The Economic Future of Nuclear Power in Competitive Markets

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The question to be addressed is whether there is any economic future for nuclear power, especially in more competitive electricity markets and assuming the need for private capital. The answer to this question is yes and maybe. For operating plants, the economic gains can be high - some are money printing machines. Hence, there exists a strong interest in extending the life times of these reactors. For new plants, at least in more competitive electricity markets, the answer under present conditions is rather no unless major changes are made in the capital costs of these plants. This paper explores what the future might be if such changes can be made, what the most important changes are that need to occur, and how such changes might be brought about by a combination of changes in engineering and regulation. For one, a focus on cost-effective safety must be an essential part of the economics of future nuclear power plants. For another, full inclusion of waste disposal and decommissioning costs must be an integral part of nuclear cost analyses, as they generally are today, in order to minimize uncertainties concerning potentially open-ended liabilities. The question then is whether evolutionary improvements of current generation nuclear power plants can do the job or whether new nuclear technologies need to be developed and commercialized.

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1. Introduction

Most of the world's electricity markets are now moving towards greater competition, driven in part by technology, and in part by the experience that competitive markets are more self-sustaining. Electricity companies are now in the business of selling a commodity (kWh) and commercial services instead of a strategic good. Increased competition has generally led to a downward tendency in the cost of electricity generation when compared to cost incurred under more protected and monopolistic market structures.

This is true both in markets where demand is stagnant and where it is growing. In all markets, various combinations of excess capacity, low demand growth and lower product prices, competing demands for government funds to meet the needs of growing populations, and technological change, have forced power generators and their suppliers in major energy markets to be more concerned with the costs of their operations and of their investments. Power companies increasingly need a commercial, profit-oriented approach to doing business if they are to survive and prosper. Freed from their traditional regulated and social monopoly status, they will focus on supply technologies that are low cost and low risk, and hence more profitable in a competitive market. Off-the-rack instead of tailor made plants and equipment will be the fashion, and rapid, high and secure returns more of a requirement. Even more, generators will need to make substantial cost reductions over the next few years.

How does nuclear power stack up in this environment? The answer will vary depending on whether nuclear power is considered for the near-, medium- or long-term, and on whether prospective electricity markets are growing or stalled. This corresponds roughly to a discussion of existing plants[1], upgrades and life extensions, or new plants. In general, nuclear power has the potential to be a competitive contender in all three markets, but realizing that potential will require significant changes in the way the industry and its regulators do business.

2. Existing Plants

- Electric power is now being sold on the Nordic grid, in parts of the USA, in Victoria State, Australia and in South Africa for less than US$ 0.02 per kWh (IAEA, 1999). Can nuclear generation match these prices? Where not, can it be made to do so?
- Over-capacity and inefficiency can no longer be hidden or ignored in these increasingly competitive markets. Can nuclear power compete without special dispatching or other considerations?

Nuclear power plants already built have generally fared well in restructured markets. The operating costs of nuclear power plants, including fuel costs, are usually lower than for most other major power generation alternatives, with the exception of hydroelectricity. Capital is largely depreciated and a plant with operating and maintenance costs (O&M) below market prices turns in a profit (see Figure 1, columns I & II). Data on nuclear power operating costs are most available in the United States, where electricity prices are publicly known and transparent. In 1998 operating costs averaged around US$ 0.018 per kWh. The most efficient plants saw costs of around US$ 0.012 per kWh. Moreover, the cost trend is still downward leading to optimistic anticipation that even lower operating costs are possible in the near future (Nash, 2000). Similar low and declining operating costs are experienced in other economies. The result has been that existing nuclear power plants have been quite successful within the new commercial environment.

While most operating NPPs produce power at competitive costs and with a positive cash flow, others are being closed in bankruptcy (see Figure 2, column III). More than half the nuclear sites in the USA are considered competitive in changing markets, with two-thirds of the units producing power for under US$ 0.02 per kWh, yet others have costs of US$ 0.06–0.13 per kWh. In the United Kingdom, each of British Energy's eight privatized nuclear stations sells power profitably at competitive market prices (an average of around US$ 0.03 per kWh), while the Magnox plants assigned to BNFL are still producing at around US$ 0.05 per kWh, or are being closed as uneconomic before the end of their design lifetime (IAEA, 1999).

The difference between success and failure depends on a number of factors including astute decisions about financing and choice of technology, and successful estimates of demand growth, coupled with good plant management that provides cost control and efficiency gains (IAEA, 1999; Whitfield, 1997). But in the end, the most important variable for commercial viability is the marginal cost per kWh of generation, compared to the market price and the marginal cost of competing generation. Whether an existing nuclear power plant can operate profitably translates into whether the plant's incremental revenues can cover marginal operating costs.

[1]Globally, at the beginning of 2001 there were 438 nuclear generating stations in operation with a cumulative capacity of 351,300 MW_e providing 2,448 TWh or 16% of global electricity supply.

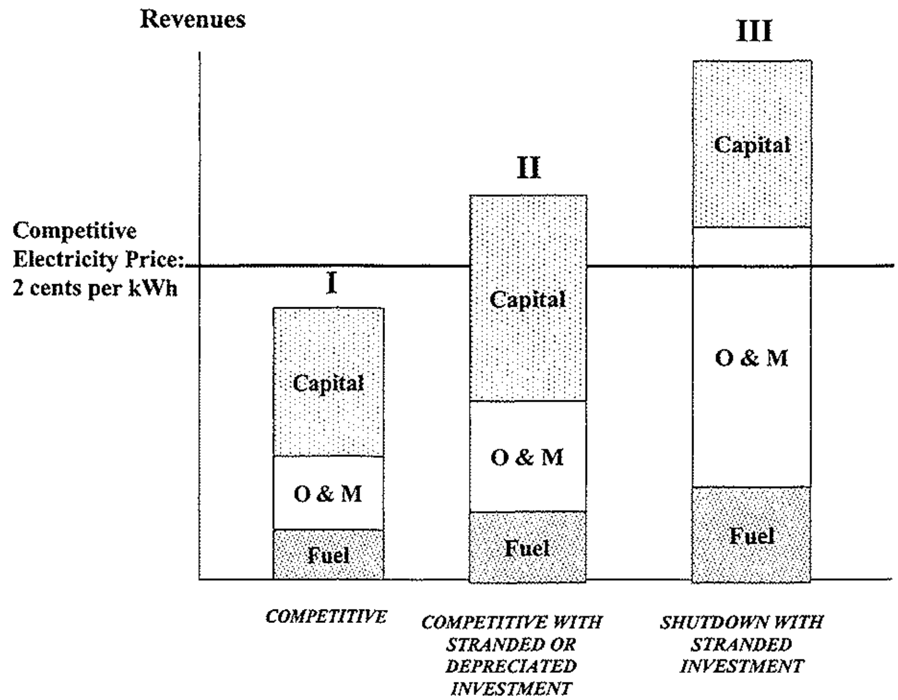

Figure 1: Existing nuclear plants in a competitive market. Source: Gonzales deUmbieta, 1998

For nuclear plants, the ability to compete depends on cutting unit costs (especially operating and maintenance costs), without compromising safety, and on increasing plant availability (or for some plants, maintaining already high levels of availability). There will thus be intense management pressure in both areas. The importance of good management is emphasized for two reasons. First, a commercial and competitive management approach is new to many electricity and nuclear industry managers, and so bears mention. Second, good management can make a telling difference in the bottom line (IAEA, 1999). Nuclear plant managers need to develop a commercial culture parallel to the safety culture already in place, that permeates all levels of plant operation with a focus on profitability, providing incentives for performance, innovation and initiative. Other factors include: effective change management; efficient trade-offs among goals and resources; clear communication of responsibilities; optimising the over-all use of assets by streamlining work processes and operational performance, increased on-line maintenance and improved outage planning, benchmarking, efficient use of contractors, and a focus on core competencies.

Almost all nuclear plants that are now competitive have made significant if not dramatic improvements over the last decade in their availability and operating costs. During the 1990s individual plant availability has increased in many cases by some thirty percentage points, approaching (and in some cases, exceeding) 90%. Globally availability increased from 71% to over 81% - the equivalent of an additional generating capacity of 28,000 MW_e essentially free of charge. Operating costs have fallen by as much as 40% (BNFL, 1998). Many nuclear power plants have achieved these operational improvements while at the same time maintaining or improving their safety performance.

Well managed nuclear plants now enjoy a cost advantage over many other generators. But as the average cost of all generation inches lower, operators of nuclear plants will have less of a cost advantage. As net cash flow margins converge under competition, nuclear operators will need to reduce their costs and increase their margins even further to survive.

In this regard, cost-effective safety regulation is crucial to the continued profitability of existing nuclear power plants. Insisting on the importance of safety-related costs in no way argues for less stringent safety. Such costs are the daily concern of nuclear plant operators and cannot be ignored. Maintaining high levels of safety is non-negotiable for nuclear plant operators, but the cost of safety compliance, along with other operating costs and on-going capital expenditures, will be a significant factor in management decisions about plant operations. Where cost are too high, the plant operators will shut down the plant; where safety risks are too high, regulators will shut it down. Plants subject to frequent outages do not produce revenue, while accidents that damage the plant's productive assets also interrupt the investors' anticipated revenue stream. Repairs and replacement of damaged parts constitute non-productive investment. All of these should be avoided to assure efficient and profitable asset productivity (IAEA, 1999). Safety, for a commercial enterprise, is thus a major form of asset protection.

Spending more money on safety does not necessarily make a plant safer, just as cutting costs does not necessarily make a plant more unsafe. However, plant safety is only relevant if the plant is operational, not if it has been priced out of the market. Even a safe plant, if not operating profitably, eventually will not operate at all. Cash flow and profitability, as well as safety, must become a basis for operating decisions.

Experience shows that safe plants can be operated profitably, and profitable plants can be operated safely. In the USA and the UK, there is a close correlation between nuclear power plants with high efficiencies and those with a high safety performance (see Figure 2)[2]. Those commercial plants with the best safety ratings also had the highest availability and the lowest operating cost (IAEA, 1999).

3. Capital Investment Decisions

Commercial funding will not be available for investment in a nuclear power plant – or in any plant – if the plant does not meet established financial criteria. Lenders intend to get their money back, with interest. Capital investment decisions, whether for new plant or for life extension or upgrade of an existing one, will be made on the basis of the costs, risks, anticipated revenues and securities involved in the proposed investment vs. other alternatives. This financial evaluation in its simplest form is a comparison of only two elements: net present value (NPV) of the cost of the proposed investment project versus the anticipated future revenue stream from the completed project (generating revenue minus costs, discounted over the amortization period for the plant).

[2] The Systematic Assessment of License Performance (SALP) is a system used by the U.S. Nuclear Regulatory Commission (NRC) to (a) guide NRC's conclusions regarding a licensee's safety performance and safety risk perspectives, (b) serve a vehicle for meaningful dialogue with each licensee regarding its safety performance, (c) assist NRC management in making sound decisions regarding the allocation of NRC resources to oversee, inspect, and assess licensee performance, and (d) inform the public of the NRC's assessment of licensee performance. The assessment is carried out for four standard functional areas: (1) plant operations, (2) maintenance, (3) engineering, and (4) plant support. Performance in each area is rated on a scale 1 to 3. Category 1 rating is assigned for clearly demonstrated superior safety performance while a Category 3 rating indicates concern on part of the NRC even though the licensee has demonstrated acceptable safety performance. A Category 2 rating means the licensee's attention to safety performance is normally well focused but deficiencies may exist. In the wake of electricity market liberalization and competition, the SALP process has now been replaced by a new reactor oversight and assessment program. Many operators believe that the SALP would reveal commercially sensitive information to their competitors.

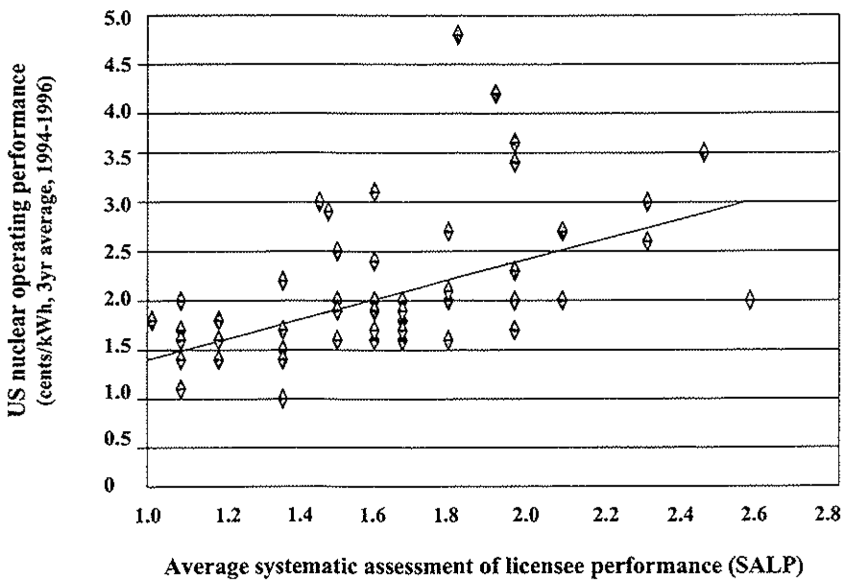

Figure 2: Unit Cost of Production of US Nuclear Plants and Regulatory Performance. Source: Gonzales deUmbieta, 1998.

Capital Costs

High capital costs are the largest single barrier to financing and building new nuclear plants, accounting for some 70% of total generating costs of a new nuclear plant as shown in Figure 3. (OECD, 1998; NEA, 2000). Under current estimates these capital costs would need to be reduced by some 35%-50% before new nuclear plants can compete with new coal and gas fired generating technologies. Certainly such reductions are possible, but would require a number of measures, including reactor designs that (a) are tailored to market needs at competitive prices, (b) reduce the cost of enhanced safety, and (c) reduce the uncertainties associated with regulation and with post-operational liabilities.

Investment costs for lifetime extension, while not trivial, are likely to be only a fraction of the cost of a new plant, in part because costs such as reactor vessel, civil works, land acquisition and site preparation are not incurred. Such plants usually carry little debt, being largely amortized by the time of renewal, and already have a revenue stream attached to assure repayment of any financial obligations incurred for the relicensing or life extension. Assuming the financial calculations are sound, financing should therefore be less of a problem.

Safety upgrades may be required for a number of reasons, and may or may not result in increased efficiency or may, in fact, carry efficiency penalties. Upgrading a plant for safety reasons may be essential to the continued operation of the plant, whether to protect assets or to protect the license. However, owners faced with safety upgrades could face investments they cannot expect to amortize over the extended life of the plant. Moreover, plants with insufficient cash flow simply cannot finance needed upgrades, no matter how closely these might be linked to safety concerns. This has been a particular problem for economies in transition, where power suppliers are short of cash due to non-payment by customers (SNN, 1999). If continued regulatory approval for the operation of the plant hinges on the upgrade, the cost of such investments needs to be weighed both against expected revenues and against the cost of closing the plant. A financial NPV analysis would reveal the relative economic benefits of both the investment and the continued operation of the plant or its closing.

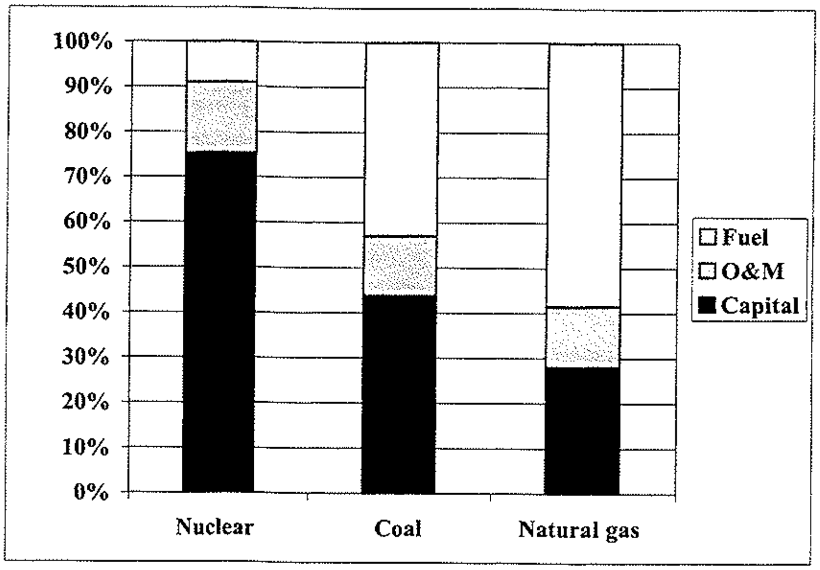

Figure 3: Average electricity generation cost structure for nuclear, coal-fired and natural gas combined cycle plants, 10% discount rate and 25 year planning horizon. Source: Adapted from OECD, 1998.

Investors in completion of stalled or unfinished projects, where previous experience with cost control and risk management has probably not been good, must be assured they will get their money back with interest, which may involve freeing the project from past debts. Contracts must be negotiated with incentives to avoid construction delays, and the cost of materials can be kept down through inventory control, competitive procurement, a balance of local content and imports, and by using adequate, affordable and appropriate instead of top of the line products.

A final non-negligible investment cost is the high cost of licensing a nuclear plant. The cost of extensive environmental impact and safety assessments, pubic hearings, the need to satisfy public opinion, all add to the transaction costs of obtaining a license to construct, operate or extend the life of a nuclear power plant. Significant investment in a project must already be committed before this process is even begun putting at least initial investment at risk if the license is ultimately refused, or amended in such a way to invalidate the initial financial assessment. In order to minimize such risk, the concept of "bankable" licensing for specific reactor designs has been advanced. Utilities can apply for and receive site-specific construction and operating licenses without being committed to a definite construction and operating schedule.

Before deciding on any of these investments, one should make all possible provisions for reducing anticipated costs. Failure to do so could skew the investment decision, and make financing more difficult. Capital cost are a function of the source and structure of the investment and financing package negotiated, especially interest rates and payment schedules, the amount of equity financing available, the currency in which the financing is provided, construction time, the degree of risk involved, and where and how it is all secured.

Risks

Uncertainties, risks and liabilities are economically significant because they carry a cost, sometimes high, that can be reduced or managed more or less. They must all be estimated and accounted for and are every bit as important to investors as the estimated cost of generation. They in fact have tipped the balance in some of the recent decisions to shut down operating plants in the U.S., before their operating licenses have expired. They were also a major factor the privatisation of the electricity sector in Argentina and in delaying the privatisation of British Energy. Therefore, reducing financial uncertainties will be just as important as reducing nominal costs.

New nuclear plants, and new construction at existing plants, carry high financial risks that are not necessarily unique to nuclear power. These include completion risk (that the plant will never be finished and never generate revenues to repay the investment), regulatory risk (that approved requirements might change in midstream), and political risk (that government policies affecting the profitability or even the desirability of nuclear power may change). Investors will require compensation for these risks. Added to these are commercial risks such as changing markets and changing demand, and the financial uncertainties associated with incremental safety requirements and post operational activities.

The safety risks associated with current nuclear plants have already been reduced to very low levels, while the financial risks associated with additional investments in nuclear power plants are large and growing. Some sense of economic proportion needs to be defined. Investors will scrutinise lifetime extension decisions, new plant and new plant designs on the basis of cost/benefit and net present value analyses. Using these techniques, investors will identify improvements for which the lowest achievable cost may still be very high, may be disproportionate to the consequent safety gains or to the costs associated with the risks to be reduced, and may threaten the economic and financial viability of the investment. For a company selling power in increasingly cost conscious and competitive markets, the net cost of safety measures - like all generating costs - is a crucial concern. It is also significant in choosing nuclear versus non-nuclear technologies for generation.

This question of diminishing returns is not unique to nuclear safety, but in fact governs most environmental and health protection standards. In air pollution control, for example, the cost of 90-98% removal may be tolerable, but removing the last 2% is exorbitant in relation to the benefits gained.

Clearly, there is a need in the nuclear sector for financial analysis and liability management, particularly in the face of increasingly stringent and rapidly changing regulatory and political requirements. Political risks and uncertainties need to be factored into a company's financial strategy from the outset, in exactly the same way as engineering costs have been. Continual risk assessment, risk and scenario modelling that are tied to the company's bottom line, and prudent financial provisions for possible scenarios that can affect the company's assets or revenues, are all standard corporate risk management strategies. Yet, with a few notable exceptions, primarily in the UK and the USA, very little seems to have been done by nuclear plant owners and operators to implement such techniques for managing their uncertainties, risks and liabilities efficiently.

Unfinished Plants and Life Extensions

The aging of the world's nuclear power park and the potential for lifetime extension are matters of considerable interest that need to be evaluated objectively. Completion of unfinished nuclear power plants, or extending the life of a successful one, can be an economically attractive and practical alternative either to building a new plant or to decommissioning an old one. But the decision needs to be made dispassionately, and without regard for sunk costs.

A decision on project completion, relicensing or life extension of an operating NPP hinges on whether or not the relicensing or life extension is financially beneficial. In this instance, the relevant financial analysis would compare the NPV of anticipated costs and revenues, as described above, with the cost of plant closure or stopping construction. Once these numbers are computed and compared, the basis for decision is clearer. This holds true even when the project is government financed or when the decision to be made is a "defensive" one: i.e., choosing the option that loses the least money.

Project Completion. It is a trap to of think that the current status of a project is a basis for deciding on its completion. A plant that is 90% built is thus viewed as a better candidate for completion than a plant that is 60% complete. There may be little correlation between these engineering estimates of completion and the remaining costs, and it is these remaining costs that are key to future investment decisions. A plant that is 90% complete does not necessarily have only 10% of its costs unpaid. The remaining investment cost could be less and very frequently is much more, perhaps even more than the anticipated revenues from the completed plant. The revenue side of the NPV equation is also independent of the per cent completion of the NPP, except in the timing of revenue receipts, which is also key to decisions on future investment[3].

One curious note: Shutting down a construction project is potentially expensive, as most construction contracts have cancellation costs or penalties if a project is terminated. Completing the project at a loss may be cheaper than closing down the project. In these cases, it makes economic sense to complete the project. An analogous situation results when asking, on the basis of NPV, whether an operating NPP should be shut down. Shutting down a plant incurs many costs and sometimes the firm is better off operating the plant at a loss, because that loss is less than the losses incurred in shutting it down.

Lifetime Extension. This can be very profitable, and offers a real possibility for continued use of nuclear power in the short to medium term. There are several major benefits to lifetime extensions over the building of new plants. One assumes that operating costs are already low or else extension would not be considered. The plant's decommissioning fund obligations should also be fully satisfied, further reducing operating costs. Life extension of nuclear power plants can also be attractive for environmental reasons in regions where compliance with air pollution standards or commitments to greenhouse gas emissions reductions argue against increased use of fossil fuel fired generation. And, lifetime extensions offer ancillary benefits in terms of maintaining and updating the skills of the industry's trained labor force. A lifetime or license extension can also result in a power uprating and hence the effective addition of new capacity. This is attractive financially because it reduces generating costs. In Sweden the nuclear industry has added some 600 MW of capacity -- equivalent to that of a new nuclear power plant -- by improving its existing eleven operating nuclear stations. The investments needed to achieve power upratings are not trivial, but, they are less expensive than building new capacity (nuclear or otherwise).

New Plants

- New NPPs can cost 2–4 times more to build than fossil-fueled plants (see Table 1). These costs do not include the cost of risks due to non-completion, exchange rate fluctuations or cost over-runs, risks that can affect a power generator's credit rating. OECD investment rules already add a 1% risk premium to lending rates on all OECD export credits to developing countries where nuclear power plants are concerned. Can such risks and costs be reduced or secured sufficiently for nuclear power to compete in capital markets for the financing of new nuclear plants?
- Investment in a nuclear plant would require well over twenty years to repay. Competitive capital markets would require a higher return on investment to justify these longer-term risks. The big question for nuclear power is whether market prices will permit nuclear utilities to afford such premiums and still turn a profit.

[3]At the beginning of 2001, there were 33 nuclear plants under construction, twelve of which with construction having started more than 15 years ago.

- Generating costs have fallen fast. In 1995, US$ 0.043 per kWh was considered the price to beat for a new nuclear power plant to be competitive in the USA. By 1998 estimated costs came in below US$ 0.03 per kWh, absent government intervention, for a plant to be considered a potentially profitable investment (Davis, 1998). The average is now around US$ 0.02 per kWh.

Table 1: Capital costs, generating costs and construction times for different electricity generating options. Sources: OECD, 1998; IPCC, 2001.

	Cost per kWe installed US $ [a)]	Total cost for 1,000 MW capacity Billion US $	Construction period Years	Typical plant size MW	Typical plant turn key costs Billion US $	Indicative generating costs [b)] US c/kWh
Nuclear LWR	2,100 – 3,100	2.1 – 3.1	6 - 8	600 – 1,750	1.5 – 4.2	4.9 – 6.8
Nuclear, best practice	1,700 – 2,100	1.7 – 2.1	4 - 6	800 – 1,000	1.3 – 2.1	4.0 – 4.7
Coal, pulverized, ESP	1,000 – 1,300	1.0 –1.3	3 – 5	400 – 1,000	0.5 – 1.3	3.2 – 4.5
Coal, FGD, ESP, SCR	1,300 – 2,500	1.3 –2.5	4 - 5	400 – 1,000	0.6 – 2.5	3.6 – 6.3
Natural gas CCGT	450 – 900	0.45 – 0.9	1.5 - 3	250 — 750	0.2 – 0.6	2.6 – 4.8
Wind farm	900 – 1,900	0.9 – 1.9	0.4	20 — 100	0.03 – 0.12	3.5 – 9.2

ESP= Electrostatic precipitator; FGD = Flue gas desulphurization; SCR = Selective catalytic reduction; CCGT = Combined Cycle Gas Turbine.

[a)] Including interest during construction

[b)] Based on 10% discount rate, 20 year planning horizon and fuel costs ranging from 1$/GJ to 2$/GJ for coal and 1$/GJ to 5$/GJ for natural gas. Wind generating costs depend on mean wind speeds and availability factors.

This decline in generating costs did not just result from competition, but also from low fuel prices and from significant improvements in efficiency in the use of coal and gas. The thermal efficiency of gas use has risen to well over fifty percent with promises of further improvements. Despite occasional extreme price volatility, fossil fuels are likely to enjoy relatively low prices over the longer run (Rogner, 1997; WEA, 2000). While investment decisions are generally made on the basis of long-term price expectations, operational effectiveness often responds to short-term price hikes, often resulting in efficiency gains. Low cost and high efficiency will therefore be essential characteristics of any plants to be built in the future, and non-nuclear technologies are developing rapidly in this direction.

The generating cost ranges presented in Table 1 are subject to different sensitivities. Because of high capital costs and long lead times, nuclear power costs are highly sensitive to interest rates. Coal plant capital costs vary greatly with the pollution abatement schemes required. Gas generation costs are highly sensitive to gas prices, which are a relatively high proportion of total costs. Figure 4 shows the impact of a doubling in fuel prices on total generating costs. In the case of nuclear, costs increase by less than 5 percent[4] while natural gas generation faces a hike of almost 60 percent. Having nuclear power in a utility's generating mix hedges against fuel price and exchange rate volatility.

[4]Uranium costs account for some 20 to 30% of nuclear fuel costs, which in turn account for 10 to 15% of total generating costs. The price of nuclear fuel depends primarily on the cost of nuclear fuel services: conversion, enrichment and fuel fabrication.

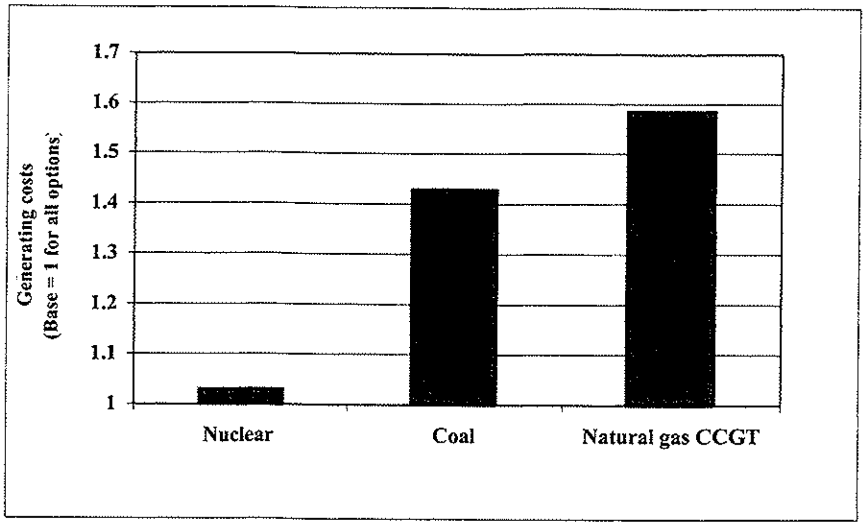

Figure 4: The impact of a doubling of fuel prices on generating costs (discount rate 10% and 20 year planning horizon).

Since investors in new generating plants have no sunk costs and are free to choose at the outset the fuel, technology, site, plant design, financing operations and risk allocation that suits them best, they will tend to opt for the highest return, least risk alternative. Under these circumstances, will new nuclear plants be built? Unless the nuclear industry takes dramatic action to reduce capital costs and financial risks for new nuclear plants, nuclear power could well be priced out of the market, even where it offers other significant advantages.

New nuclear plants are sometimes divided into evolutionary and innovative designs (IAEA, 1997). Evolutionary designs can be defined as those not requiring a prototype for development, such as the Westinghouse AP600 and the joint Framatome/Siemens European Pressurized Reactor (EPR), and are generally understood to include incremental improvements on existing designs or technologies. They bear the burden of proof that modifications made will result in commercially competitive reactors. Innovative designs (defined as those which may require a prototype for demonstration) encompass both revolutionary and more radical design changes. They offer perhaps a greater potential for competitive advances, primarily because they can be designed explicitly for current and future market conditions. Yet with the exception of the ongoing development of the Pebble Bed Modular Reactor (PBMR) in South Africa, and the Advanced Light Water Reactor (ALWR) in the USA, no advanced reactor development has identified as its primary goal a commercially competitive reactor that will meet and beat prevailing market prices, with increased efficiency, profitability and performance, as well as enhanced safety. The development of most advanced reactor designs, prompted by the Three Mile Island and Chernobyl accidents, focus on enhanced safety, but with a cost premium. For the Sizewell-B reactor in the UK, one of the most expensive reactors built to date, up to 20% of the capital cost has been estimated as attributable to "enhanced" safety for an "enhanced" reactor (Board, 1996).

Cost Effective Safety

Enhanced safety is a major focus in the design of new nuclear power plants, and its costs will be a significant factor in any decision to invest or not in nuclear power. Improving the cost-effectiveness of these safety-related investments can therefore contribute to the financeability of new plants. While the share of safety costs as a percent of total costs for a new NPP cannot be determined with any precision, it is significant, some estimates range up to 40-60%.

(Forsberg and Reich, 1991; Hewlett, 1996; Brocker, 1996; Hibbs, 1997; Davis, 1998; IAEA, 1999).

There are a number of approaches being explored to reduce the costs of enhanced safety in new reactor designs, many of which include making a standard of no significant off-site consequences even under worst case accident scenarios instead of specifying a number of individual performance requirements and regulations (IAEA, 1998). These include among others:

- the use of passive safety designs;
- the reduction of the number of components and materials subject to "nuclear grade" quality requirements, which for some components can add 200% to the cost of procurement. (PBMR, 1999);
- a move to more risk informed safety regulation; and
- regulatory prescription of goals rather than means, permitting greater flexibility in compliance.

In the past 20 years, certain new safety goals and requirements have been established for NPPs with little consideration of economic costs and benefits, or of alternative and perhaps more cost effective ways of achieving the desired safety goals. This approach was encouraged by the fact that most nuclear plants operated in monopoly markets where costs could be rolled into rates and so were not necessarily a primary concern. But times and markets have changed, and regulatory approaches must also change, to permit a clearer definition of when a plant is safe enough and, at the same time, to provide for flexibility in achieving this goal. It must be unequivocally stated that the level of safety-related expenditures are not a measure of a plant's safety level. What has to be accomplished is to reduce safety costs while at the same time not compromising rather improving safety.

Managing Liabilities for Decommissioning and Waste Disposal

High cost, high-risk projects require high returns. How costs and risks are managed in competitive markets will govern which generating technologies will be retained or phased out, dispatched or not, and selected for future plants or not. The crux of the matter for nuclear power is that long-term financing for capital intensive and high risk investments requires rewards to investors that are commensurate with long term commercial risk. Can the nuclear industry afford the required rewards in competitive markets, or can it reduce investors' commercial and financial risks to affordable levels. It should be kept in mind that these are moving targets.

Post-operational liabilities, namely the costs and risks associated with NPP decommissioning and waste and spent fuel disposal, are perhaps after capital costs, the second most important impediment to financing new nuclear plants. The engineering and technology are available to successfully handle these tasks in a variety of ways[5].

The engineering plans and cost estimates for decommissioning and waste disposal have been thoroughly researched and are regularly updated, primarily to serve as a basis for assuring that sufficient funds are set aside to cover the eventual cost of the decommissioning and waste disposal efforts. Nonetheless, present cost estimates will surely differ from the costs ultimately incurred, because the circumstances on which these costs are predicated will surely change. Examples include: the availability of waste disposal facilities and the policies governing their use, early plant closings; changes in allowed radiation standards for release of

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[5] Nature itself has demonstrated the suitability of geological repositories. A natural nuclear chain reaction occurred 1.7 billion years ago at the Oklo site in Gabon, Africa. Once the natural reactor ran out of fuel, the chain reaction stopped leaving behind the highly radioactive waste it had generated. The waste was held in place at a depth of 10 to 12 meters by the granite, sandstone and clays surrounding the reactor area. Since then, the waste has moved less than 3 meters from where it was formed 1.7 billion years ago (Cowan, 1976). The essential features of the Oklo site are its semiarid climate and natural barriers. In addition to these features, today's disposal concepts seek more appropriate natural barriers and add a third line of defence – engineered barriers. There is no reason to assume that technology combined with nature will do worse today than nature has done for millennia at Oklo.

materials and sites; regulatory policies that affect the economics of plant operations, decommissioning and waste disposal; changes in tax and accounting rules; restructuring, privatization or increased competition. What will matter in the end is not so much the precision of relevant engineering cost estimates, but how a company is prepared to deal with unanticipated change.

Most of the nuclear industry is not well equipped to deal with the uncertainties that surround their post-operation activities. Nor do many operators regularly review the financial risk and economic consequences of increasingly stringent regulations. As a result, significant economic costs and inefficiencies are likely to be incurred by the industry and by society, and the financial risks associated with these post-closing operations can grow rapidly unchecked. Efficient cost management, a degree of flexibility in meeting standards and an appreciation of the costs of uncertainty and of political and regulatory change must all be cultivated. The focus should be on prudence rather than foresight, and on the possible financial provisions for uncertainties in post-closing costs for nuclear power plants.

Given the long lead times involved in decommissioning and waste disposal, companies will usually have time to adjust their practices to changing circumstances, assuming they have techniques and provisions in place to monitor and manage such uncertainties and have the flexibility to change their strategies appropriately. There is no doubt at all that decommissioning and waste disposal can be and will be accomplished. The only questions are those of timing, priorities, efficiencies, and hence costs, many of which lie outside the control of nuclear plant managers. The choice of how expensive and how efficient decommissioning and waste disposal will be is largely political. The major choice for the nuclear plant owners and operators is how best to incorporate and minimize the uncertainties involved.

Nuclear Power and Public Policy

Nuclear power does offer clear advantages when it comes to public policy considerations about energy supply security and diversification, health and environmental protection (external costs) including a significant greenhouse gas mitigation benefit.

Supply Security: Because of nuclear power's low volume fuel requirements per unit of electricity, strategic nuclear fuel inventories can be readily established for the lifetime of the plant, and the exposure to fuel market price volatility and sudden changes in the terms of trade can be minimized. Nuclear power thus offers a definite level of energy security. This has been an important factor in most recent decisions to build new nuclear power plants (for example, in China, India, Japan and the Republic of Korea[6]), just as it was earlier in countries like France, Germany or Sweden.

External costs: Nuclear power generates minimal air pollution, making it an attractive alternative to mitigate the adverse health and environmental impacts caused by particulates, acid rain precursors or greenhouse gas (GHG) emissions. In fact, in the short-to-medium term, there is no economic alternative to nuclear power as a GHG mitigation option for baseload electricity generation. These advantages are often translated into a comparison of the external costs[7] of nuclear power and those of alternative generating technologies. In contrast to non-nuclear power generation, most nuclear externalities are already internalized. The ability to offset external cost advantages against the higher capital costs of nuclear power will depend on the willingness of environmental regulators to force the internalisation of the externalities associated with fossil fuel combustion[8].

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[6] Since 1995 construction of 17 new nuclear power stations has begun representing some 15,000 MW_e of generating capacity. Without exception, all stations are located in these four countries.

[7] External cost estimates are, unlike emissions data, difficult to quantify, often assumption driven and thus highly uncertain.

[8] A ratification of the Kyoto Protocol by at least 55 of the Annex-I countries (industrialized countries) representing 55% of Annex-I greenhouse gas emissions would convert nuclear power's avoidance of

Whether and to what extent they do so remains an open political question, and in the political arena, environmental opposition to nuclear power is not cost or externality based. Note that each of these "benefits" of nuclear power is defined by government policy, and so their importance will vary as policies change. In competitive markets, these societal considerations are only of concern to investors or plant operators insofar as compliance with related regulation – once in place - affects the costs and operations of a plant. However, where electricity markets are still government-managed, policy makers can more readily impose the satisfaction of their goals on the generating sector. Where governments still choose technologies, nuclear might be chosen to satisfy any number of public policy objectives.

5. CLOSING

So what is the economic future of nuclear power? Existing plants, where efficient, can be expected to thrive, and life extensions of successful plants can be expected. But few new plants are being built and fewer can be expected unless the nuclear industry initiates clear and strong measures to change dramatically, and policy makers are ready to drastically change its regulatory context. Key to such changes will be a strong focus on cost-effective safety, on liabilities management and on innovative and competitive nuclear technologies. Finally, policy makers will have to address the question of waste disposal, and be willing to let the industry demonstrate the availability of appropriate and sufficient technology to manage nuclear waste. Such a demonstration is essential to establishing informed public perceptions about the safety of nuclear waste disposal as an industrial process.

It is true that nuclear power offers governments the opportunity to achieve a number of national policy goals, including energy supply security and environmental protection, particularly by reducing air pollution and greenhouse gas emissions. But these policy-related "benefits" are vulnerable to policy change, and are insufficient by themselves to assure a nuclear future. Similarly, the further internalization of externalities – to a large extent already imposed on nuclear power - is a policy decision and it is unclear when and to what extent such policies will be implemented. Those who pin their hopes for nuclear growth on externalities or on the Kyoto Protocol - and ignore reform and the need to innovate - will be doomed to disappointment. The nuclear industry has to bootstrap itself to economic competitiveness by way of accelerated technological development and innovation.

such emissions into a real economic benefit visible to investors on the bottom line.

REFERENCES

BNFL 1998: "Presentation to NEA Experts Group on the Deregulation of the Nuclear Industry", by British Nuclear Fuel Limited (BNFL) at the Nuclear Energy Agency (NEA), Paris, France.

Board J. and M. Acero, 1996: "Balance of Safety Versus Economics," Presentation at TOPNUX 96, Economic Nuclear Power for the 21st Century; Towards the New Generation of Reactors, Paris, 30 September to 2 October 1996.

Brocker H., 1996: "Maintenance Costs: Preussen Elektra and Sydkraft compared". *Nuclear Engineering International*, July 1996, pp. 30-31.

Cowan G.A., 1976: "A Natural Fission Reactor", *Scientific American*, 235:36.

Davis G.A., 1998: "Assuring the Competitiveness of New Nuclear Plants in a Deregulated U.S. Market", Paris, France.

Forsberg C.W. and W.J. Reich, 1991: *Worldwide Advanced Nuclear Power Reactors with Passive and Inherent Safety: What, Why, How, and Who*, ORNL/TM-11907, Oak Ridge National Laboratory (Oak Ridge, TN, USA), September 1991.

Gonzales deUmbieta A., 1998: *Economic Sustainability of Nuclear Power.* Proceedings: FISSION – European

Seminar "Nuclear in a Changing World". European Commission XII/0318/98.EN, Volume II, Brussels, Belgium.

Hewlett, J.G., 1996: "Economic and Regulatory Factors Affecting the Maintenance of Nuclear Power Plants," *The Energy Journal*, (17)4.

Hibbs M., 1997: "German O&M Costs Three Times Higher than EdF's, VDEW Says," *Nucleonics Week*, vol. 38, no. 31, 31 July 1997, pp. 1 ff. The original study by the Cologne Institute of Energy Economics is summarised by the authors in: Hensing I., Nolden A., Riechmann C. and W. Schulz, "Analyse der Strompreisunterschiede zwischen Frankreich und Deutschland," *Zeitschrift für Energiewirtschaft*, no. 4, 1997, pp. 269-294.

IAEA (International Atomic Energy Agency), 1997: Terms for Describing New, Advanced NPPs, IAEA TECDOC-936, IAEA, Vienna, Austria.

IAEA (International Atomic Energy Agency), 1998: Developing Safety Culture in Nuclear Activities, Practical Suggestions to Assist Progress, Safety Reports Series No. 11, IAEA, Vienna, Austria.

IAEA (International Atomic Energy Agency), 1999: "Strategies for Competitive Nuclear Power Plants" IAEA-TECDOC-1123, International Atomic Energy Agency (IAEA), Vienna, Austria.

IPCC (Intergovernmental Panel on Climate Change), 2001: Climate Change 2001: Mitigation. *Third Assessment Report* of the United Nations Intergovernmental Panel on Climate Change, Working Group III, Chapter 3. Cambridge University Press, Cambridge, UK.

Nash D.A., 2000: "Marking Nuclear Production Costs by Components" IAEE Newsletter, First Quarter.

NEA (Nuclear Energy Agency), 2000: *Reduction of Capital Costs of Nuclear Power Plants*, Organization for Economic Cooperation and Development, OECD/NEA, France.

OECD (Organization for Economic Cooperation and Development), 1998: *Projected Costs of Generating Electricity: Update 1998*. Organization for Economic Cooperation and Development (OECD), International Energy Agency (IEA) and Nuclear Energy Agency (NEA), Paris, France.

PBMR (Pebble Bed Modular Reactor Ltd.), 1999: Private communication with representatives of Pebble Bed Modular Reactor Ltd., Centurion, South Africa.

Rogner H-H., 1997. "An Assessment of World Hydrocarbon Resources". *Ann. Rev. Energy Environ.* 22: 217-262.

Rust J. and G. Rothwell, 1995: "Optimal Response to Shift in Regulatory Regime: The Case of the U.S. Nuclear Power Industry," Indexed in *Research Papers in Economics* (www.inomics.com), archived at econwpa.wustl.edu, July 1995.

SNN (Nuclearelectrica), 1999: Private communication, September 1999.

WEA (World Energy Assessment), 2000: *World Energy Assessment: Energy and the Challenge of Sustainability.* Goldemberg J. (ed). United Nations Development Programme (UNDP, United Nations Department of Economic and Social Affairs (UNDESA) and World Energy Council (WEC), New York.

Whitfield M.B., 1997: "Electricity Restructuring in the USA and its Effects on the Nuclear Industry". The Uranium Institute, Twenty-Second Symposium, 3-5 September, London, UK.