WNA Report

The New Economics of Nuclear Power

World Nuclear Association

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Introduction by the Director General

Of all factors affecting prospects for the substantial growth of nuclear power in the 21st century, cost is the most fundamental. What are the essential economics associated with the construction and operation of advanced state-of-the-art nuclear power plants?

Certainly other factors will affect the pace of the global nuclear renaissance now under way. The nuclear debate continues to feature expressions of concern about nuclear arms, terrorism, operational and transport safety, and effective waste management and disposal. In addressing all of these concerns, however, the combined efforts of science, diplomacy and industry have achieved substantial advance in ensuring that civil nuclear power can be used without substantial human or environmental risk.

This achievement in meeting legitimate public concerns has provided the foundation for the nuclear renaissance by prompting governments in countries representing the preponderance of world population and economic activity to consider a wider exploitation of the benefits of nuclear energy. These benefits fall into two categories:

- National: price stability and security of energy supply
- Global environmental: near-zero greenhouse gas emissions.

Today, given the urgent environmental imperative of achieving a global clean-energy revolution, public policy has sound and urgent justification for placing a sizeable premium on clean technologies. Such environmentally-driven incentives can come through carbon taxes, emissions trading, or subsidies for non-emitting generators of power.

But the enactment of public policies fully infused with such vision and rationality is a slow process, perhaps too slow. A key question then is whether nuclear energy requires such policy intervention in order to be economically competitive. In short, is nuclear investment warranted in the absence of policy incentives?

This WNA Report addresses the question by providing an authoritative analysis of the economics associated with the construction and operation of nuclear power plants in the 21st century. To achieve this, the report draws upon numerous respected studies published since 2003, describes their premises and parameters, and summarizes the findings. To this synthesis the report adds analysis from member companies of the World Nuclear Association.

The Report was prepared by a WNA Working Group comprised of experts on nuclear economics and chaired by Roger W. Gale, President and CEO of GF Energy. The project was managed by Stephen Kidd, WNA Director of Strategy and Research.

Taken as a group, this and previous studies illustrate how sensitive the numerical conclusions of such analyses are to the particular assumptions and local conditions on which they are based. Despite these variations, a common theme emerges from this report and the studies that preceded it: The economic case favouring new nuclear build is now virtually universal. Nuclear energy today represents an affordable, economically competitive means to meet the world's growing demand for electricity.

Governments thus have two distinct roles with respect to the nuclear renaissance:

- To combine their regulatory, safety-oversight responsibilities with efficient licensing procedures that facilitate the timely introduction of advanced nuclear power plants
- To introduce incentives, as appropriate from a public policy perspective, to accelerate the transformation to clean-energy economies.

As this Report shows, the "new economics" of nuclear power means that the role of government intervention in the energy marketplace today is primarily a matter of stimulating the pace of energy decisions favouring nuclear power that now have a pure long-term economic rationale.

This WNA Report demonstrates that nuclear power in the 21st century will be economically competitive even without attaching economic weight to the global environmental virtues of nuclear power or to national advantages in price stability and security of energy supply. Although sound energy policies should attach great significance to those benefits and hasten investment to realize them, this analysis has isolated the basic economic argument.

The Report's compelling conclusion is that the case for nuclear energy is now solid on economics alone. Nuclear power's clean-energy advantage thus comes cost-free – an economic bonus that is also an environmental necessity. In recognizing and acting to exploit this benefit, our world has little time to lose.

JOHN RITCH

Executive Summary

Principal Conclusion

This World Nuclear Association Report entitled "The New Economics of Nuclear Power" provides international perspective and definitive analysis of the costs of constructing and operating nuclear power plants in the 21st century.

The Report's principal conclusion holds fundamental importance for energy planners: In most industrialized countries today, new nuclear power plants offer the most economical way to generate base-load electricity – even without consideration of the geopolitical and environmental advantages that nuclear energy confers.

Sources and Assumptions in the Analysis

This assessment is authoritative. It distils the analysis of numerous studies produced in recent years by various governmental and academic institutions, and then incorporates expert analysis from the WNA's worldwide membership of nuclear industry enterprises.

The Report was prepared in a global context in which governments are turning increasingly to nuclear power to achieve: (1) national goals of price stability and energy security; and (2) global goals of environmental preservation through reduced carbon emissions.

Significantly, the Report attaches no economic weight to those benefits. Instead, the findings constitute today's best available data on worldwide nuclear economics examined in isolation.

Future Nuclear Construction: An Expansive Market

Global energy consumption is growing rapidly. The International Energy Agency projects a doubling of world electricity demand by 2030, creating the need for some 4,700 GWe of new generating capacity in the next quarter century. Worldwide energy investment will be directed primarily at satisfying local base-load requirements.

As to the role of nuclear energy, WNA analysis uses three scenarios. Starting from current global nuclear capacity of 367 GWe, the WNA's Reference and Upper scenarios project an expansion of nuclear capacity to a range between 524 and 740 GWe in the next 25 years. These scenarios represent construction of 200 to 400 new reactors worldwide – some for replacement, most for new capacity.

WNA Nuclear Generating Capacity Scenarios, GWe

	2005	2010	2015	2020	2025	2030
Reference	367	381	410	446	488	524
Lower	367	372	372	367	317	281
Upper	367	389	447	518	613	740

Source: WNA (2005)

Factors in Nuclear Power's Increased Economic Competitiveness

The increased economic competitiveness of 21st century nuclear power arises from cost reductions in construction, financing, and plant operations, and a still further reduction in already low costs for waste management and decommissioning.

- *Construction costs* per kW for nuclear plants have fallen considerably due to standardized design, shorter construction times and more efficient generating technologies. Further gains are expected as nuclear technology becomes even more standardized around a few globally-accepted designs. Meanwhile, recent new-build experience has demonstrated that new plants can be built on time and on budget.

- *Financing costs* for new nuclear plants, a critical component of nuclear economics, are expected to fall as new approaches are developed and tested to increase certainty and to lower investor risk. Meanwhile, in many countries, licence procedures are being streamlined – a development facilitated by the nuclear industry's strong worldwide safety performance. Streamlined licensing will retain rigorous standards but reduce regulatory cost and uncertainty by establishing predictable technical parameters and timescales, from design certification through to construction and operating licences.

- *Operating costs* of nuclear power plants have fallen steadily over the past twenty years as capacity factors have increased, squeezing far more output from the same generating capacity. (In the USA, operating costs per KWh shrank by 44% between 1990 and 2003.) As marginal costs of generation from nuclear plants have fallen below prices of most other generating modes, owners have found it worthwhile to invest in nuclear plant refurbishment and capacity up-rates. Nuclear power's low marginal cost and its high degree of price stability and predictability have also encouraged nuclear plant owners to seek operating licence extensions for nearly all reactors.

- *Waste and decommissioning costs*, which are included in the operational costs of nuclear plants, represent a tiny fraction of the lifetime costs of a reactor's operation. Nuclear plant economics are thus largely insensitive to these costs and will become even less so as fuel efficiency continues to increase and as waste and decommissioning costs are spread over reactor lifetimes that are becoming even longer.

The Bottom Line: A Nuclear Advantage on Economics Alone

Nuclear power has always been characterized by a combination of higher construction and lower operating costs as compared to fossil energy. The key development in the "new economics" of nuclear power is that, both costs considered, nuclear power has now become less expensive than fossil and any other form of electricity generation.

This WNA Report reinforces intergovernmental analysis published earlier this year by the International Energy Agency and the OECD's Nuclear Energy Agency. Their joint publication, entitled *Projected Costs of Generating Electricity*, recorded the remarkable improvement in nuclear competitiveness in recent years.

Summary of generating costs in US$ per MWh

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

Source : IEA & OECD-NEA (2005)

This WNA Report accepts the IEA-NEA figures as essentially valid, while noting that they may well underestimate the nuclear advantage. Basic data for the IEA-NEA analysis were collected before recent price increases for fossil fuel – changes that would shift the calculation even more in favour of nuclear generation.

While this WNA Report makes no prediction regarding future changes in fossil prices, it should be recognized that any such increases – arising either from anticipated fossil supply limitations or the expected enactment of public policies to abate carbon emissions – will serve to tilt the economic balance still further in favour of nuclear power.

By implication, this WNA Report:

- Underscores how important it is that the necessary regulatory role of government – through licensing and safety oversight – be performed with an efficiency that does not undermine the fundamental competitiveness of nuclear economics
- Demonstrates that nuclear power does not, over the long-term, require subsidy. Governmental measures to stimulate nuclear investment may be extremely well justified in serving geopolitical and environmental aims, but are not required by the fundamentals of long-term nuclear economics.

The value of nuclear power in providing price stability, security of energy supply, and low-emission base-load electricity has, in recent years, been increasingly recognized. Less recognised has been the equally significant advantage that this WNA Report serves to document: nuclear power's long-term competitiveness in pure economic terms.

The combined virtues of nuclear power have sparked the nuclear renaissance. Those same virtues should galvanize governments to continue in:

- Streamlining nuclear power licensing and safety oversight
- Adopting adroit measures to hasten investment in a technology that is both competitive economically and urgently needed environmentally.

1 Purpose

The aim of this report is to highlight that new nuclear build is fully justified on the strength of today's economic criteria. It is written to promote a better understanding of this complex topic 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 markets, nuclear plants must demonstrate on their own merits their economic competitiveness as well as their life cycle advantages. The attention paid to combating global warming has indeed increased the attention paid to nuclear power as a near-zero carbon-emitting technology. In some markets, nuclear is already receiving an economic benefit from this, through carbon trading regimes.

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 better to compete 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 widespread intervention in energy markets, but it is uncertain which business models will become established in the longer term. Various business models may achieve national objectives and some may retain 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 standards. Safety and the best economic operation tend, in any case, to go hand in hand.

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

Section 4 examines the ability of new nuclear plants to compete in liberalized power markets

Section 5 contains some 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 permitted long-term investment. In some countries, nuclear plants were primarily built for national security of supply reasons, although competitively priced electricity with a stable cost was clearly 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 of costs was also an important consideration in favour of nuclear and remains a strong argument today.

As the world is moving towards liberalized power markets, an electricity generating station should remain on line if its forward (or marginal) costs are competitive with those of alternatives. Previous costs of construction are effectively sunk. These 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, unit 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 demand, capacity 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.

The impact of higher capacity factors can be seen in the stability of nuclear's share in world electricity generation since the late 1980s. This has been maintained at 16-17%, despite few new plant openings. Nuclear generating capacity has been rising at only 1% per annum, but nuclear electricity production by 2-3% per annum.

2.3 OPERATING 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 1983-2005 (OECD-NEA/IEA 2005 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 due to lower uranium and enrichment prices together with new fuel designs allowing higher burnups, while O&M costs have now stabilized at levels competitive with other base-load generation.

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

Nuclear fuel costs in the United States have fallen from 1.28 cents per kWh in the mid-1980s to only 0.44 cents per kWh today. Uranium prices have risen sharply in the past two years, but the impact on electricity costs will be 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), have limited the rise of operating costs per unit of electricity.

Overall marginal 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 1.72 cents per kWh in 2003, the lowest of any generation technology in this country. The trend has been strongly downwards in real terms since the mid-1980s as shown in Table 1.

Table 1: Average US nuclear production costs, 1981-2003, 2003 cents per kWh

	1981	1985	1990	1995	2000	2003
O&M costs	1.41	1.93	2.07	1.73	1.37	1.28
Fuel costs	1.06	1.28	1.01	0.69	0.52	0.44
Total	**2.47**	**3.21**	**3.08**	**2.42**	**1.89**	**1.72**

Source: FERC[4]/EUCG[5]

In Europe, levels of 1 euro cent per kWh have been achieved 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 marginal costs are usually around 1.4 euro cents per kWh. In France, the combined O&M and fuel cost for EDF's fleet of plants has also been quoted at 1.4 euro cents per kWh (Stricker and Leclercq (2004).

At such levels, nuclear power plants have been operating 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. It cannot be assumed that uranium prices will decline further – indeed, they have recently risen and 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[6] 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 etc.

[4] FERC = Federal Energy Regulatory Commission (USA)
[5] EUCG = Electric Utility Cost Group (USA)
[6] Burnup = Amount of heat released by nuclear fuel relative to its mass, usually expressed as gigawatt days per tonne (GWd/tU)

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 5GWe could be added to nuclear capacity via this route between 2005 and 2010.

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 are then prepared to make substantial capital investments in the plants. This process is most visible in the United States as 30 units have already been granted with a 20-year life extension and many others are in the process of doing so. This started with a small number of plants, but is now expected to spread to virtually every plant 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 reduce their annual depreciation charge thereby spreading decommissioning charges over an extended lifetime and further improving 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, Constellation 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 small 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. A similar trend has been observed in continental Europe (Germany, Slovakia).

2.7 CONCLUSIONS

The overall picture with current nuclear plants is very clear. They are operating more and 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.

3 Market Potential for Electricity Generation to 2030

3.1 INTRODUCTION

World energy production and consumption have recently been growing at around 2% per annum and most projections see this continuing in the period to 2030. For example, the reference case in IEA[7] (2004) projects that global primary energy demand will increase by two-thirds in the three decades to 2030, reaching 16.5 billion tonnes of oil equivalent. This represents a growth rate of 1.7% per annum in the period 2000-2030.

It is also likely that 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.

Within the electricity sector, a huge amount of investment in new generating capacity will be required by 2030 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, investment in electricity generation capacity will take about $4.5 trillion and installed capacity will rise to 7,157 GW by 2030 from 3,498 GW in 2000. As around 1,000 GW of capacity is likely to be retired over the period, a total of 4,700 GW of new build is required, costing some $4.1 trillion. The remaining $400 billion will be needed for plant refurbishment.

The IEA report does not break down the 4,700 GW of new capacity into that required for base-load generation and that aimed at covering peaks. It does, however, note 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

IEA (2003) and IEA (2004) are conservative about the ability of nuclear to be an economic option for new generating capacity. By 2030, they envisage only 150 GW of the 4,700 GW of new capacity being nuclear, concentrated very much in Asia. However, over this period they also expect an identical quantity of existing nuclear capacity to be retired, so nuclear generating capacity remains unchanged. On IEA's projections, nuclear's share of world electricity supply will nearly halve from 16% today to 9% by 2030.

[7] IEA = International Energy Agency

The IEA model assumes that the capital costs of new nuclear plants will largely rule them out of consideration, particularly as gas prices are set to rise only slowly. In the reference case of IEA (2004), gas-fired plants account for nearly 2,000 GW of the new capacity by 2020 and more than 1,400 GW is coal (nearly half of this will be in China and India alone). 470 GW is oil-fired, 430 GW hydro and nearly 400 GW in other renewable energies.

The consequence of so much of the new capacity being fossil-fired would be that world carbon emissions from the electricity sector are set to carry on increasing steeply in the period to 2030.

3.4 THE POTENTIAL POSITION OF NUCLEAR POWER – WNA[8] VIEW

WNA (2005) shows three substantially different scenarios for nuclear to 2030. These are summarized in Table 2 and can be compared with the IEA reference view.

Table 2: WNA Nuclear Generating Capacity Scenarios, GWe

	2005	2010	2015	2020	2025	2030
Reference	367	381	410	446	488	524
Lower	367	372	372	367	317	281
Upper	367	389	447	518	613	740

Source: WNA (2005)

The reference case in WNA (2005) assumes that nuclear's economic position and public acceptance continue the slow but steady improvements recently achieved. It shows nuclear generating capacity rising by 157 GW to 2030, compared with the static position in the IEA report. The IEA assessment of nuclear shutdown capacity of 150 GW by 2030 looks very high, given recent experience. Although smaller and older reactors will shut down in many countries and politically-inspired closures may take place in others, the current stock of reactors is generally performing very well in economic terms and operating lives are being extended (see Section 2). Other features to note include the extent of actual and planned capacity increases and the widespread development of life extension programmes for existing reactors as they are refurbished (Belgium, France, Netherlands, Spain, Sweden, USA).

The IEA's substantial retirement schedule is similar to that included in the lower scenario of WNA (2005). This assumes that nuclear's economic position and public acceptance deteriorates, so existing reactors are retired earlier. There are relatively few new reactors, compared to the IEA case, so nuclear generating capacity falls by 86 GW by 2030.

The upper scenario in WNA (2005) assumes nuclear'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 and the current phase-out policies in Sweden and Germany are reversed. There is approximately 400 GW of new nuclear build, spread across many of the countries with current reactors but with particularly strong building programmes in the USA, China and India. This therefore constitutes a substantial revival of nuclear power.

[8] WNA = World Nuclear Association

3.5 CONCLUSION

The IEA model assumes that the capital costs of new nuclear plants will largely rule them out of consideration, particularly as they see fossil prices set to rise only slowly. This is likely to be substantially wide of the mark on both counts.

Even when ignoring all environmental considerations, it is clear that the extent of the requirement for new generating capacity to 2030 affords nuclear a great opportunity for a sharp revival. Oncoming 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 with new build.

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. This discount rate is sometimes set by a public authority as a target rate of return on capital, but in a liberalized market 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 fuel price volatility.

Operations and maintenance (O&M) costs are very variable for nuclear plants, depending on factors such as plant size and age but on average account for 20% of the LCOE. Other relevant factors include the regulatory regime and the efficiency of the plant operator. Liberalization of electricity markets has helped in introducing best practices in reducing O&M costs throughout the industry, while maintaining or improving high safety standards.

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 – less than 1% – 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[9] (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

Construction costs of nuclear plants completed during the 1980s and 1990s in the United States were high compared with what the industry believes is possible today. Regulatory delays, redesign requirements and difficulties in construction management and quality control all inflated costs. Many plants were also completed at a time of high general inflation, which dramatically exacerbated the impact of delays. 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.

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 engineer-procure-construct (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. This is likely to be some 40 to 60 years in the future.

Most studies of the competitiveness of nuclear power base their estimates of capital costs on data of construction costs of recent reactors in Asian countries and use overnight costs (i.e. without interest

[9] 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.

charges and financing costs) of at and above $2000 per kW of capacity. For example, EIA[10] (2004) used a starting point of $2083 per kW for its estimates in its 2004 *Annual Energy Outlook*, while MIT[11] (2003) used $2000 per kW. In both cases, lower costs were also considered, based on learning benefits of later units and the innovative designs of the latest reactors.

Estimates have been produced by vendors and their partners and scrutinized by outside reviewers as far as is possible without building a test plant. For designs such as the Westinghouse AP1000, the GE[12] ESBWR and the AECL[13] ACR-1000, the overnight capital costs of building twin units on one site are in the range $1000-1500 per kW including all costs from first to nth unit. This would include all the first-time costs for completing design, engineering and licensing of an initial project. The industry feels strongly that the $1000-1500 per kW level is achievable now and reflects a rigorous design, engineering and construction assessment. Achieving costs at this level will make a major contribution to the competitiveness of new reactors against alternative technologies. For those reactors achieving orders, such as EPR[14], their competitiveness is already clearly recognized by customers.

4.3 VARIATION OF CAPITAL COSTS

University of Chicago (2004) greatly clarifies why overnight cost estimates vary so much and additionally stresses the importance of interest charges.

Alternative reactor technologies can 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 (FOAKE) 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.

About 80% of overnight costs are engineer-procure-construct (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, FOAKE costs are a fixed cost of a particular reactor and can amount to $300-600 million. How these are added to overnight capital costs depends on how the vendor wishes to allocate these across various reactors. If he wishes to recover them all on the first reactor, this could easily add 35% to an overnight cost of $1000 per kW.

The example of France (58 reactors) 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 75 billion euros at 2004 prices. When divided by the total installed capacity (63 GW), the average overnight cost is less than 1300 euros 2004/kW. This is much in line with the costs that were then provided by the manufacturers.

10 EIA = Energy Information Administration, an agency within the US Department of Energy
11 MIT = Massachussets Institute of Technology (USA)
12 GE = General Electric Company (USA)
13 AECL = Atomic Energy of Canada Limited (Canada)
14 EPR = Evolutionary Pressurized Water Reactor, a design developed and promoted by Framatome ANP, an AREVA and Siemens Company

4.4 REDUCING THE CAPITAL COSTS OF NUCLEAR PLANTS

OECD-NEA (2000), a comprehensive report on the subject, highlights several areas where vendors have identified specific steps to reduce capital costs to a range they regard as feasible: $1000-1400 per kW of installed gross capacity. Key areas of cost reduction include the following:

- Larger unit capacities provide substantial economies of scale, suggesting that nuclear plants should, for economic reasons, use higher-capacity reactors.
- 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 can save substantial capital costs, both through replication at the factory for components and at the construction site for installation.
- Simpler designs, some incorporating passive safety systems, can yield sizeable savings, as can improved construction methods.
- A predictable licensing process can avoid unexpected costs and facilitate getting the new plant up to safety and design requirements at an early date to start electricity – and revenue – generation.

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 can 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 takes the view that these are unwarranted, on the basis that recent nuclear plants in Asia have been built on schedule and on budget.

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, meeting 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 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. Seven of these from recent years are summarized in the Appendix, while base cases from six of them are shown in Table 3.

Table 3: Studies of comparative costs of new generating plants

	MIT (2003) $	DGEMP (2003) euros	T&L (2003) euros	RAE (2004) £	UofC (2004) $	CERI (2004) Can$
Capital Cost per kW						
Nuclear	2000	1280	1900	1150	1500	2347
Gas	500	523	600	300	590	711
Coal	1300	1281	860	820	1189	1600
Construction period - years						
Nuclear	5	5	5	5	5	5
Gas	2	2	2	2	2	2
Coal	4	3	3	4	4	4
Cost of capital or D rate %						
Nuclear	11.5	8	5	7.5	12.5	8
Gas	9.6	8	5	7.5	9.5	8
Coal	9.6	8	5	7.5	9.5	8
Gas price	3.50/MBTU	3.30/MBTU	3.00/GJ	2.18/GJ	3.39/MBTU	6.47/Mcf
Electricity price per MWh						
Nuclear	67	28	24	23	51	53
Gas	38	35	32	22	33	72
Coal	42	34	28	25	35	48
Electricity price, nuclear=100						
Nuclear	100	100	100	100	100	100
Gas	57	125	133	96	65	136
Coal	63	121	117	109	69	89

Sources: see Appendix

IEA & OECD-NEA (2005) is excluded from the table owing to the difficulty of showing all the country-level results in similar tabular form. Nevertheless, this is a very interesting report as it highlights the increasing competitiveness of nuclear since the previous report in 1998, owing mainly to improved operating performances by nuclear plants and to higher fossil fuel price expectations. A summary of the results (see Table 4) shows that, even at a 10% discount rate, nuclear is the cheapest option in the majority of countries.

Table 4: Summary of generating costs in US$ per MWh

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

Source: IEA & OECD-NEA (2005)

Although there is a range of assumptions used in the 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 8% is used then nuclear is competitive with overnight capital costs in the $1400-$1800/kW range. In MIT (2003) and University of Chicago (2004), much higher discount rates were applied to nuclear for risk assessment reasons, which means the capital cost will need to be lower. With overnight capital costs below $1400 per kW (which many vendors confirm as realistic), nuclear is likely to be highly competitive.

A reduction of capital costs can be expected once the FOAKE 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.

It should be noted that the gas price assumptions used in all these studies are very low compared with recent market trends.

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. For example, the sensitivities in CERI (2004) examine the imposition of an emission cost of Can$15 per tonne of emitted CO_2. The impact is to raise the generating cost of the coal plant by 27% from Can$48 to Can$61 per MWh, bringing it into line with nuclear in the Canadian context. The impact on the gas plant is less dramatic, increasing the generating cost by around 8%.

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, for example with the fifth reactor in Finland, 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 now 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 Concluding Remarks

The attractiveness of nuclear energy from the standpoint of economic performance can clearly be demonstrated today, against the economics of alternative generating technologies. Over the years, more output is being achieved with each reactor through improved availability and capacity up-rates. Safe reactor operation is set to continue for many years in the future, backed up by all necessary investments in refurbishment. These improvements are now routine and integrated into the new plant designs.

Given the magnitude of global power demand in the decades to come, requirements for new generating capacities afford a strong opportunity for a sharp revival in the use of nuclear energy. The key to benefiting from this situation is undoubtedly getting the economics attractive, both with the current fleet of reactors, where the case is already strongly made, and with the potential new build.

Many studies from various sources have been carried out in recent years largely in response to increased interest in the possibility of a revival of nuclear plant construction. Their approaches rely on the same levelized cost methodology but their working assumptions differ substantially and explain the rather large spectrum of conclusions reached. If nuclear fuel and other operating costs are very competitive, the cost of financing the new reactors is often underlined as a major question for demonstrating the economic attractiveness of new nuclear build. The issue essentially involves three main factors at play in the analyses; the level of the capital costs (or overnight cost), the length of the construction period, and the rates of interest.

Feedback from international construction experience, mainly in Asia, combined with thoroughly scrutinized budgets given for new designs and the recent orders in Finland and China show that these vital factors are clearly understood. Yet each of these projects features its own and unique features. As more of these standardized and efficient new reactors are completed, we may expect learning-by-doing and replicating projects to generate cost and time reductions. Public regulation is also likely to move along in a more predictable way and may take on a greater international collaborative dimension. Such trends will provide fewer reasons for imposing financing premiums on the nuclear option against alternative generation options. Nevertheless, policies of public support to help overcome the investment hurdles faced by initial units in some countries can easily be justified in a number of ways related to concerns about energy security of supplies, diversity of power sources and avoidance of carbon emissions.

New nuclear plants are robust, secure long-term investments as part of a portfolio of environmentally-sound technologies that make the world less dependent on damaging carbon emissions. The most recent new build experience has already demonstrated that new plants can be built on time and on budget, so that nuclear plants can deliver electricity at predictable low and stable costs for many decades to come.

6 References and Further Reading

CERI (2004) - *Levelised Unit Electricity Cost Comparison of Alternative Technologies for Baseload Generation in Ontario*
http://www.cna.ca/pdf/CERI_LUEC_Report_August_27_2004-ed.pdf

DGEMP (2003) - *Reference Costs for Power Generation*
http://www.industrie.gouv.fr/energy/elecric/cdr-anglais.pdf

European Commission (2001) - *Report of ExternE Project*

EIA (2004) - *Annual Energy Outlook*

IEA (2003) - *World Energy Investment Outlook*

IEA (2004) - *World Energy Outlook*

IEA and OECD-NEA (2005 - earlier editions too) - *Projected Costs of Generating Electricity*
http://www.nea.fr/html/pub/ret.cgi?id=new#5968

MIT (2003) - *The Future of Nuclear Power*
http://web.mit.edu/nuclearpower

OECD-NEA (1994) - *The Economics of the Nuclear Fuel Cycle.*

OECD-NEA (2000) - *Reduction of Capital Costs of Nuclear Plants*

Royal Academy of Engineering (2004) - *The Cost of Generating Electricity*
http://www.nowap.co.uk/docs/generation_costs_report.pdf

Stricker L& Leclercq J (2004) - *"An Ocean Apart" in Nuclear Engineering International, December*

Tarjanne R & Luostarinen K (2003) - Competitiveness Comparison of the Electricity Production Alternatives

University of Chicago (2004) - *The Economic Future of Nuclear Power*
http://www.anl.gov/Special_Reports/

World Nuclear Association (WNA) (2005) - *The Global Nuclear Fuel Market: Supply and Demand 2005-2030*

APPENDIX

Studies of Comparative Costs of New Generating Plants

The following studies have all been carried out over the past few years, largely in response to increased interest in the possibility of a revival of nuclear plant construction, following a period where most new investment in generating capacity has been gas-powered.

Each uses basically the same levelized cost methodology, but the working assumptions differ substantially and explain the rather different conclusions reached. In particular, the cost of financing the new reactors is crucial and explains the rather negative view of new build economics, which comes in some of the scenarios.

1. IEA AND OECD-NEA (2005)

Description and Methodology

The sixth in a series of studies, estimating the costs of generating electricity by base-load power plants expected to be commercially available in the medium term. Ten countries submitted data on nuclear for the 2005 report which can be compared with coal and gas generating stations in the same countries.

Information was provided by country experts and generating costs calculated using standard constant money levelized lifetime cost methodology.

Major Assumptions

The report attempts to standardize country responses as much as possible by taking common commissioning dates, economic lifetimes of 40 years for all technologies, 85% load factors and also directing what responses should include with regard to capital investment, O&M and fuel costs. Calculations are made at discount rates of 5% and 10%.

However, each country provides its own data on cost levels and the likely escalation of these. These vary considerably from country to country. Base construction costs for nuclear power plants range from $1000 per kW installed in the Czech Republic to $2500 per kW in Japan; coal-fired plants were in the range $1000 to $1500 per kW but gas-fired plants significantly lower at $500 to $1000 per kW. O&M and fuel costs (and their escalation) also vary considerably by country.

Conclusions

The competitiveness of the nuclear plants is markedly superior than in the previous study (1998). This is explained by a combination of the higher capacity factors now being achieved at nuclear plants and substantial increases in forecasts of fossil fuel prices, particularly gas prices. At the 5% discount rate, nuclear is generally the lowest cost option with costs ranging from $20 to $40 per MWh. Nuclear is cheaper than coal in seven of the ten countries and cheaper than gas in nine. The lowest costs for nuclear production were recorded in Korea, the Czech Republic, Canada and France and the highest in Japan. At the10% discount rate, the comparison is closer, with the levelized cost of nuclear generation in the range $30 to $50 per MWh (with the exception of Japan at nearly $70 per MWh). Yet nuclear is still cheaper than coal in seven of the ten countries and cheaper than gas in eight.

2. MIT (2003)

Description and Methodology

The complete study is a wide-ranging examination of the future of nuclear power, particularly in the context of the chances of a nuclear revival in the United States. It contains an analysis of the economic competitiveness of alternative generating technologies by calculating the levelized cost of electricity production. The comparison is made between nuclear, CCGT and coal plants.

Major Assumptions

The overnight capital cost of the nuclear plant is fixed at $2000 per kW in the base case ($1500 per kW in the sensitivity), which was based on recent nuclear plant construction experience in Asia and estimates made by other bodies such as the US EIA. The CCGT has a capital cost of $500 per kW in the base case, and the coal plant $1300 per kW. The financing assumptions are similarly demanding for nuclear. Assuming a 50/50 split of equity and debt, equity requires a 15% nominal rate of return and the debt portion 8%. For the CCGT and coal plants, these are 12% and 8% respectively. Project lives are 40 years or 25 years and capacity factors 85% or 75% in each case. The gas price is taken as $3.5 per MBTU in two of the cases, then escalated at either 0.5% or 1.5% per year.

Results

Given the assumptions, it is not surprising that the nuclear plant comes out as an unattractive option. With a 40 year life and 85% capacity factor, the levelized power cost is 6.7 cents per kWh, compared with 3.8 and 4. 1 cents per kWh on the two gas price scenarios mentioned and 4.2 cents per kWh for the coal plant. Only if nuclear construction costs can be reduced to $1500 per kW, the construction time reduced by one year to four years, nuclear O&M costs reduced further and the plant finance come under the same equity terms as the CCGT and coal plants does it become competitive, assuming also higher gas prices.

3. DGEMP (2003)

Description and Methodology

A study carried out by the French Ministry of the Economy, Finance and Industry with the collaboration of power plant operators, construction companies and other experts. It examines costs of power generated by different methods (nuclear, coal, gas and oil-fired) with plants commencing operation in 2015.

The study is undertaken mainly from an investor's perspective and discounts future costs back to current values using standard discount rates. Investment costs include interest during the construction time. The impact of greenhouse gas emissions is assessed as are various sensitivities on discount rates and cost escalation.

Major Assumptions

The central case uses a discount rate of 8% but full calculations are made with rates of 3%, 5% and 11% too. The nuclear plant is a European Pressurized Water Reactor (EPR) with an overnight construction cost of approximately 1280 euros per kW, but this rises to 1663 euros per kW at the 8% discount rate when interest payments and other costs are added. For a CCGT, the overnight construction cost is 523 euros per kW and for the coal plant 1281 euros per kW.

Results

At a 8% discount rate, nuclear is the cheapest technology at 2.84 euro cents per kWh, followed by a coal plant at 3.37 euro cents per kWh and the CCGT at 3.50 euro cents per kWh. At the 11% discount rate, the gap is eliminated with each technology very close in generating costs. At lower discount rates (such as 5%) the advantage of nuclear is greater.

4. TARJANNE & LUOSTARINEN (2003)

Description and Methodology

The report calculates electricity-generating costs for various new plant options in Finland. The comparisons are between a nuclear plant, a gas-fired CCGT, a coal-fired condensing power plant and also some renewable options, including a wind turbine.

Costs are based on the price level at March 2003 and reflect a judgement of what will be the true costs of constructing and operating the plants in Finland. Levelized cost methodology is then utilized to produce estimates of generating costs. The impact of emissions trading is assessed, as are some sensitivities covering capital costs, fuel prices, the plant load factor and discount rate.

Major Assumptions

There is a high standard load factor or 91.3% taken for each of the plant types, excluding wind, with a real discount rate of 5% per annum. The investment costs are 1900 euros per kW for nuclear, 600 euros per kW for the CCGT and 860 euros per kW for the coal plant. The gas price taken is approximately 3 euros per GJ, with lifetimes of 40 years for the nuclear plant and 25 years for gas and coal.

Conclusions

In the base case, the nuclear comes out the cheapest, at 2.37 euro cents per kWh generated, ahead of the coal plant at 2.81 euro cents per kWh and the CCGT at 3.23 euro cents per kWh. Wind power comes out twice as expensive as nuclear at 5 euro cents per kWh. At a 7% rather than 5% discount rate, the comparison becomes much closer with nuclear and coal both at 3 euro cents per kWh and the CCGT at 3.4 euro cents per kWh. The sensitivities demonstrate the importance of the investment cost and discount rate to nuclear economics and the fuel price to both gas and coal plants. Emissions trading has a positive impact on relative nuclear economics and is particularly adverse for coal, owing to its high carbon emissions.

5. ROYAL ACADEMY OF ENGINEERING (2004)

Description and Methodology

A study carried out by consultants of the comparative costs of generating electricity by a number of available technologies in the UK. The objective was to increase the clarity about what is the best generating mix by comparing generating costs in an even-handed and dispassionate manner. The comparisons are between coal, gas and nuclear plants, together with some renewables such as wind turbines and biomass.

The study takes what are regarded as the best estimates of what it costs to build, maintain and run various power stations in order to produce electricity, by using a common financing model and standard discounted cost analysis. Sensitivities are calculated with regard to fuel prices and emissions costs.

Major Assumptions

The discount rate taken is a common nominal 7.5% per annum. For nuclear, the capital cost taken was identical to that of the MIT study (above) at £1150 per kW installed, with a 5-year construction period and 40-year lifetime. For a CCGT plant, the capital cost was taken as £300 per kW with a 2-year construction period and 25-year life. The gas price taken for the study is approximately £2 per GJ.

Conclusions

For base-load operation, generating costs came out at 2.2 pence per kWh for a CCGT, 2.3 pence per kWh for a nuclear plant and between 2.5 and 3.2 pence per kWh for coal plants, depending on their type. If fuel prices are 20% higher or carbon taxes introduced, it is demonstrated that nuclear can easily become the cheapest option. Renewables, offering only intermittent power, are markedly more expensive, the cheapest being onshore wind farms at 3.7 pence per kWh. When the cost of standby generation is added to this, however, it becomes 5.4 pence per kWh.

6. UNIVERSITY OF CHICAGO (2004)

Description and Methodology

A report carried out on behalf of the US Department of Energy that produces estimates of the competitiveness of nuclear power plants and compares them with the main alternatives, namely coal and gas-fired generating units. A relatively detailed financial model is developed which allows a range of scenarios to be produced, based on the plant being a merchant plant required to make a commercial rate of return. The report examines first-of-a-kind engineering (FOAKE) costs in some detail for nuclear plants and suggests ways in which they can be recovered, while also looking at the possible impact of learning-by-doing, which may cut costs by 3% per annum.

Major Assumptions

The study looks at three different overnight costs for nuclear plants, depending on how much FOAKE cost is included - $1,200 per kW, $1,500 per kW and $1,800 per kW. Coal plants are included with overnight capital costs of $1,189 to $1,338 per kW and a gas combined cycle gas turbine plant (CCGT) at $590 per kW. The gas prices taken are constant in most scenarios, at $3.39 or $4.30 per MBTU, while coal prices are expected to fall from 2003 levels. Construction time for a nuclear plant is five or seven years, while the cost of capital is 10% on loan capital and 15% on equity.

Conclusions

With no policy assistance, the first nuclear unit will have a levelized power cost of $47 to 71 per MWh, depending on the cases taken, whereas the CCGT and coal plants will be in the range $33 to $45 per MWh. However, a fourth and fifth nuclear plant, without FOAKE costs and assuming a 3% learning-by-doing improvement, a 5-year construction period and no 3% risk premium on financing, will produce power at $34-36 per MWh, in other words fully competitive with coal and gas. The conclusion is that initial nuclear plants with merchant financing will require some assistance in the possible form of investment and production tax credits, which will be sufficient to reduce costs to those of coal and gas.

7. CERI (2004)

Description and Methodology

An independent study conducted for the Canadian Nuclear Association (CNA), which provides a comparison of the lifetime cost of constructing, operating and decommissioning new generation capacity suitable for supplying base-load power in Ontario. The options considered are nuclear, coal-fired steam turbines and combined cycle gas turbines (CCGTs).

The report estimates levelized electricity costs using two cases for financing assumptions, one with "merchant" financing and the other with "public" financing. The former requires a real rate of return of 12% on equity and 8% on debt with 2% inflation, while the latter assumes a real discount rate of 8%.

Major Assumptions

The study examines two nuclear plants, twin ACR-700s, with a total plant cost of Can$2,347/kW and twin CANDU 6s, at Can$2,972/kW. The reference coal plant costs Can$1,600 per kW and CCGT Can$711 per kW. The gas price of Can$6.47/Mcf in 2005 is escalated by 2.5% per annum to 2025. A wide range of sensitivities is run on financing costs, capital costs and fuel prices.

Conclusions

In the majority of scenarios considered, coal-fired generation appears to be the most attractive option, but the ACR-700 becomes very attractive if carbon emissions costs of $15 per tonne are included. In fact, under both merchant and public financing options, the ACR-700, representing the deployment of the latest nuclear technology, is very close to coal in levelized cost in many of the scenarios. Owing to the price of gas and the expected cost escalation, CCGTs are not economically attractive in Ontario.

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