technologies. The level varies considerably by country – see Table 4. This also compares estimated costs in 1998.

By 2009, there are marked differences between Korea at below $2000 for various reactors, Japan and Russia at around US$3000 per kW and Western Europe/United States, where the level is quoted at anything from US$3500 per kW upwards.

Table 4: Capital cost estimates for a new NPP, US$/kWe

Country	Technology	Overnight cost[A]		Investment cost[B]	
		1998	2009	1998	2009
Europe					
Belgium	PWR (EPR)		5 383		7 117
Finland	BWR	2 256		2 672	
France	PWR	1 636		2 280	
	PWR (EPR)		3 860		5 219
Germany	PWR		4 102		5 022
Netherlands	PWR		5 105		6 383
Spain	PWR	2 169		2 957	
Switzerland	PWR		4 043		5 612
East Asia					
Japan	BWR	2 521		3 146	
	ABWR		3 009		3 940
South Korea	PWR	1 637	1 876	2 260	2 340
North America					
Canada	PHWR (Candu)	1 697		2 384	
USA	APWR	1 441	3 382	2 065	4 296
OECD Average		**1 908**	**3 845**	**2 538**	**4 991**

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 percent a year.

Sources: IEA, 2001, Nuclear Power in the OECD, Paris: OECD-NEA & IEA, 2010, Projected Costs of Generating Electricity, Paris: OECD

These capital cost levels are also reflected in other studies and by what is known about nuclear projects currently under construction in Asia and Europe. For example the Cour des Comptes (2012) in France puts the cost (including interest payments) of the EPR currently under construction at Flamanville at 3700 Euros per kW (so about US$5000 per kW) and the 2009 update to the MIT 2003 report "The Future of Nuclear Power" puts overnight costs in the United States at US$4000 per kW.

4.3 VARIATION AND ESCALATION OF CAPITAL COSTS

The significant variation of capital costs by country, particularly between the emerging industrial countries of East Asia and both Europe and North America, has a variety of explanations, including differential labour costs, more experience in the recent building of reactors, economies of scale from building multiple units and streamlined licensing and project management within large civil engineering projects. The variation also exists with other non-nuclear generation technologies and no doubt with major infrastructure projects such as roads and bridges too. However, its existence is particularly crucial for nuclear as its economics depend so much on minimising the capital investment cost.

The University of Chicago study (2004) also showed that alternative reactor technologies can also generate different cost estimates while reactor components can be quoted at higher or lower levels at various times. Allowances for contingencies are necessary when vendors make firm fixed price offers while some estimates may include first-of-a-kind engineering (FOAK) costs and others may not. Some estimates include reductions for nth-of-a-kind reactors, through learning-by-doing, or for building two or more reactors simultaneously on one site. A follow-up study was issued in 2011.

About 80% of overnight costs are EPC costs, with about 70% of these direct (physical plant equipment with labour and materials to assemble them) and 30% indirect (supervisory engineering and support labour costs with some materials). The remaining 20% of overnight costs are contingencies and owners' costs (essentially the cost of testing systems and training of staff). In addition, FOAK costs are a fixed cost of a particular reactor and can amount to up to $1 billion. How these are added to overnight capital costs depends on how the vendor wishes to allocate these across various reactors. If it wishes to recover them all on the first reactor, this could easily add one-third to an overnight cost of $3000 per kW.

Another issue is the apparent escalation of nuclear capital costs over time, also shown in Table 4. Between the two MIT studies in 2003 and 2009, the estimated overnight cost of a new nuclear plant in the United States doubled from US$2000 per kW installed to US$4000. Some of the early estimates (largely from vendor interests) about the likely costs of the latest Generation III reactors were clearly over-optimistic, but the degree of subsequent escalation (also borne out by the experience of the EPR projects in Finland and France) is of concern. Nuclear is usually regarded as a mature technology and one might therefore normally expect costs to fall rather than rise over time.

The 2011 University of Chicago Study came to a similar conclusion, saying that there had been a rise in overnight capital costs from US$ 2000 to US$ 4210/kW. It reported that in the view of experts consulted, "the 'number one' reason why nuclear capital costs have increased" was to be found in the EPC contracting arrangements, whereby the main contractor took on the construction risk and was subject to penalty clauses. These terms were in turn passed onto suppliers through similar contract provision so that there was a 'pancaking' of contingencies built into the full EPC price. This attribution is, however, open to question. As already mentioned, the US$ 2000/kW cost could well have understated the actual costs pertaining at the end of the 1990s, although this figure was widely quoted at the time[9]. Indeed, the study's authors noted that "these costs were probably understated significantly … due to the limited level of knowledge" and failure to include the full scope of works (for example, roads, warehouses and security). They suggested that the 2004 figure should be uplifted by US$ 1000/kWe, which would then

[9] WNA's previous report cited the cost of € 2000/kW for new nuclear build in Europe and North America. This value appeared reasonable in the light of significantly lower costs realized from actual construction in Asia.

imply that commodity prices contributed 41.3 percent to the overall increase, owner's costs 28.9 percent and the balance of 29.7 percent is attributable to design maturation and the shift in risk allocation to the EPC contractor. Indeed, the recent volatility of commodity prices has forced EPC contractors and their suppliers to include more contingency within their prices.

Commodity prices, labor and construction costs rose rapidly in the US between 2004 and 2008. Labor shortages and productivity and a tight supply chain were significant pressures, according to ratings agency Standard & Poor's[10]. A similar study by Moody's also pointed to rising constructions costs driven by labor and commodities[11]. Uncertainty in prices has meant that the EPC contractors and their suppliers have had to raise the contingency element where there is no escalation provision in their contracts.

The French programme also provides some useful data. The Cour des Comptes has said that the costs of building NPPs has increased over time from 1170 Euros per kW (at 2010 prices) when the first of the 50 PWRs was built at Fessenheim (commissioned in 1978), to 2060 Euros per kW when Chooz 1 and 2 were built in 2000 and a projected 3700 Euros per kW for the Flamanville EPR. Nevertheless, 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 failing to achieve obvious economies of scale. The French programme also arguably shows that industrial organization and standardization of a series of reactors allowed construction costs, construction time and operating and maintenance costs to be brought under control. The total overnight investment cost of the French PWR programme amounted to less than 85 billion Euros at 2010 prices. When divided by the total installed capacity (63 GW), the average overnight cost is 1335 Euros per kW. This is much in line with the costs that were then provided by the manufacturers.

It is clear that the economics of nuclear power are much improved if a series of standard models can be ordered. Economies of scale and scope then come into play and the commercial risks involved in the supply of nuclear grade components and systems can be amortized over several units.

4.4 REDUCING THE CAPITAL COSTS OF NUCLEAR PLANTS

OECD-NEA (2000) is a comprehensive report on this subject and identifies many areas where improvements have been proposed by vendors to get costs down to the levels that will ensure that nuclear is competitive. For example,

- Larger unit capacities provide substantial economies of scale with nuclear plants, suggesting that reactor sizes should target high levels for economic reasons.
- 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.

[10] Standard & Poor's, Construction costs to soar for new US nuclear power plants, Ratings Direct, 15 October 2008.
[11] Moody's Investment Service, *New nuclear generating capacity: Potential credit implications for US investor owned utilities*, Moody's Corporate Finance, May 2008: p.14.

- Simpler designs, possibly incorporating passive safety systems, can also yield savings as can improved construction methods.
- A final key element is the regulatory process. Clearly 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.

Looking at the recent experience in Asia, particularly China and Korea, has proven that series construction and standardization can indeed reap significant benefits in lowering capital costs – this can be seen in the latest OECD-NEA and IEA study.

4.5 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 this, 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, University of Chicago (2004) shows that the interest payments during construction can be as much as 30% of the overall expenditures. This increases to 40% if applied to a seven-year construction schedule, demonstrating the importance of completing the plant quickly. The industry, however, believes that the construction period could be as low as four years, in line with recent plant orders. 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 is unwarranted, on the basis of consistent achievement of building plants on schedule and on budget, as is already the case in East Asia.

4.6 EVALUATIONS OF NUCLEAR COMPETITIVENESS

As nuclear plants have relatively high capital costs but low marginal operating costs, they run most economically at very high load factors, supplying the demand for "base load" electricity. Although renewable energy sources are likely to take an increasing share of incremental electricity supply in many markets (whether for purely economic reasons, government subsidy or consumer choice), it is still likely that most incremental and replacement generating investments to satisfy the base load will use fossil fuels (coal or gas), or nuclear.

There have been many studies carried out which assess the relative costs of generating electricity by new plants utilizing different technologies by producing levelized cost comparisons. Probably the most respected are the two already mentioned, from OECD-NEA & IEA and MIT. The former has the advantage of having been produced regularly at roughly five-year intervals in the past (the last edition in 2010) and the MIT report was originally from 2003 but was updated in 2009.

OECD-NEA & IEA provides generating costs included in Table 5:

Table 5: Levelized Costs of Electricity, US$/MWh

Technology	Regional/Industry data	Levelized Cost (US$/MWh)
Nuclear	OECD Americas	77
	OECD Asia	42-76
	OECD Europe	83-137
	Non-OECD Americas	105
	Non-OECD Asia	44-55
	Non-OECD Europe	68
	EPRI	73
	Eurelectric	106
Coal-fired with CCS – Black coal	OECD Americas	88-94
	OECD Europe	110
	Non-OECD Europe	118
	ESAA	82-90
	Eurelectric	102
Coal-fired with CCS – Brown coal	OECD Europe	95-143
	ESAA	86-90
Combined-cycle gas turbine with CCS	OECD Europe	118
	OECD Americas	104
Large hydroelectric	OECD Europe	140-459
	OECD Asia	282
	Non-OECD Americas	33-61
	Non-OECD Asia	23-52
	Eurelectric	71
Large hydroelectric with pumped storage	Eurelectric	149
Onshore wind	OECD Americas	70-146
	OECD Europe	122-230
	Non-OECD Asia	72-126
	Non-OECD Europe	90
	EPRI	91
	ESAA	114
	Eurelectric	155
Offshore wind	OECD Americas	146-195
	OECD Europe	187-261
	Eurelectric	163-182
Wave	OECD Europe	224
	ESAA	242
Solar photovoltaic	OECD Americas	333-436
	OECD Europe	388-616
	Non-OECD Asia	187-283
	Eurelectric	361
Tidal	ESAA	348

Source: OECD-NEA & IEA, 2010, Projected Costs of Generating Electricity, Paris: OECD: Table 3.7.

This report highlights the continued competitiveness of nuclear in many countries since the previous report in 2005 and the general improvement since the 1998 report. This is generally due to the improved operating performances by nuclear plants and to higher fossil fuel price expectations. A summary of the results (see Table 6) shows that, even at a 10% discount rate, nuclear is the cheapest option in the majority of countries. For the OECD countries however, the report does assume a cost of carbon of $30 per tonne.

Table 6: Summary of generating costs in US$ per MWh

Fuel	5% Discount rate	10% Discount rate
Nuclear	29-78	42-136
Coal	57-103	82-152
Natural gas	36-119	39-123

Source : OECD-NEA & IEA (2010)

In 2005, the costs were, according to NEA and IEA as shown in Table 7.

Table 7: Summary of generating costs in US$ per MWh

Fuel	5% Discount rate	10% Discount rate
Nuclear	21-31	30-50
Coal	25-35	35-60
Natural gas	37-60	40-63

Source : OECD-NEA & IEA (2005)

The key messages of the 2010 report are very relevant:

- It points out the key role of government to provide a predictable and durable regulatory environment, with visibility and credibility for the investors and help ensure the competitiveness of low-carbon technologies, via the internalization of CO_2 prices.
- There is clearly no overall global conclusion on whether nuclear is the best option. In all circumstances an assessment of the specific conditions is required: Nuclear discounted at 5% is generally really competitive, but less so if it is discounted at 10%.

Other points are –

- Excluding special cases, the upper range of costs of nuclear, gas and coal is limited to less than $120/ MWh.
- Where gas is cheap (as in the United States today) it is hard for nuclear to compete. Continuation of low gas prices is, however, far from certain – low prices induce significant demand increases and possible curtailment of supply plans, hence prices have tended to be volatile.
- In good sites, the cost of large hydro is very low (<$50/ MWh).
- Except for some sites, solar remains expensive, more than $200 per MWh.

Although there is a range of assumptions used in various studies, it is possible to draw some general conclusions. Nuclear energy competitiveness mainly depends on the capital cost of the plant (and implicitly the construction time) together with the discount rate used. If a discount rate of 5-8% is used, then nuclear is competitive with overnight capital costs in the typical ranges apparent today.

A reduction of capital costs can be expected once the FOAK costs are absorbed, combined with learning-by-doing and reduced construction time. In addition, after a few plants are successfully completed on time, finance may be forthcoming for subsequent units on more favourable terms.

4.7 GREENHOUSE GAS EMISSIONS

As fossil fuel begins to incur costs associated with its impact on the climate through carbon taxes or emissions trading regimes, the competitiveness of new nuclear plants clearly improves. 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 Europe where an emissions trading regime has been introduced.

WNA has issued a report comparing greenhouse gas emissions from various generating sources that indicates that nuclear power plants are amongst the lowest of any power generation technology (WNA 2011b).

4.8 CONCLUSIONS

The various key parameters for new nuclear are well-understood and set out in the studies quoted. In particular, capital costs and also the period of construction must be kept as low as possible and financing secured at reasonable costs of capital. Where this is achieved, the economic case can be very strong. It is clear that new nuclear plants can be competitive against alternative generation technologies and provide better predictability of prices.

New nuclear plants should indeed be regarded as good, conservative long-term investment prospects. Once the initial significant capital cost burden for the very first units of a series is overcome, they can offer electricity at predictable low and stable costs for up to 60 years of operating life. Investment in nuclear should therefore be attractive to industrial companies who require significant base load amounts of low cost power for their operations in the long run.

5 Risks of Nuclear Projects and their Control

Structuring a nuclear new-build project for success requires the identification and understanding of the various the 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. 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 operations. Nuclear plants are also subject to public scrutiny and concern. In normal operation, nuclear plants are environmentally friendly. At the same time, public concerns often focus on the questions of long-term management of nuclear waste and potential consequences of low-probability safety events.

Table 8 overleaf lists risks that are associated with a nuclear project. Table 9, in Section 6, shows how these may be mitigated.

Table 8: Nuclear power project risk matrix

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

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 REGULATORY

Safety is of utmost importance in nuclear operations. Regulatory power is significant and concerns can delay or halt nuclear plant construction or operations. 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 (made easier in locations with previously constructed reactors). Next come licenses for construction and operation. Additionally, in most countries local planning approvals are needed both by law and as a means of achieving and demonstrating public acceptance.

Recent U.S. experience provides a good example of a step forward in 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 license to build and operate a new plant using a certified design and a pre-approved site – a combined construction and operating license called a COL.

The new approach moves all design, technical, regulatory, and licensing issues to the front of the licensing process. 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, of course, that adequate staffing of regulatory agencies is important for timely decisions.

5.2 PROJECT DELIVERY

New-build risks include costly delays due to problems with designs, equipment supply, project management, construction and commissioning. These risks, not unique to nuclear, can be allocated amongst the plant owner-operator, the plant engineering, procurement and construction (EPC) contractor, 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.

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 modeling, 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 design advances include a variety of safety features.

The nuclear industry (the large reactor vendors and utilities) is now working in cooperation with national and international regulatory and safety bodies with the aim of harmonizing regulatory and utility requirements to reactor designs throughout the world. Such harmonization would lower costs for manufacturing, construction, maintenance, and refueling outages. Standardized designs can be produced *en masse* and with economies of scale.

It has been recognized that those who build the first reactors of a new design (first of a kind, or FOAK) 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. These may be deemed appropriate in other markets.

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.

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.

5.3 OPERATIONS

While nuclear operations clearly involve a variety of risks, it should be noted that existing nuclear plants are now being run very professionally in some thirty 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 programs, 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.

Clearly the risk of poor operational performance can be controlled by the employment of 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 include a contingency fund for some capital expenditure through the life 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.

On nuclear liability, plant owners carry insurance to cover most operating risks. Liability for severe accidents is defined by international conventions (notably, the Vienna and Paris conventions) and/or by national legislation (such as Price Anderson in the United States). In contrast to many other industrial sectors, these frameworks have the advantage of precisely defining the liability borne by the operators, with public authorities covering the interests of residual claimants.

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

5.4 DECOMMISSIONING AND WASTE MANAGEMENT

End of life risks relate to the radioactive waste and used fuel management and plant decommissioning. Used fuel is regarded as part of the fuel cost, with an annual charge levied to take account of management. It depends, however, on an appropriate national political framework being established.

Decommissioning costs are covered by annual charges levied to cover the ultimate cost, fixed by national rules, similar to used fuel. Alternatively, a sum can be added to the capital cost of the plant and guarantees can be granted by the owners to the government for any uncovered sum from plant start-up.

5.5 ELECTRICITY GENERATION

A fundamental aspect of any new-build project is that the plant will achieve a ready market for its electricity at favourable prices. This evaluation must include future levels of grid power demand (or availability of potential customers for electricity), future market status of competing energy sources, and the long-term prospect for emission-trading mechanisms and other penalties on carbon.

The plain economics of electricity generation, whether from base-load or peak-load plants, requires electricity prices at a level sufficient to cover the full costs of capital and operations. Spot and short-term prices that reflect business cycles must be complemented by guaranteed long-term prices both on the wholesale and retail markets. Peak-load and semi-base-load plants with relatively high generating costs are the most exposed to market risks, but base-load plants such as nuclear must also achieve some market assurance. A sole nuclear generator with no retail customers is particularly vulnerable to the risk of low prices. Measures to control this risk could include long term power off-take arrangements or managing a nuclear plant within a vertically integrated utility that has a diversified portfolio of generating sources and its own customer base.

Fuel price risks must be taken into account. For example, gas-fired plants have faced major problems as gas prices have escalated. In liberalized power markets, where coal or gas is the predominant fuel, the electricity price is likely to be correlated with the marginal costs of these plants. The volatility of the prices of these fuels can then partly be transferred to electricity prices, which bear no correlation with costs of nuclear generation. This is a risk for volatility in earnings for a nuclear plant that utilities may seek to control through the measures highlighted above. It is important to note that all base-load generation modes require major capital investments and some security in power off-take, so they can encounter difficulties in the merchant plant model. In the significant bankruptcies of merchant plants that occurred in the USA in 2001-2002, not surprisingly most of the plants affected were those fueled by natural gas.

The degree of market risk depends crucially on the market structure. It is certainly no coincidence that many of the early new plants proposed in the USA are located in areas where electricity markets are still regulated, so that plant investment costs can be recaptured with greater assurance.

International and national emission-reduction policy frameworks should benefit nuclear investments and reduce market risks. In countries with a significant proportion of fossil fuels in the energy mix, an increased penalty on carbon will entail rises in the marginal cost of fossil generation. By raising wholesale electricity prices, carbon penalties increase the rate of return on nuclear investment. Still, because of the relative novelty of emission-reduction policies, nuclear investors will need to gain confidence in the government commitment to carbon pricing or any other mechanism designed to reward long-term investment in low-carbon technologies.

5.6 POLITICAL

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

Another political risk is that the tide of public acceptance can turn, undermining a project's viability during or after construction. Barring unforeseen and extreme events, however, utilities are in a strong position to minimize 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.

6 Project Structure and Risk Allocation

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

The structure of a new nuclear power project will be also be influenced by the market in each particular country or region. A project in a liberalized 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 most costs to be passed through to the consumer. This structure still depends on the quality of the regulator and its control processes.

There is no "unique way" to structure a nuclear project. A number of project models can succeed. The essential characteristic is a suitable sharing of risks and benefits.

Although project structures may vary, and can be complex in some markets, there will still 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 – which is responsible for overall energy policy and, in some cases, financing.
- 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 – engineering, procurement and construction 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.
- Safety authority – which is responsible for addressing all matters related to protecting public safety and the environment, from the design stage to plant operation and fuel management.

Table 9 overleaf shows ways in which the risks of nuclear projects can be monitored and controlled, to match Table 8.

Table 9: 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 near the site Previous construction experience Strong project management	Involvement in WANO, INPO etc 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
Business Case	Seek investment from major power users Build business case on various demand scenarios	Stick to standardized designs Use good mix of permanent and contract staff	Develop sound long term power contracts Develop good balance of fuel contracts Nuclear knowledge management	Contribute to well-defined fund as required Societal and Political
Societal and Political	Public debates and hearings Regular opinion polling Gaining cross party political support Emphasize environmental advantages of nuclear Develop WM policy with government			

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 at risk, even before the first concrete is poured.

6.2 STAKEHOLDER INVOLVEMENT

Stakeholder participation is a key to allaying legitimate concerns about waste management and the safety and security of nuclear installations. Public hearings and debate are sound means for improving dialogue and ultimately saving time. Providing information to the public and their representatives is essential to building trust with the wider community. Such information also serves a documentary function, placing in the open 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 still reside with the utility. Because nuclear plants are very expensive, impacting upon 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, for achieving high capacity factors, and for maintaining control of O&M costs. In controlling fuel and O&M costs, the utility can use long-term deals with suppliers and contract 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 EDF and stakeholder representatives.

6.5 DECOMMISSIONING

Plant decommissioning, as well as the management of waste and used fuel, must be the responsibility of industry players, operating within a sound regulatory framework. Public authorities must, however, bear ultimate policy responsibility for ensuring the establishment of facilities for the management, storage and disposal of long-life wastes. This requires the establishment of arrangements whereby plant operators establish and contribute to adequate funds to cover decommissioning expenses, which are effectively "ring-fenced".

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, and governments must respond. How effectively government responds in satisfying public concerns affects the political and public context – the degree of uncertainty – 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 must have a commitment to nuclear power as a part of national energy strategy. This must include a considerable degree of cross-party consensus. Clearly there cannot be cast-iron guarantees that government policy will not change, but there needs to be at least an agreement that the need for nuclear power is recognised as a long-term commitment. This essential requirement is not unique to nuclear energy.

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

- Energy policy – As a reference point and guide for all stakeholders, government must define a sound long-term energy policy addressing the major challenges of energy efficiency, 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 twin objectives of protecting public safety and security while facilitating the gain from the production of clean and reliable nuclear power. This should ideally be as clear, consistent and proportionate as possible 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 imposing unnecessary burdens on trade and the transfer of technology. To enhance efficiency and lower costs, construction and operating licenses can be issued together. The local planning process should concentrate on local issues, insuring full deliberation with 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 a full share of costs, governments must lead on this sensitive but fundamental issue, which involves all users of radiological and nuclear materials (hospitals, other industries, etc.). In some cases, governments will need to work with neighboring governments to develop shared storage and disposal facilities.
- Decommissioning – Government policy must ensure that each plant operator makes financial provision for decommissioning, using a fully 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 conduct an affirmative policy designed to facilitate and ensure an efficient and reliable energy market that 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.
- 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 institutionalized carbon penalties is the European emissions trading scheme (EU-ETS), a regional system of GHG tradable quotas, within a sequenced framework to encourage the cutback in emissions necessary to avoid runaway global warming and ocean acidification. An alternative is direct carbon taxes. Whatever policies are introduced, nuclear should be treated, without discrimination, 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. Contrary to common belief, there is no magic formula which financiers can suddenly produce to allow difficult projects to proceed to completion.

The two elements of financing are equity and debt. Equity holders – investors willing to take risk in exchange for adequate return – have a differential tolerance for risk. With more complex project structures, investors will perceive more risk, increasing what they will require in expected return.

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. More often, the borrower will be a single organization such as a large utility; here the lender will look for a strong balance sheet 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 certainty that their loan will be repaid on a given date.

In the 1970's and 1980's, many investors, notably in the US, lost money on nuclear and coal plant investments when market liberalization 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 1990's and early 2000's, 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 but there are limitations on what they can achieve. Nonetheless, today they do not appear reluctant to invest in nuclear. There is indeed, it is said, a huge wall of money seeking profitable investments. For nuclear projects to gain financing requires only that projects be structured so as to demonstrate clearly that they are "creditworthy" – in its widest sense (as financiers differ considerably in their requirements).

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 – depend heavily on the model of plant ownership and nature of the power market. Both are crucial in how risks are handled.

There is now a wide variety of electricity markets, representing many important national differences. In general, they fall under four headings:

- Regulated utility – This is the "traditional" model for the power market. Here generating plants operate under cost-of-service rate regulation and have market outlets for the electricity within the same company. This model gives potential investors more comfort as costs can usually – subject to scrutiny by regulators – be passed onto customers. Lenders are secured by access to the assets and revenues of generating companies as well as by a strong degree of market assurance.

- Unregulated merchant generating plant – This is the "new" model of the power market. Here generating plants compete and have no direct outlets for selling electricity. This liberalized market entails a significantly greater exposure to price risk, which must be mitigated by long term power purchase agreements (PPAs) or support from a parent company. Projects in these higher-risk markets will require a less leveraged balance sheet – more equity and less debt – and also greater security for debt.
- Hybrid – World experience with electricity market liberalization has generally tended to produce the kind of evolution that has occurred in Europe. Power markets there consist of some merchant generating plants but evolve towards a small number of vertically integrated large utility groups, with a spread of generation facilities and regional supply outlets. Such large groups use their large balance sheets to invest in generation projects with some security on the selling side.
- Investment in nuclear is now attractive to utilities previously not involved in the sector. These are likely to participate via long term partnership agreements for building and operating nuclear plants, typically with other companies more experienced in the business.

The early stages of a nuclear project will generally require substantial equity investment, probably from major power companies or at least financing via their own balance sheets. This requirement, particularly if a fleet of nuclear plants is planned, will often invite the creation of a consortium of companies. As a project proceeds and risk points are passed and first revenues come closer, debt financing will usually become easier, and refinancing of earlier loans can occur.

Specific financing routes for nuclear projects include:

- Balance sheet financing by utilities – Many utilities, especially in Europe, are integrated electricity service providers with strong balance sheets that enable them to finance even large capital costs, such as nuclear power plants.
- 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 has advantages for sponsors as projects are highly leveraged. They need to contribute much equity only at a later stage, while their other assets are protected. The difficulty is attracting debt financing at reasonable rates, but a government loan guarantee (as is proposed for initial new plants in the United States) could change this.
- Public-private partnership – These have been adopted for many infrastructure projects, especially in the United Kingdom. At one extreme this could see a government-run competition for a company (or more likely a consortium) to build, finance and operate a specified number of nuclear plants. Locations and technology could be specified, and the guarantee of an order for a series of standard NPPs would enable FOAK costs to be spread over a number of plants, resulting in a much keener construction cost per unit.
- Power user investment – In this model, which was adopted for the 5th Finnish reactor, the equity has largely been contributed by a consortium of local energy-intensive industries and local utilities. They will take the output of the plant at cost, amortizing the debt portion from the market. If the plant operates well, owners will receive relatively cheap electricity over a long period, avoiding the risks of having to buy or sell power on the open market at uncertain prices.

- BOOT (Build, own, operate, transfer) and BOO (Build, Own, Operate) – this model of vendor finance has been developed in nuclear by Russia in the context of its prospective investment in initial nuclear units in Turkey, but is quite common in infrastructure projects in other sectors. During a concession period, the vendor builds, owns and operates the facility with the prime goal to recover the costs of investment and operation through selling the power at a pre-agreed price to the local distribution companies, while trying to achieve some margin on the project. The equity in the project may eventually be transferred to a local company (BOOT) or remain for an extended period with the vendor (BOO).

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 in some countries has resulted in the perceived need for a substantial risk premium on lending for new nuclear investment – between 3% and 5%, as compared to other technologies. Nuclear projects may 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 syndrome must slowly be overcome.

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 companies 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. They are more 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 5th Finnish reactor, where there is no risk premium) or in the US regulated market, the cost of capital should be relatively low as many risks are mitigated.

Clearly, 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 make clear 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 a context of high-priced and volatile electricity markets, certain inherent features of nuclear energy should contribute to this lowering of risk perception, as compared to alternative technologies. These include:

- Cost stability, resulting from the low share of fuel in overall operating costs
- Fuel supply security
- High capacity factors, resulting from professional management and low variable costs
- Absence of any need for long-term subsidy (leaving aside the desirability of certain pump-priming measures to accelerate the nuclear renaissance)
- Absence of risk of carbon emissions costs.

9 Concluding Remarks

Nuclear projects have unique characteristics. They are capital intensive, with very long project schedules, but – once operational – they have remarkably low fuel and other operating costs. Nuclear plants also exist in a rigorous regulatory environment and are subject to significant public scrutiny and concern. These characteristics affect the structuring of nuclear new-build projects.

Experience has shown that nuclear projects are structured for success when risks are allocated amongst key stakeholders in a way that is equitable and encourages each participant to fulfill its responsibilities.

Government policy that recognizes the value of nuclear energy must be accompanied by government action to create the conditions for private investment in new nuclear power plants. Several models for such investment are available, and once a sound project structure is created, the ultimate key to success is strong project management.

10 References and Further Reading

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