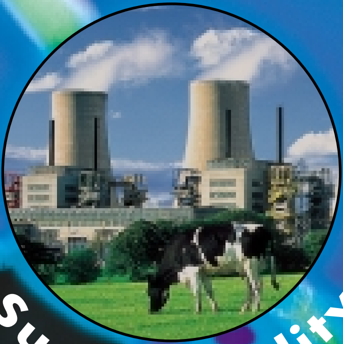
INTERNATIONAL ENERGY AGENCY



Sustainability

NUCLEAR POWER

Competition

Climate Change

FOREWORD

Nuclear power today provides nearly one quarter of the electricity supply in OECD countries. Sixteen OECD countries produce electricity in nuclear power plants with a total capacity of 300 GW. They have a history of safe operation. Yet, the accidents at Three Mile Island and Chernobyl shook government and public confidence in nuclear energy, while changing technologies and economics in power generation also weakened the prospective cost advantage of nuclear power. After a period of rapid expansion in the 1970s and 1980s, growth has slowed or stopped in most countries. Many now question whether nuclear power will ultimately play the important role once envisioned for it. Indeed, some governments are strongly committed in their opposition to nuclear power.

This book explores the implications for nuclear power of three increasingly important energy policy issues: sustainability, climate change, and competition in electricity markets.The fact that nuclear power does not emit greenhouse gases is a strong argument in favour of considering it as one possible response to climate change concerns. Competitive markets will provide the economic context – and economic challenge – for nuclear power.

There are widely divergent views on nuclear power's acceptability among OECD countries. The debates about nuclear issues are passionate and, today, largely unresolved. What to do with high-level radioactive wastes? What level of nuclear plant safety should be mandatory? How to ensure that civil nuclear materials are not misused for military purposes? Can industry and government institutions responsible for nuclear power command public confidence? These questions are fundamental to the future of nuclear power, regardless of other policy issues. This book does not recommend what the role of nuclear power *should* be; rather, it tries to analyse how that role could be influenced by other key policy developments in the wider energy context.

As an international organisation which is in close contact with the realities of energy policy and energy markets, the International Energy Agency is an authoritative source of national energy statistics and information for OECD countries, data upon which policy analyses must rely. The nuclear-specific work of the OECD Nuclear Energy Agency is also an important input to our analyses. It is within the full context of energy policy that the IEA believes nuclear power must be considered.

This report reflects the views of the IEA Secretariat. It is published on my responsibility as Executive Director and does not necessarily reflect the attitudes or positions of the Member countries of the IEA.

Robert Priddle
Executive Director

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The principal author of this report is Dr. John Paffenbarger of the Energy Diversification Division, working under the direction and editorial oversight of Mrs. Caroline Varley, Head of Division, and Mr. Jean-Marie Bourdaire, Director of the Office for Long-Term Co-operation and Policy Analysis.

A series of papers presented at the Uranium Institute, the Japan Atomic Industrial Forum, and the International Atomic Energy Agency in 1997 and 1998 form the basis of the text. The OECD Nuclear Energy Agency offered many useful comments on the drafts of these papers, although the views expressed remain those of the IEA Secretariat. The helpful comments provided by IEA and NEA Secretariats are gratefully acknowledged, in particular those from Richard Baron, Evelyne Bertel, Peter Fraser, Philippe Savelli, Lee Solsbery, Makoto Takahashi, Sam Thompson, François Verneyre, and Madeline Woodruff.

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EXECUTIVE SUMMARY

SUSTAINABILITY

There is general agreement that long-term energy use patterns should be sustainable indefinitely and that they ought not to degrade the environment. However, the "sustainability" of energy use is an elusive concept, involving environmental, supply, and economic dimensions. Can nuclear power contribute to a sustainable energy supply? Three essential components of any answer to this must involve:

- the input supply of nuclear fuel
- potential environmental effects from the fuel cycle, plant operation and decommissioning, and from the by-products of nuclear power production
- overall power production economics.

Nuclear power was seen in its early days as offering a potentially limitless source of energy. The input energy source, combined with the recycling of spent fuel, does indeed offer a possible long-term energy source — for millennia. But this promise relies on new technology, the costs and precise features of which are not yet known with certainty. The reduction of operational risks from nuclear power plants has always (especially in OECD countries) been given top priority in plant design, and the very limited radioactive emissions from commercial plants since nuclear power's inception suggests that the environmental risks from nuclear power can be made small. Still, the risk of a catastrophic accident causes significant public concern. The by-products of nuclear power generation also lead to a great concern for the environmental sustainability of nuclear energy. Can fission by-products and long-lived wastes be handled safely and not endanger the environment? The technical evidence seems to suggest a positive answer. Ensuring this in practice, however, involves political uncertainty and some considerable perseverance. There is the possibility that attaining publicly acceptable safety in plant operation and spent fuel management could render nuclear power uneconomic in comparison to other options.

There are, as well, other political challenges to nuclear power which would have to be surmounted before it could play a significant role contributing to future energy supplies. First, public acceptance of new nuclear facilities, or even an extension of the lifetimes of currently operating facilities, is a key issue. Second, real, complete programmes and facilities for disposal of high-level waste and processing of used fuel are not in place in any country. Third, in the international context, an important issue is ensuring that any expansion of civilian nuclear power does not lead to proliferation of nuclear weapons.

On balance, nuclear power could provide a contribution towards sustainable energy development, but only if it able to surmount its economic and political challenges.

CLIMATE CHANGE

The potential impact of energy use on the earth's climate is a subject of increasing international importance. The meeting of the parties to the Framework Convention on Climate Change that took place in Kyoto, Japan in December 1997 set out a real international commitment to curb emissions of greenhouse gases. In a general sense, and regardless of the specific agreements of the Kyoto meeting, if emissions of carbon dioxide are to be curbed there must be some recognition of the value of producing less carbon dioxide from energy use. Market-oriented plans using tradeable permits or offsets are possible means of recognising this value. Command and control measures to mitigate carbon dioxide emissions also will establish carbon values, though implicitly.

Workable policies to curb carbon dioxide emissions from energy consumption must take into account the sectoral characteristics and regional patterns of energy use. Development of a carbon value would change the results of interfuel competition, tending to favour lighter (less carbon intensive) fossil fuels and particularly natural gas. The fuel mix to electric power plants will be affected because the cost of energy is a major component of the final electricity cost.

In the near term, changes to the fuel mix will be constrained by the existing stock of power plants and their fuel switching capability. Coal-fired power plants will be strongly disadvantaged because they have the highest carbon dioxide emissions per unit electrical output. Natural gas-fired plants would be strongly favoured. Nuclear power plants could not play a significant role to reduce carbon dioxide emissions in the near term because they operate near their maximum output already and cannot provide much incremental output. In the long term, power plants based on nuclear and renewable sources of energy could be favoured, because their costs are unaffected by any potential carbon value. Nuclear power would provide a limit to carbon value by providing a large source of carbon dioxide emissions reductions.

Nuclear's ability to produce electricity with no carbon dioxide emissions will not lead to its increased use, even if it may be an economic solution, unless some of the non-economic impediments to nuclear power are removed.

COMPETITION

The advent of competition in electricity markets throughout the OECD will affect the operation of power plants and prospects for new power plants of all types. Nuclear power will not remain immune from the changes brought about by market liberalisation. Competition brings a focus on reducing generating costs that will reinforce the trend towards improved economic performance in nuclear plants. Plants with low fuel and operating and maintenance costs will be strong competitors and well placed to continue operating, most likely with life extensions to the extent that they are permitted by regulatory authorities. Conversely, high-cost plants must improve or face closure sooner than expected. Whether or not new nuclear plants will be built under competitive market conditions remains a theoretical question for the moment, because the political will allowing new nuclear plants does not exist in most countries, and nuclear power is more expensive than fossil alternatives in most world markets. If, in the future, political and economic conditions once again make nuclear feasible, competitive markets will select the generation technology with the lowest total cost, even capital-intensive ones.

Safety regulations and safety regulators must adapt to the changing market conditions. Perhaps most significantly, they must take into full account the economic impact of safety regulation and balance it with real safety improvements. Changing corporate structures and cost pressures will require continued vigilance to ensure that existing high standards of safety are maintained.

Electricity market competition does not remove the well known hurdles of high cost, lack of spent fuel disposal facilities, and public acceptance issues faced by new nuclear power plants; it highlights them and provides a better perspective of the critical steps to be achieved to keep the nuclear option open. As for other electricity generation technologies, competition will provide better policy transparency and accountability, together with a strong impetus for cost reduction and innovation, perhaps laying the economic foundation for a stronger nuclear power industry in the future.

2

SUSTAINABILITY

Sustainability is a term coined to mean the goal of practices, methods and technology which provide growth but do not degrade the environment in the long term. This sense has been first and foremost, but has expanded over time as the debate about sustainability has taken shape. It encompasses the idea that today's activities must not destroy sensitive natural resources, leave problems or debts for the future, that they must be economically sound, and, depending on the observer, a host of other ideals. The European Commission, for example, considers that the use of adequate labour inputs is an element of sustainable development (EU, 1997). Reducing human or social stress can be part of the concept.

It is fair to say that many of the strongest supporters of sustainability view the use of fossil fuels as unsustainable. They cite pollution and finite fossil fuel resources as, by definition, being unsustainable. The alternatives most often proposed are renewable sources of energy, which, almost tautologically, are sustainable. Various forms of solar energy seem ideal: solar photovoltaic electricity, solar thermal energy, and wind power figure high on the renewables list. Improved energy efficiency, biomass and household waste streams are part of many environmentalists view of a sustainable energy future.

Nuclear power, most definitely, is not seen as part of the future by most advocates of sustainable energy use. Examples of this are not difficult to find. The United Nations Development Program, in its document Energy After Rio (UNDP, 1997), does not suggest a role for nuclear power except in the most doubtful of terms. The Swedish parliament's February 1997 law beginning the phaseout of nuclear power is entitled "Government Bill on A Sustainable Energy Supply." The environmental organisation Greenpeace (1997), in a statement for the June 1997 United Nations "Earth Summit II" declared that "the essential solution [to nuclear power problems] is a phase-out of nuclear power and the end to nuclear fuel reprocessing. Nuclear power must be replaced by ecologically sustainable energy systems — such as solar, wind, bio-fuel plantations, energy efficiency and conservation." Other environmental organisations have made similar statements on the incompatibility of sustainable energy use and nuclear power.

The debate on sustainability has not gone unnoticed by those who recognise the potential advantages of nuclear power. The concern about climate change, at a time when nuclear power's fortunes are declining in many countries, has been seen as a lever to revitalise interest in nuclear power. The plenary session of the 1996 annual meeting of the American Nuclear Society was on the sustainability of nuclear power. The Director General of the International Atomic Energy Agency, in his address to the 1997 Earth Summit II, stated that nuclear power deserves to be examined in the search for a sustainable energy mix. The Nuclear Energy Agency of the OECD has recognised the potential role of nuclear power in sustainable development (Stevens, 1997). The Uranium Institute has in a number of its publications discussed the advantages of nuclear power as a concentrated source of energy and as a means to reduce emissions of carbon dioxide. Following the December 1997 Conference of the Parties to the Climate Change Convention, those in the nuclear industry have increasingly discussed the sustainability of nuclear power. Nuclear organisations and proponents see nuclear power as an eminently sustainable energy source.

Member countries of the International Energy Agency also acknowledge the potential contribution of nuclear power to a sustainable energy mix. They adopted a statement of "Shared Goals" in 1993 which outline the principles by which energy sectors of their economies can make "the fullest possible contribution to sustainable economic development." The Shared Goals make reference to nuclear power both in its contribution to energy supply diversity and to the environmentally sustainable provision and use of energy. The Shared Goals state that "a number of IEA members wish to retain and improve the nuclear option for the future, at the highest available safety standards, because nuclear energy does not emit carbon dioxide."

This chapter briefly takes another look at nuclear power's sustainability. It is argued that nuclear power could indeed play an important role in a sustainable energy mix of the future, but that this role is by no means assured. Three key aspects are discussed:

- **energy supply:** is a nuclear fuel supply indefinitely available?
- **environment:** is nuclear power compatible with respect for the environment?
- **economics:** is nuclear energy an economic option in the long-term?

To the greatest extent possible the focus is on the sustainability of nuclear power in its own right, not on the "unsustainability" of other potential energy sources. The latter approach leads to the unsatisfying polemic that any "less sustainable" energy source is itself unsustainable. That said, economics is a key aspect of sustainability since a number of sustainable energy paths can be imagined that differ essentially only in their cost. The comparative economics of the paths will determine which among them will be followed. In this respect there must be some consideration of the relative strengths of different options providing some part of a sustainable energy supply.

The time scale considered here for sustainability is very long — centuries rather than decades. For this reason we place less emphasis on issues which relate to the near-term prospects for nuclear power, which do look quite different than the long-term prospects.

This would seem to be one of nuclear power's strong points. Conventional thermal reactors consume relatively small amounts of fuel and known global reserves of uranium are widespread. Yet, at current rates of use of about 70 thousand tonnes per year in world nuclear reactors, known resources of 4.3 million tonnes (NEA, 1997) amount to only 60 years of supply. If 11 million tonnes of additional speculative (undiscovered) resources are included, some 220 years of resource can be identified. This is not greatly different than the horizon for fossil fuels. Coal alone is thought to be present in sufficient quantities to represent 300 to 400 years of supply at present rates of use. Like any other non-renewable energy source, reserves of fissile material for nuclear energy are limited. Current nuclear technology based on fission of uranium in thermal reactors is thus not sustainable using known and speculative uranium resources.

Uranium is distributed throughout the world in reserves having various costs of exploitation. The above figures for known resources include those of less that 130 US$/kilogram. Even though large amounts of uranium may be available beyond known or speculative reserves, this does not mean that the supply of energy for nuclear power is simply proportional to whatever quantities can be identified. For example, sea water is often cited as a source of natural uranium without reference to the cost of extracting it. Uranium dispersed throughout the earth's crust or in seawater may be a large energy resource, but is not necessarily an economic energy source in comparison with other options.

A qualification to the notion of finite energy resource is given by the example of fossil fuel reserves. Oil and gas have seemingly always been in danger of depletion 30 years from the moment any estimate is made. This has to do with the state of knowledge at any point, as driven by commercial interest, prospecting technology, and activity in fossil fuel extraction. Economic reserves of fossil fuel have consistently risen over the years even as the rate of consumption has increased. Nuclear fuel reserves would follow the same pattern. They could be expected to grow as demand and uranium price increased. Unlike the case for fossil fuels, uranium accounts for a relatively small proportion of final electricity cost, so large price increases could be tolerated in the cost of finding and extracting uranium before this had a significant impact on final electricity production costs. This places less of a sharp edge on reserve estimates and depletion rates for natural uranium.

The key to long-term energy supply from nuclear power is not uranium ore reserves, or even reserves of fertile materials like thorium. Rather it is new, as yet non-commercial nuclear technology that could allow nuclear power to be sustained over a very long period. Today the first step appears to be the use of breeder reactors. Thermal reactors use only 2% of the energy available from natural uranium. Most of the energy remains unused in depleted uranium. Breeder reactors could overcome this deficiency in two ways: 1) recycling plutonium produced in thermal reactors, and 2) converting fertile uranium-238, normally concentrated in depleted uranium, into fissile plutonium. (A breeding fuel cycle based on thorium-uranium is also possible.) Together these improvements could increase the energy use from natural uranium to 75% or higher. The reserves of uranium mentioned above could thus be extended by 40 times. Eight thousand years does indeed sound sustainable.

The World Energy Council has prepared projections that show in one scenario a need for breeder reactors to become acute between 2030 and 2050, depending on the rate of growth in energy demand and the use of nuclear power. This leaves time to develop breeder reactor technology, if it is called upon. Today the experience with breeder technology is limited. A few demonstration plants have already been built and operated, including France's Phénix and Superphénix plants (the latter in the process of permanent closure), Japan's Monju (currently shut down due to technical problems), and Russia's Beloyarsk plant. Still, the capacity of breeder plants operating today (2400 MWe) is less than that of cancelled and permanently closed breeder reactor projects (2500 MWe). The French and Japanese plants have proven to be very expensive compared to conventional thermal reactors. Many of their essential systems, such as reactor, heat transfer, and safety systems, are completely different than commercial reactors, and so could not take advantage of the designs and experience accumulated with conventional plants. Although the technical potential of breeder reactors has been partially demonstrated, results from the first few plants are not sufficient to define the precise features and costs of technically mature plants.

Extending the nuclear energy supply via breeder reactors would require a fuel cycle with reprocessing. The essential elements of potential fuel cycles, mainly using the uranium-plutonium route, have been demonstrated and do not pose any major technical problems. They do not appear to have any major economic problems, although the cost of implementing adequate safety measures for long-term fuel cycle operation and waste disposal are not fully known today.

Other potential technological developments would allow nuclear power to last well into the far future. Fusion is of course often cited as offering a "limitless" supply of energy. Yet fusion concepts under development today rely on the use of tritium, in turn produced from limited world reserves of lithium. The considerable technological and economic hurdles to commercial fusion reactors have no immediate prospects of resolution. Human ingenuity may one day overcome the technical hurdles, but there is considerable doubt regarding when this could be achieved and the ultimate cost of power produced using a fusion reactor. For the moment fusion power is no more than a concept.

In summary, natural resources of energy supply for nuclear power plants are indeed limited using current technology. To extend this supply to a period on the order of many centuries, breeder reactors and recycling of fissile material generated in them would be required. The technical ability of this approach to provide a very long-term source of energy is clear, but its comparative economics are not.

ENVIRONMENT

This area is the one on which views on the sustainability of nuclear power seem most divergent. On the one hand, nuclear proponents point out that nuclear power does not produce emissions of airborne pollutants or carbon dioxide, and that solid wastes produced are small in volume compared to wastes from fossil fuelled plants. Opponents to nuclear power believe accidental releases of radiation and nuclear wastes pose grave threats to the environment. They correctly state that it is potential health effects of wastes, not volume, that matters. Experience to date with properly engineered nuclear power stations and scientific knowledge on nuclear waste disposal suggest that the view of nuclear power as environmentally benign is closer to reality. However, this is not necessarily the broad societal view of the issue. The three main environmental considerations when exploiting nuclear energy relate to ongoing emissions of radioactivity, accidental emissions, and radioactive waste disposal.

Ongoing Emissions of Radioactivity

Emissions of gaseous pollutants of any kind from nuclear power stations are nil on an ongoing basis. No special control systems are needed since energy release is contained within the solid state, in an enclosed reactor, rather than in an open, gas-phase system as in fossil fuelled power plants. Governments have developed increasingly stringent regulations on the emission of sulphur dioxide, nitrogen oxides, particulate matter, and a host of other airborne pollutants. Likewise, as part of the Climate Change Convention, most OECD governments have made commitments to control or reduce carbon dioxide emissions, although the depth of this commitment remains to be measured. Nuclear power is certainly sustainable in the long term if emissions of "traditional" energy-related pollutants or carbon dioxide emissions are discouraged. The economics of nuclear power will be unaffected by new or more stringent regulations on non-radioactive airborne emissions of any kind.

Thermal emissions from nuclear power plants are relatively high because of low thermal efficiency. This can pose a problem if a large nuclear plant uses river water and a once-through cooling system. The temperature of river water can be raised to a point which is detrimental to the river ecosystem. However, this problem can be overcome, at a cost, by closed loop cooling systems. There is no technical impediment to reducing thermal emissions from nuclear power plants to rivers or bodies of water.

Potential emissions of radioactivity are a concern unique to nuclear power. During normal operation of a nuclear power plant, all potentially harmful radioactivity is controlled and kept within specifically identified areas of the plant. This protects first and foremost plant personnel, but necessarily protects the environment outside the plant structures. Over time governments have instituted regulations on the control of radioactivity in power plants and these have proven to be effective in protecting plant workers and the public.

Accidental Emissions of Radioactivity

Exceptional emissions of radioactivity from plant accidents or mishaps must be considered the issue of greater relevance to the long-term sustainability of nuclear power. It was the Three Mile Island and Chernobyl accidents which focused attention on the potential dangers of accidental radiation releases from nuclear power plants. In the 1980s nuclear regulators multiplied safety regulations, imposed many new design requirements, and constrained operating practices. The cost of plant systems, operation, and staffing increased substantially. While there remain questions about the cost effectiveness and even usefulness of some of the measures taken in the wake of these accidents, it is clear that nuclear power plant safety has been improved beyond the levels already found prior to 1979. The Three Mile Island incident did, after all, demonstrate most dramatically that engineered safety systems could be expected to prevent the release of radiation to the environment, even when badly operated. The emphasis on human factors as a contributor to overall plant safety was a very useful development. The safe operation of existing commercial nuclear power plants has been sustained now for almost 40 years in OECD countries. There is nothing to suggest this cannot be maintained indefinitely, even without the inevitable incremental improvements to nuclear power plant designs.

The counter-argument to the generally good safety record within the OECD is that the consequences of a serious accident at a nuclear plant could be very grave indeed, far worse than from most power plants. Even if the risk of an accident is small, the potential consequences could be catastrophic. The use of probabilistic assessments and worst-case scenarios in design and licensing of nuclear plants has been the technical response to this concern. Those in the nuclear power industry, including regulators, are generally assured that this has produced a satisfactory approach to protecting human health and the environment. It places nuclear power in a comparable light with, say, hydroelectric power production or industrial chemicals production, where serious accidents (notably dam failures) can and do cause loss of life and environmental damage. But the technical reasoning is not widely understood or accepted by other public bodies or the public at large.

Outside the OECD, the Chernobyl accident did raise grave concerns about the ability to safely design and operate nuclear reactors. Unlike at Three Mile Island, there were significant releases of radioactivity to the environment. The nuclear industry and governments have credibly responded to these concerns by demonstrating the inadequate attention to safety considerations, both in design and operation of the Chernobyl-type RBMK designs. These deficiencies were engendered by the political system under which the plant was created. Reliance on an open, transparent process for nuclear plant regulation makes a similar re-occurrence seemingly very remote. However, it is not a foregone conclusion that governments around the world will be able to implement such a regulatory process and safety culture, as one can conceive of situations where inattention to safety is tolerated. Inadequate external supervision, combined with financial pressures, could lead again to a serious release of radiation from a nuclear power plant of current design.

This is why continued improvement to nuclear power plant designs and operation must be a part of any view of nuclear power sustained in the long-term. A number of new plant designs have been developed in recent years which further reduce the possibility of accidental radiation release, even in a mis-operated or poorly maintained plant. The Advanced Boiling Water Reactor, the AP600, the System 80+, and the European Pressurised Water Reactor are examples of this evolution towards safer nuclear plant designs. All rely upon simplification of systems, passive safety systems requiring (in some cases) no power or operator intervention, and standardisation of design. The latter reduces the potential for improper field construction to introduce safety risks.

A shift to breeder reactors would bring new safety risks because of the greatly different design and initial lack of experience with this technology. The increased transportation of plutonium would also engender additional risks. The transition period to breeder reactors might be one during which the greatest risk to the environment could be projected. The large-scale introduction of thermal reactors was punctuated by the two accidents cited above, plus quite a few less publicly visible ones. It is again not a foregone conclusion that this experience should be sufficient to prevent similar "learning" experiences as a shift to breeders took place. There is reason to believe that a safe transition would be possible. However, the issue cannot be ignored in characterising nuclear power, in the long-term, as presenting little risk to the environment from accidental releases of radiation.

If historical experience increasingly proves that commercial nuclear power plants and fuel cycle facilities can be operated without serious accidents, operating safety should become a smaller perceived obstacle to the sustainability of nuclear power. Waste disposal is becoming the focus of concern for both existing and future plants.

Waste Disposal and Decommissioning

The disposal of high-level radioactive wastes is the single most important issue calling into question the sustainability of nuclear power. The fate of material from decommissioned plants raises a similar concern. Nuclear waste is thought by many to pose an unsolvable environmental problem whose consequences will be borne by future generations. Simply put, can nuclear waste of all kinds be stored or isolated safely until its radioactivity is no longer harmful to humans or the environment?

The nuclear technical community thinks the answer is "yes." The disposal of radioactive waste has, since before the beginning of nuclear power generation, been based on the principle of protecting human health and the environment. It has been manifestly clear that a primary goal must be to minimise the chance that the waste would come into contact with humans in the future. There is broad consensus on the merits of geological disposal of long-lived radioactive wastes in deep and stable geological formations in order to do just that. The Radioactive Waste Management Committee of the OECD Nuclear Energy Agency, for example, has issued a "collective opinion" of the environmental and ethical basis of the geological disposal of long-lived radioactive waste (NEA, 1995). This finds that a geologic disposal strategy "can be designed and implemented in a manner that is sensitive and responsive to fundamental ethical and environmental considerations." This view was developed specifically in reference to the concept of sustainability. They conclude that

- "it is justified, both environmentally and ethically, to continue development of geological repositories for those long-lived radioactive wastes which should be isolated from the biosphere for more than a few hundred years; and that
- stepwise implementation of plans for geological disposal leaves open the possibility of adaptation, in the light of scientific progress and social acceptability, over several decades, and does not exclude the possibility that other options could be developed at a later stage."

Affirming the acceptability of the approach involves a complex argumentation, often hidden in a dense mass of scientific detail. Identifying suitable disposal sites, developing the appropriate engineered infrastructure, and assessing the systems' potential ability to minimise potential long-term radiological impacts on humans and the environment involves a great many technical evaluations and a certain number of hypotheses regarding the future. The Yucca Mountain Project in the United States has a 6000 page plan for characterising the adequacy of the site and has spent well over one billion US dollars in the 1990s alone on site characterisation. The safety assessment approach is complex and typically involves probabilistic assessments of geological events, evaluations of fluid mobility through rocky, but porous or fractured geological formations, and estimate of long term properties and behaviour of engineered systems. The complexity of such evaluations is daunting to all but specialists. The very strong public reaction against many projects to develop waste disposal sites shows that the general societal view is indeed far from the specialist view.

The volumes of wastes produced by nuclear power plants are small compared to those produced by fossil fuelled electricity plants. This is an environmental advantage to the extent that wastes from a widespread activity can be put in one location. The geographic extent of any potential environmental damage (say in the worst case) can thus be made very limited. The volume of nuclear wastes, however, is not the essential determinant of their environmental acceptability. High-level wastes have potential health affects much more acute and severe than wastes from fossil fuel plants precisely because they are concentrated and much more toxic. They are deadly if not shielded, they cannot be chemically or physically neutralised like many other toxic wastes, nor can they be dispersed safely. Furthermore, the wastes are generated in many locations and must be transported in order to geographically concentrate them, increasing the opportunities for transportation mishaps. The costs of properly handling high-level wastes, on a unit basis, are very high. So the small volume of nuclear wastes is technically helpful but is only one among other relevant factors in the environmental acceptability of their disposition.

Apart from the scientific or technical aspects of high-level waste disposal are the particularly difficult questions of institutional adequacy and future human behaviour. In the time scale of concern for safe isolation of high-level wastes (e.g. 10 000 years has been used as a design criterion in some repositories), no government or even civilisation could be counted on to actively ensure an undisturbed waste site. A passively safe situation must be sought to ensure waste isolation from the environment.

Short-lived wastes pose less of a technical and institutional problem because, by definition, their radioactivity declines within a relatively short period. It is therefore easier, and less costly compared to long-lived wastes, to take measures ensuring that wastes will remain isolated for the prescribed period. No permanent problem is left for later generations to deal with. The generation of low-level wastes should not, therefore, pose a problem of environmental sustainability.

It appears that there are no inherent technical impediments to the environmentally safe use of nuclear power. Higher levels of environmental safety have been pursued relentlessly in the nuclear industry, both in operation and in waste disposal. This has been an undeniable factor in the increase in costs of generating electricity from nuclear power.

ECONOMICS

Can nuclear power compete with other sources of electrical energy? Assuming a sustainable energy supply to be the goal, the least cost solution should be chosen to reach it. Inevitably then, the evaluation of nuclear’s economic sustainability must be with reference to other energy sources. Today, the economic viability of nuclear power is being questioned by many industry observers.

Near-term Competition from Fossil-fuelled Plants

New coal-fired and gas-fired power plants appear in many evaluations to offer a lower cost of electricity than new nuclear plants. Gas-fired combined-cycle gas turbine (CCGT) power plants look especially attractive in light of today’s price of natural gas in many markets. Their low capital costs and short construction times are often-cited financial advantages that indeed are economically attractive in comparison with nuclear power. In some situations it appears that electricity from gas-fired combined cycles may be obtainable at roughly half the cost of that from "traditional" nuclear plant designs. Coal-fired power plants, fitted with high-efficiency pollution control equipment, also look attractive compared to nuclear power in many markets. It is true that the lack of construction of nuclear plants in OECD countries is at least partly due to their currently uncompetitive economic position. Although nuclear does still appear competitive in some markets, the reality is today that in many countries nuclear plants face very strong competition from fossil-fuelled alternatives.

The current debate on nuclear power's competitiveness in newly liberalising electricity markets confirms the general situation just described. It exposes clearly that a certain number of nuclear plants built in the past were vastly expensive or are uneconomic to operate. At the same time it highlights the excellent performance and low operating cost obtained from other existing nuclear units. However, it does not particularly inform the debate about nuclear power's long-term economic competitiveness.

In the long term, various factors affecting the relative costs of competing electric generation technologies can change. We need look only as far back as the mid-1980s to find a graphic example of this. At that time very few CCGT plants were being sold, and one major world manufacturer nearly liquidated its production capability in light of the supposedly dim commercial prospects for gas-turbine based power. Today gas-fired CCGT plants are capturing large shares of new generating capacity around the world thanks to their competitive economics. An appraisal of long-term economic sustainability cannot be based on conditions in today's energy markets or today's technology.

In the case of nuclear power, its long-term economic viability is critically dependent on fossil fuel prices, the value attached to reducing gaseous emissions from fossil power plants, and technological developments in nuclear and competing technologies, such as renewables. The level of safety demanded also influences nuclear power's cost.

Fossil Fuel Prices and Energy Security

The oil shocks provided a strong stimulus for the development of nuclear power in the 1970s. Fuel prices for power generation increased dramatically. In addition future fossil fuel prices were projected to inexorably increase as well. Since fuel costs account for some 50-80% of fossil plant lifecycle costs, the increased fossil energy prices, both current and projected at the time, enhanced the competitiveness of nuclear power.

The view of ever increasing fossil fuel prices has since been proven wrong, and the nuclear advantage has eroded in parallel with stable or declining real fuel prices in most markets after 1986. The oil shocks did, nonetheless, drive home the clear advantage of nuclear if fossil fuel prices increase substantially and permanently. Should the time arrive when fossil fuel resources become, finally, truly more expensive, nuclear power would once again enjoy the economic advantage perceived in the 1970s and early 1980s. Today it seems the wait for this time to arrive could be long.

Concern about the security of fossil fuel supplies could again play a role in economic evaluations of nuclear power. Many countries supported nuclear power development as an economic baseload power source immune from price increases in fossil fuel markets. By diversifying energy sources, nuclear power can provide a hedge against large increases in the national energy bill. Also, nuclear fuel is regarded as indigenous by OECD countries, which possess about half of the world's reserves of uranium. The risk of an interruption in the supply of natural uranium seems remote compared to oil or natural gas. In the past the value of both energy diversity and fuel security were folded into economic evaluations through informal mechanisms such as fuel price projections or capital cost contingencies on different technologies. In the future some governments may wish to make the value of energy security more explicit in considering the economics of different power generation options. In this case nuclear power will have an advantage.

A Carbon Value and Nuclear's Competitiveness

The concern over climate change could have a much more dramatic effect on the relative economics of nuclear and fossil fuelled plants well before then. It is clear that real commitments to reduce emissions of carbon dioxide and other greenhouse gases would effectively place a value on not producing them. This idea is developed further in Chapter 3. Emissions limits at the level of individual producers such as power plants or automobiles would implicitly place values on carbon dioxide emissions. Market-based policies would make the value explicit. In the case of carbon dioxide emissions from fossil fuel use, we may speak about a "carbon value" or the cost to energy users to emit carbon dioxide. (Equivalently, this may be thought of a value to not emitting carbon dioxide.) The situation is analogous to existing regulations to control emissions of traditional fossil fuel pollutants (sulphur dioxide, nitrogen oxides, particulate matter).

Power generation would be strongly affected by limits on carbon emissions or an explicit carbon value. Most importantly, the relative competitiveness of different generating sources would be changed. Nuclear and renewables' costs would remain unaffected since they are not dependent on carbon-bearing energy sources. But coal, oil and gas-fired power generation would become more expensive.

In summary, restrictions on carbon emissions in the power sector, either with implicit or market-based restrictions on carbon dioxide emissions, could place coal-fired power generation at a significant cost disadvantage, while favouring first gas-fired power, nuclear, and ultimately renewables. Such a carbon dioxide constraint could be an important potential contributor to nuclear power's economic sustainability in the long-term, regardless of the ultimate resources of fossil energy available.

Competition from Renewables

There is not yet a strong commitment by governments around the world to firmly restrain carbon dioxide emissions. The introduction or development of a carbon value will likely take a long time to arrive. In the meantime, the technology and economics of renewable energy could improve relative to nuclear and in turn pose an economic challenge. Renewables have enjoyed, like nuclear, an early period of subsidised development and technical improvement. The costs of electricity production obtainable from some non-hydro renewable technologies have dropped substantially in recent years. Yet currently they are not serious competitors to baseload power supply except in very limited situations. Although not at all assured based on today's concepts, non-hydro renewables could develop into true competitors to fossil or nuclear generation. Given time and technological advances, renewables might be in a better economic position than nuclear power to "receive the baton" from fossil fuels.

Safety Versus Cost

Apart from independent technological developments, there is the question of finding a balance between safety and cost. As noted earlier, the cost of nuclear power production increased dramatically due to the multiplication of safety regulations related to plant design, construction, and operation. Costs of low-level waste disposal also have increased dramatically. For example, in the United States these costs escalated at a rate of 13% during the period 1980-95 (ANS, 1996) due to more stringent requirements on disposal sites and a scarcity of new sites. The cost of decommissioning a retired nuclear power plant will vary enormously depending on the level of residual radioactivity permitted, linked to regulators' and the public's perception of the safety and health effects of such radioactivity.

Siting has become extremely difficult in many countries as potential neighbours to nuclear facilities have increasingly protested against them on the grounds of environmental dangers. The increasing difficulty and cost of siting commercial nuclear facilities is intimately related to the perception and demonstration of safety at these facilities. Recent examples in which nuclear facilities have faced considerable opposition are the Nirex Rock Characterisation Facility in Sellafield, United Kingdom, the Ward Valley waste facility in the United States, the Mount Muria nuclear power plant in Indonesia, and the Maki nuclear power plant in Japan. The Japanese government provides subsidies to townships which host nuclear power plants in an effort to improve their local attractiveness. The development of environmental impact assessments or equivalent documents for nuclear facilities has become very time consuming and expensive in many locations as the scientific detail required to prove safe operation has vastly increased. Uncertainty about ultimate decommissioning policies adds to the concern and cost of siting new facilities.

This balance between safety and cost has not yet found its equilibrium in OECD countries. Safety regulations should be based upon an appraisal of potential health and environmental impacts and the cost of minimising them. This is an approach which has gained acceptance in the safety regulation of other heavy industrial activities such as fossil power production, chemicals production, and mining. Many in the nuclear field argue that this approach has not been uniformly applied to their industry.

In some jurisdictions it appears that regulations may have been used to move towards the political goal of stopping nuclear power development. In some instances it seems regulations have been introduced without due consideration to their costs relative to any incremental gain in safety. Fox (1995) cites the example of protection against pipe whipping required in the United States. Compliance with the regulation cost some US$ 500 million, by his estimate, but the benefits were sufficiently ill-defined that ultimately the regulation was rescinded. Part of the difficulty has also been in estimating the health effects of low-level radiation. The linear, no-threshold model of radiation risk is the one on which much nuclear safety regulation has been based, but it is increasingly being called into question on a scientific basis as being vastly too conservative if not simply wrong. A combination of political influences and technical inability to quantify risk have thus tended to increase the costs of complying with safety regulations over time.

If nuclear power is to be sustainable economically, safety-related costs cannot continue increasing indefinitely. A consensus must be found on how to value safety. An insistence on safety at any price without reference to potential health benefits would handicap, if not stop, nuclear power's further development. That outcome is not impossible if public acceptance concerns are not alleviated. While it seems the question may be at least commonly understood for power plants, nuclear waste disposal has yet to be fully drawn into the debate because progress on high-level disposal sites has been limited. The nuclear safety debate of past decades must be resolved if nuclear power is to be sustainable.

POLITICAL CHALLENGES FOR NUCLEAR

There are both economic and political issues that are central to nuclear power's future in the near term. Arguably, the greater challenges are political. This is especially true in OECD countries. However, political challenges seem less important when considering the long-term fate of nuclear power. Political issues will either allow nuclear power to proceed, or they will not, leading to its end. The most important issues are:

- public acceptance of nuclear power plants;
- development of the back end of the nuclear fuel cycle; and
- assurance that civil nuclear technologies and fuel will not be used for military purposes.

In fact the first two might both be described as one relating to public acceptance of nuclear power, because the chief impediment to reprocessing and to long-term storage of high-level waste is essentially political rather more than technical. Public acceptance of nuclear power also involves acceptance of related activities such as fuel and waste transportation, disposal of low-level radioactive waste, emergency evacuation plans, operation of test reactors, and many other activities outside the confines of power generation stations. The violent demonstrations against shipments of high-level waste and spent fuel in Germany in March 1997 and the recurring public attention on reprocessed fuel shipments from France to Japan clearly illustrate this.

"Public acceptance" could alternately be described as "demonstration of nuclear safety." Public concerns ultimately stem from the fear that nuclear technology and materials could lead to release of unsafe levels of radioactivity into the environment. In this regard nuclear power plants have shown considerable technological progress since 1980 in improving safety through improved design and operational features. The historical absence of dangerous radiation releases from civilian nuclear power plants in OECD countries must be seen as a prerequisite for future maintenance or expansion of nuclear power in the OECD. In developing countries where new plants are being considered, ensuring safety in the absence of well developed institutional and technological experience is an important challenge. New, simplified plant designs involving passive safety features could help both in obtaining public acceptance and improving the economics of nuclear power.

The nuclear power industry may still be struggling with the legacy of military nuclear development which frequently, under the demands of rushed, secret programs, did not take precautions with nuclear plant operations or nuclear waste that would be considered adequate for modern civilian nuclear power programs. Lake Karachai in Chelyabinsk, Russia, rusting tanks of high-level waste in Hanford, Washington, and the 1957 Windscale incident in the United Kingdom illustrate that early practices were clearly unsustainable. Commonly agreed principles today are to adequately plan for waste disposal when embarking upon new projects, and to allocate sufficient resources to safely implement long-term operational and waste disposal plans. Over time, the transparent, open planning for nuclear operations and waste disposal will help nuclear power to outlive its negative military legacy.

The prominence of public acceptance as a political challenge to nuclear power may be related to the economics of today's energy supply. An important factor in today's energy supply situation is the relative abundance of energy at reasonable prices. Energy supply is not an issue in the public eye and the likelihood of long-term shortages seems remote. In this situation, the need for nuclear energy seems less imperative than it did during the period of the 1970s oil shocks. The public may be less willing to accept nuclear power when other less threatening energy sources are available without any large economic penalty. However, if the future energy supply situation included substantially increased energy prices due to development of a carbon value or simple growth in overall energy demand, public attitudes towards nuclear power could become more favourable as the balancing of nuclear's risks and rewards would shift. Part of nuclear's long-term challenge of public acceptance will be to demonstrate that its public health risks are small and that it brings economic benefits compared to other energy sources.

Concerns about the fate of radioactive species in spent fuel has been a serious impediment to development of adequate plans and facilities for isolating civilian nuclear wastes from the environment. Spent fuel reprocessing in particular has always raised concerns about the fate of plutonium and making sure that it is not used for military purposes. In a number of countries the issue of high-level waste disposal has reached a stage of near paralysis in public debate, as for example in the United States. There, the government administration has been unable to develop definitive plans for a permanent high-level waste repository, even as the judicial branch has been brought into play to enforce the now 16 year old law providing for temporary storage of high-level waste. In Germany and the United Kingdom, the sites identified as the most likely ones for waste storage face strong public opposition. Plans for reprocessing of wastes have been similarly blocked in some countries by safety concerns and, the last of the three main political challenges identified above, the fear of nuclear weapons development.

Non-proliferation is a key political challenge for nuclear. At the 1996 annual meeting of the American Nuclear Society, one commentator went so far as to state that the "sustainability of nuclear power is in the management of plutonium." This could be true from both a technical and political standpoint. The plutonium produced in light water reactor fuel cannot be used directly from spent fuel elements, but reprocessing to isolate and reuse plutonium in mixed oxide fuel poses a problem with potential diversion for military purposes. The 1970 Non-Proliferation Treaty was indefinitely extended and strengthened in 1995, and the number of parties to it has grown to 178. It is the main international instrument for supporting the objective of non-proliferation. Still, it is not universal, and several countries not party to it have active civilian nuclear programs. Further, the safeguards it provides must be adequately implemented for it to be effective. Strengthening the functioning of the Non-Proliferation Treaty must be an important part of the development of civilian nuclear power.

Nine countries initiated a parallel effort in 1994 to establish an international framework to increase the transparency in the management of plutonium. The first agreement of the group was to make public their inventories of civil plutonium and they are nearing agreement on detailed guidelines for plutonium management. In fact the success of non-proliferation efforts aimed at civilian nuclear power programs is indicated from the fact that nuclear weapons programs detected to date have not used civilian materials. They have instead relied on special-purpose equipment and material cycles which are outside the view of nuclear power non-proliferation measures. A sustained and wider effort to prevent proliferation using civilian nuclear materials would help address this challenge to the future of nuclear power.

Beyond administrative-type controls, there are also the practical realities of working with bomb-grade materials and the cost of producing them in reactors otherwise designed for electric power production. Spent fuel handling and extraction of bomb-grade material are costly, hazardous and sophisticated operations. Very significant investments in equipment and people are required to obtain nuclear materials for military use. These characteristics do make it extremely unlikely that organisations operating outside of government control, such as terrorist organisations, could produce nuclear weapons from civilian nuclear materials.

Parallels in nerve gas production suggest that a truly determined country can produce dangerous weapons regardless of the presence or absence of parallel industrial capability in civilian chemicals production. Fertiliser plants have not been banned because of chemical weapons, and it seems unlikely that nuclear power plants should be ultimately banned or limited because of their links with nuclear weapons. It is clear, however, that governments and the nuclear industry cannot be complacent about ensuring non-proliferation.

CONCLUSIONS FOR SUSTAINABILITY

Nuclear power has the potential to be a sustainable energy source. The preceding text outlines the arguments that there are no fundamental energy supply, environmental, or economic issues which would today exclude pursuit of nuclear power as a sustainable option for the future. There are, however, a number of serious challenges which nuclear power must face before it can play any long-term role.

The nuclear industry must develop appropriate, long-term technology solutions to allow full use of uranium reserves. The common view today is that this means breeder reactors. While demonstration breeder plants have been built and operated, this experience is not sufficient to tell us the long-term economics of this option. Long-term technological development of nuclear power also must emphasise safety obtained cost effectively. This is a trend already well underway, but which must be pursued vigorously because of competition from other energy sources.

The disposal of long-lived radioactive wastes is the single most important environmental hurdle facing nuclear power. Although there may be a technical consensus on the adequacy of geologic disposal, there is most definitely no social consensus on the issue. Nuclear organisations must explain technical views adequately if they are to convince governments and the public that waste can be disposed of safely. This is a question that must be resolved for the current generation of nuclear plants. Doing so could lay the foundation for further reliance on geological disposal, while not cutting off options by irretrievably disposing of valuable nuclear material.

Nuclear power must prove its economic merit in competition with other energy sources. In the near term nuclear power is at a disadvantage in many markets compared to fossil fuelled options. At a minimum lower cost nuclear plant designs and better performance could help to regain an economic advantage. Development of a carbon value, or value to reducing emissions of carbon dioxide, would increase the cost of fossil fuel options relative to nuclear and renewable energy. In the long term this could be the main advantage of nuclear power compared to fossil fuels.

A publicly acceptable balance of safety and cost must be found for regulation of the nuclear industry. Safer at any price means "never."

Member countries of the IEA have stated their desire to maintain nuclear power as an energy option for the future. Nuclear power has played a vital role in the electricity supply systems and economies of Member countries. It promises to maintain this role, towards sustainable development, but only with continued technological development and the active participation of those who most appreciate its potential benefits.

3

CLIMATE CHANGE

In December 1997, in Kyoto, Japan, the Conference of the Parties to the Framework Convention on Climate Change established a real international commitment to curb emissions of greenhouse gases. Past limits on greenhouse gas emissions were non-binding and will have been met in only a few countries. The power generation sector will become involved in the implementation of the Kyoto agreements because of power's large contribution to carbon dioxide emissions. Power generators could be asked to provide the same amount of electricity while producing less carbon dioxide. This potential requirement to reduce the "carbon intensity" of power generation would erode the competitive position of coal- and oil-fired power generation compared to power generation using natural gas. In the long term, it could make power generation from all fossil fuels less competitive compared to nuclear and renewable sources of electricity.

This chapter explores the implications of climate change policies on nuclear power. First, the past patterns of energy use in the OECD are described. From these, the likely trends in electricity demand are outlined in the context of overall energy demand. Next, the potential impacts of firm measures to mitigate carbon dioxide emissions are described, particularly the change in patterns of interfuel competition in energy-related services and electricity generation. The chapter concludes with the a reminder of the political challenges that face nuclear. These serious issues must be addressed before any potential economic advantage nuclear may have due to climate change concerns could be realised.

SECTORAL AND REGIONAL PATTERNS OF ENERGY USE

What can past patterns of energy use tell us about our future appetite for energy? And what did the oil shocks of the 1970s reveal about the potential for changes in energy use patterns in response to price increases? There are several conclusions:

- the link between energy use and macroeconomic activity is strong. As national incomes have increased, energy use has increased in a nearly constant relationship.
- the oil price shocks increased energy prices substantially, but not enough or long enough to change this basic relationship.
- there are, however, differences in patterns by end-uses. Stationary fossil fuel uses such as space heating and industrial uses have become less energy intensive since the 1970s, while electricity and transportation energy uses have remained in nearly constant relationships with incomes.

- there are large differences in energy use by world region. The most important is the increasing share of energy consumption outside the OECD.

Sectoral Trends

The differences in energy use patterns by sector must be taken into account when considering the potential impact of climate change policies. Figure 1 shows the growth of energy use in relation to total gross domestic product in IEA countries from 1960 to 1996. Figure 2 shows the corresponding data for the world as a whole from 1971 to 1995. Total energy use has been categorised into the three end-use types: stationary uses of energy, energy for transportation, and electricity. Each of these represents a demand for energy-related services rather than primary energy. Differences in the growth of energy use in each are evident.

The consumption of fossil fuels other than in electric power plants or in transportation, so-called stationary end-uses, includes industrial, agricultural, commercial, and residential energy uses. Of the three primary energy-related services, only stationary uses have not increased steadily with national income. This may be attributed to a number of factors, most importantly improved energy efficiency in industrial and residential uses. It was accentuated by a structural shift away from energy-intensive industry and corresponding increase in income share from services. Changes in energy use and location of steel production world-wide provide an example of these factors. In many instances, stationary end-uses involve the production of heat for space-heating or processing, where energy cost may represent a significant fraction of the total final service cost. In such cases, end-use demand is more sensitive to the price of energy. Substitution of electricity for fossil fuels and changing patterns of residential energy use also account for part of the change in energy use in this sector.

In contrast, transportation and electricity have increased steadily in line with incomes. Use of energy for transport has grown almost linearly with real income, although there was a small but noticeable readjustment after the 1979 oil supply disruption. Increasing levels of taxation on transportation fuels, promotion of mass transit, and increasing fuel efficiency of personal automobiles have not notably altered the gross pattern of energy use in transport. Perhaps the single most important reason explaining this is that there are few cost-effective substitutes for independent mobility in vehicles powered on petroleum fuels. Vehicles relying upon electricity or natural gas are today more expensive on a life-cycle basis and account for only a tiny fraction of overall energy use for transportation. Further, the price of transportation fuels, in real terms, has not risen significantly higher today its price before the oil shocks. In many countries it is in fact lower. In addition, fuel as a proportion of total automobile running costs is typically less than one third the cost of running a personal vehicle, so the impact of fuel price changes is diminished.

Figure 1.

Evolution of IEA Energy Demand by Energy-Related Service, 1960 to 1996

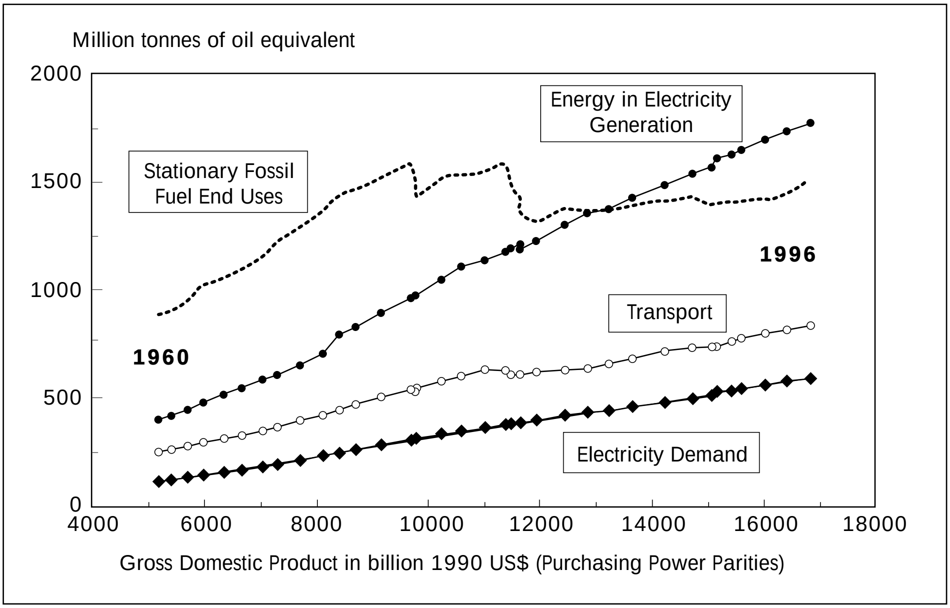
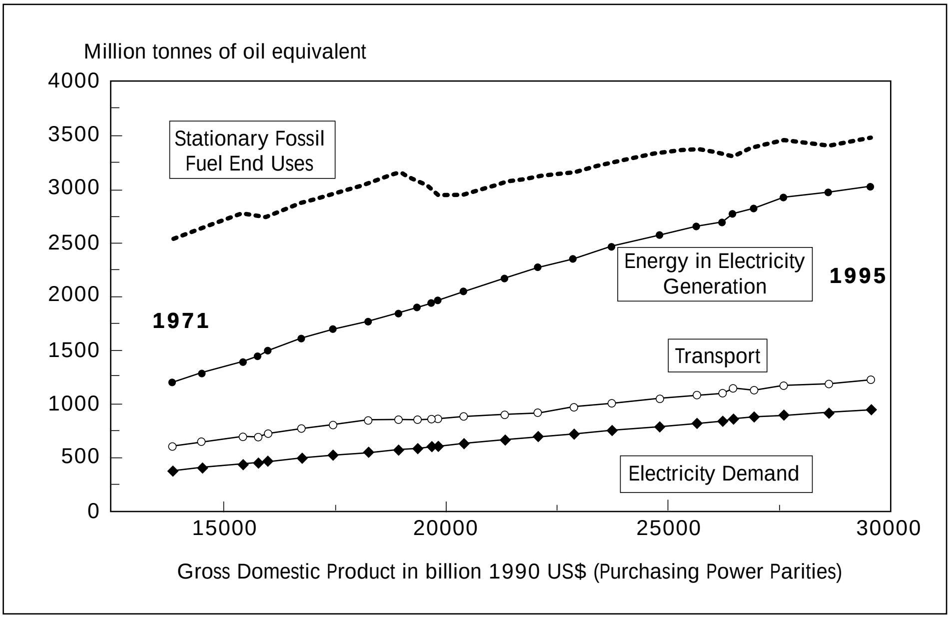


Figure 2.

Evolution of World Energy Demand by Energy-Related Service, 1971 to 1995



Electricity demand has also maintained a steady relationship with income. In nearly all end-uses, there has been a substitution of fossil fuels by electricity, driven by the cleanliness, ease-of-use, and competitive economics of electricity at the point of consumption. The steady penetration has been made possible by real electricity prices which on average have remained the same over the last decade. The period from 1975 to 1981 saw a period of increasing prices which reached 30% higher prices at its peak, and this was followed by a return to previous price levels by 1983. This period of increased electricity prices did not lower electricity intensity.

Installed power generation capacity has risen steadily to meet the growth in demand. In 1994 the OECD average stood at about 1.8 kW per capita or 100 kW per thousand 1990 dollars of gross domestic product. The latter has remained constant over past decades, as suggested by Figure 1. Acknowledging these figures, the IEA's World Energy Outlook projects installed capacity to increase by over 50% in the OECD and 150% in the rest of the world by 2020.

Within the power sector, substantial changes in the fuel mix have taken place. Oil-fired power plunged from a 25% share of total OECD generation in 1974 to less than 10% in the 1990s. In all but a few countries oil generation decreased in response to the increased cost of heavy fuel oil. Many existing oil-fired plants were switched to coal or natural gas, and few new oil-fired plants were built. This drop in oil use for power was nearly matched by an increase in nuclear power generation, from less than 5% share in the 1970s to almost 25% today. Coal's share increased overall by less than 5%, and natural gas has provided a relatively stable share of power generation energy input. The changes in coal and nuclear share varied quite a bit by country depending upon the absence or presence of nuclear power programs and access to other indigenous energy supplies. The power generation sector changed its energy supply mix over time in response to market pressures.

Regional Trends

The patterns of energy use vary not only by sector, but by region. The most important trend is that the OECD's share of world energy consumption is decreasing. The economies of OECD countries are growing relatively slowly compared to many developing country economies, particularly those of the dynamic Asian regions. Average growth in China, East Asia, and South Asia averaged 7.5% over the last decade, while in the rest of the world it averaged 2.4%. With rapid economic development comes rapid growth in energy consumption.

Somewhere between two-thirds and three-quarters of the growth in world primary energy demand over 1993 to 2010 is expected to take place outside the OECD. This is due not only to strong economic growth and industrial expansion, but also high population growth, increasing urbanisation, and substitution of traditional or non-commercial fuels by commercial energy. In many cases final energy demand is increasing from a relatively low level. Although final levels cannot be accurately predicted, the difference in demand for energy-related services between OECD and non-OECD countries can be expected to steadily decrease. For example, in many countries car ownership levels are increasing. Domestic electrical appliances are becoming more common.

The growth in energy demand for the power generation sector is likely to be based on coal to a much greater extent outside of OECD countries. Particularly in countries without access to pipeline natural gas or with relatively poorly developed natural gas supply infrastructure, coal-fired power generation is likely to dominate capacity additions. In the OECD, combined cycles fired on natural gas will account for the largest fraction of baseload capacity increase.

The regional differences in energy demand mean that patterns of growth in carbon dioxide emissions will differ by regions. They show the critical importance of non-OECD economies in eventual policies to curb emissions of greenhouse gases. As an example, emissions of carbon dioxide from China alone are expected increase as much as those from the whole of the OECD in the period 1990 to 2010.

Implications for Climate Change Policies

The trends described above suggest lessons for the debate on climate change policies. They are that:

- Any policy that significantly and permanently changes the price of fossil energy would, as the oil shocks, lead to changes in energy use that differ by the service it provides.

- Policies must involve all countries, not just OECD countries, because of the large growth in energy consumption outside of the OECD.

- Transport energy demand and electricity demand have shown a strong positive link with national incomes but are less sensitive to short-term energy price increases.

- Stationary fossil fuel end use, primarily non-electricity industrial energy use and demand for heat, is responsive to strong short term price changes. In the longer term energy efficiency improvements and evolution towards a lower share of industrial demand have in the past had a large impact on energy intensity in this sector.

- The power generation sector has responded to relative changes in fuel prices by fuel switching in existing plants and by shifting fuel choices for new plants.

It is difficult to predict potential effects of long-term fossil fuel price increases. Past prices of energy for transport and electricity have seen modest or no real long-term increases in many countries, and so do not necessarily provide a full basis for quantitative predictions of future energy demand. However, comparative studies among IEA countries confirm that demand for energy-related services certainly depends upon price, among other factors, and increases in the service prices could be expected to reduce demand for them.

Price increases in transportation fuels would probably have little near-term impact on the fuel/technology choices for transportation, because today there are few economic alternatives to fossil-fuelled vehicles. Fossil fuelled vehicles are by far the least expensive option today.

To the greatest degree among energy-related services, electricity demand decouples the primary energy source and the energy source at the point of use. That is, primary energy is transformed into electricity, today mainly in centralised facilities. This provides a flexibility in the energy supply system which allows primary energy sources to be changed while maintaining end-use equipment unchanged. The efficiency of electricity production may also change in response to fuel price changes, while end user prices are only indirectly affected. Shifts in the composition of the primary energy fuel mix for electricity generation do not require modifications to equipment for the ultimate service provided by electricity.

In electricity generation, the fuel mix has changed in order to minimise production cost as fuel prices change. This has been observed in practice, for example since the 1970s as the share of oil-fired power generation decreased and nuclear’s share increased. The competitive economics of gas-fired power generation have led to its rapid increase in many countries. Thanks to such structural changes in power generation, increases in the final price of electricity have been moderated even as the economics of underlying interfuel competition have changed over time. This has tended to maintain the relationship of electricity consumption and national incomes.

CLIMATE CHANGE POLICIES AND THEIR POTENTIAL EFFECTS ON ELECTRICITY

Parties to the Framework Convention on Climate Change have been discussing and debating policies to curb greenhouse gas emissions since 1992. The objective of the treaty is to limit or reduce national emissions of greenhouse gases to arrive at a globally sought target after 2000. The details of actual policies that will meet the objectives of the treaty are complicated by issues of equity among countries, differentiation of objectives according to national situations, timing of policies, and the practical matters of implementation. Following the third Conference of the Parties in December 1997, there has been a greater emphasis in public debate on the idea that whatever policies might be adopted to control emissions of greenhouse gases should rely upon market mechanisms. That is, producers of greenhouse gases should be able to incorporate a value of emitting them in their economic planning and decision making.

It is clear that real commitments to reduce emissions of carbon dioxide and other greenhouse gases effectively place a value on not producing them. This has been recognised since the early stages of the climate change debate. Emissions limits at the level of individual producers such as power plants or automobiles would implicitly place values on carbon dioxide emissions. Market-based policies would make the value explicit. In the case of carbon dioxide emissions from fossil fuel use, we may speak about a "carbon value" or the cost to energy users to emit carbon dioxide. (Equivalently, this may be thought of a value to not emitting carbon dioxide.)

Differences Among Energy-Related Services

If indeed market-based instruments are chosen to meet the objectives of the climate treaty, in principle the carbon value will be the same regardless of end-use, sector, or the technical details of processes producing carbon dioxide. The effect upon individual energy end-uses is difficult to predict with certainty — in fact this is precisely why market-based solutions are preferred by many economists. Rather than relying on centralised, command and control measures in specific end-uses, market-based solutions can be expected to adjust energy use patterns across all end-uses in a way which minimises the overall cost of meeting the emissions goals. However, some general observations can be made on the likely effects of establishing a cost to emit carbon dioxide.

The following factors are among those that will affect the price of energy-related services as a function of carbon value:

- the fuel price increase due to carbon value;
- the fraction of service price that is fuel input;
- the ability to use fuels with lower carbon content and, hence, lower incremental cost increases due to carbon value (availability of substitute processes or equipment providing the same service);
- the rate at which substitute processes or equipment can be introduced.

Table 1

Effect of Carbon Value of US$ 20 per Tonne on Energy Prices

Fuel	*Carbon Content (tonne C/toe)*	*1995 Avg. IEA Price (US$/toe)*	*Price Increment due to Carbon Value (US$/toe)*	*Frac. Price Increase due to Carbon Value (%)*
steam coal	1.13	§64	23	36
heavy fuel oil	0.88	141	18	12
natural gas (industry)	0.63	112	13	11
light fuel oil	0.79	260	16	6
natural gas (household)	0.63	396	13	3
gasoline	0.85	† 839	17	2
IEA electricity (equiv.)	‡ 1.30	1058	‡ 7	1

Notes: ‡ Electricity consumption releases no carbon dioxide at the point of use. Average carbon content of electricity is calculated based upon average carbon dioxide emissions per unit of IEA electricity production. Similarly, price increment is based upon increased production cost passed through to final consumer, assuming no change in generating plant mix. Fuel is assumed to represent one quarter of total electricity cost on average throughout OECD.

§ Average steam coal price excludes Germany

† Gasoline price assumed to be 0.70 US$/litre

toe is tonne oil equivalent, or 10^7 kilocalories

Source: IEA, *Energy Prices and Taxes*: Secretariat calculations

Table 2

Fuel Cost as a Fraction of Total Product Cost

Equipment	*Energy Source*	*Product*	*Fuel Cost / Total Life-Cycle Cost*
automobile	gasoline	kilometres travelled	30%
refrigerator	electricity	refrigeration	40%
power plant	coal	electricity	50%
power plant	gas	electricity	70%
space heating system	natural gas	space heating	70%
electric motor	electricity	motion	90%

Note: Values are illustrative only.

Generally the denser the fuel, the higher the carbon content and the higher the production of carbon dioxide per unit of fuel energy. So a uniform carbon value would result in fractional price increases that vary by fuel, as shown in Table 1. This table indicates that the heavier fossil fuels used most in industry and power production, coal and heavy fuel oil, are most sensitive to a carbon value. The prices of lighter fuels used in the residential and commercial sectors would be less affected by a carbon value.

The cost of providing energy-related services using the existing mix of processes and equipment would rise according to the particular fuel used and the contribution of energy to the final price. For example, using the figure from Table 1 for gasoline, the cost of providing personal mobility would rise by very little. The presumed carbon value does not result in a large gasoline price increase and, furthermore, gasoline's fraction of automobile life-cycle expenses is typically less than one third, so the net effect on total costs is quite small (2% x 30% = 0.6%). In contrast, the effect of the same carbon value on the cost of providing an end-use using coal could be much higher. Table 2 provides several illustrative values of the ratio of fuel cost to total product cost. Fossil fuels account for a relatively large share of final price in power generation.

If an energy-related service may be provided using a different energy source having a lower total cost, including the carbon emission cost, the effect of a carbon value would be to encourage fuel switching. This will tend to minimise cost increases due to a carbon value. In many instances, however, it is not possible to switch energy sources from among fossil fuels. This is particularly the case in the transport sector, where almost all energy consumption in road, marine, and aviation uses is without any close economic substitute to refined petroleum products. Similarly, in stationary energy end-uses outside of industry, it is often the case that few economic alternatives exist to allow interfuel competition. Examples are agricultural machinery and, in areas without access to a natural gas grid, space heating.

Industrial energy uses and electricity production are notably different from other energy-related services with regard to their potential for fuel switching. This is because energy typically accounts for a large fraction of final product price, and the quantities of energy used are sufficiently large to warrant dedicated infrastructure to deliver that energy. The ratios of carbon dioxide emissions from coal : petroleum products : natural gas use in OECD industry are 1 : 2.2 : 1.9 and in OECD power generation are 1 : 0.2 : 0.2. In the rest of the world, these ratios both for industry and power generation are about 1 : 0.3 : 0.2. These values indicate that there is large scope in both sectors, particularly power generation, for a shift towards lighter fuels if carbon values and fuel availability make it economically feasible.

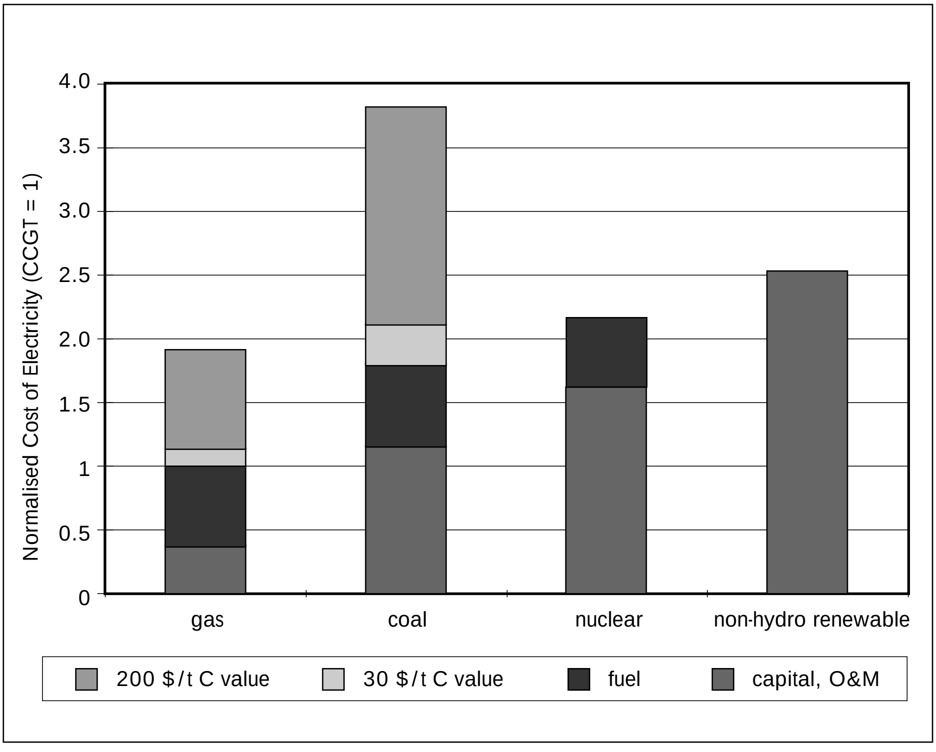
Power Generation and Carbon-free Energy Sources

Power generation would be strongly affected by limits on carbon emissions or an explicit carbon value. It accounts for roughly one third of all emissions of carbon dioxide, both in the OECD and world-wide. Fuel costs typically account for 50-80% of final cost of electricity, depending on the fuel and the capacity factor of the plant. It is also the single largest consumer of coal, whose final price is most sensitive to a carbon value. Power generation is unique in that it may use energy sources that produce no carbon dioxide and whose economics therefore would be unaffected by a carbon value arising from carbon dioxide limitations. These are of course nuclear and renewable energy, including hydroelectric. Because of the above factors, power generation potentially offers one of the largest sources of carbon dioxide reduction among the three main energy-related services.

Figure 3 shows the effect of a carbon value on the competitive position of fossil-fuelled power generation and carbon-free power generation, including their capital costs. The figures are illustrative only. They are based upon the actual average prices of coal and natural gas for power generation, and assume a cost of electricity differential compared to coal of 20% for nuclear and 40% for non-hydro renewables. Although in practice fuel choices will be made by utilities based on their individual commercial situation and local pricing of equipment and fuels, it is clear from the figure that introduction of a carbon value could significantly alter the competitive position of first coal, then gas-fired power generation with respect to nuclear power and renewable power. Further, the carbon value at which the competitive position of the different fuels changes differs in each region and in each country.

Figure 3

Effect of Carbon Value on Power Generation Choice



Notes: Calculations are illustrative only and are not representative of specific regions or utilities. Cost of electricity assumptions: nuclear power 20% more expensive than coal plants; power from renewable energy 40% more expensive.

In many countries, gas-fired combined cycle gas turbines are typically the option providing the lowest cost of electricity for baseload power generation. A key economic variable is the availability of domestic natural gas or low-cost imported gas via pipeline rather than as liquefied natural gas. Gas-fired combined cycles also have the advantage of releasing the least amount of carbon dioxide per electrical output (per kWh) of any fossil-fuelled option, both because of their use of a low-carbon fuel and their high generation efficiency. These characteristics render them the least sensitive to a carbon value of the fossil-fuelled options. So, while the introduction of a carbon value would increase their production costs, this would improve their competitive position relative to other fossil-fuelled options and still leave them as formidable competitors to non-fossil generation options. The value of carbon would have to rise to 200-300 US$/tonne for nuclear power to be competitive with gas-fired power generation under the assumptions of this illustrative calculation.

In stark contrast, coal-fired power generation costs clearly would rise to the level of nuclear power at much lower levels of carbon value. Carbon values of roughly 25-35 US$/tonne would bring nuclear power into competition with coal-fired power, while carbon values of approximately 65-100 US$/tonne would bring some non-hydro renewables into competition with coal. Regardless of the precise figures, coal-fired power generation, even with advanced technologies such as coal gasification combined cycle power plants, will become more expensive than nuclear or renewable power well before gas-fired power production.

In the long run, the technical ability of nuclear power to contribute to lowering carbon dioxide emissions is evident. A study by the OECD Nuclear Energy Agency (NEA, 1998a) concludes that a tripling of nuclear power capacity by 2050 in response to climate change concerns would be feasible from the point of view of construction, financing, siting and land requirements, and uranium resources.

There are differences in the results of interfuel competition in the long term versus the short term. The above considerations, which take into account the cost of capital in power production, relate to long-term fuel/technology choices to minimise electricity production costs. In the short term, interfuel competition would be constrained by the existing stock of power production technologies and the rate at which it was economic to convert it or renew it. In those plants where switching to a less carbon-intensive fuel were technically possible, a carbon value could result in making the switch. Plants whose fuel sources could not be economically switched would tend to be operated at lower capacity factors. For example, coal-fired plants, which typically provide baseload power, could move towards load-following service given a sufficiently large carbon value. Nuclear plants, in the near term, could not play a significant role in adjusting to a carbon value since they generally are operated at their maximum capacity and could not provide much incremental output.

These realignments of comparative power generation costs would depend on the costs and availability of each of the energy sources in a local context. A basic precondition for interfuel competition and switching is the access to the less-carbon intensive energy supply. If, for example, natural gas is not available except by import of relatively expensive liquefied natural gas, a low carbon value might not have an impact on the results of gas-oil or gas-coal interfuel competition. Similarly, if natural gas is not available locally, a carbon value could cause a shift from coal- to oil-fired generation.

We may conclude from the discussion above that restrictions on carbon emissions in the power sector, either with implicit or market-based restrictions on carbon dioxide emissions, could place coal-fired power generation at a significant cost disadvantage, while favouring first gas-fired power, then nuclear and renewables. The results of interfuel competition in the near term depend on the availability and price of fuels in local markets. In markets where gas is currently competitive, it could remain so at carbon values which increase gas price by a factor of two or more. However, in the long term nuclear power and renewables place a limit on the level to which carbon value could rise, since their costs do not rise as a function of carbon value.

Market Determination of Carbon Value

As noted earlier, a value attached to the emissions of carbon dioxide (carbon value) would result from binding restrictions on emissions of carbon dioxide, or greenhouse gases in general. If emissions limits were allocated among sectors, costs of reducing emissions would be unevenly distributed. They would, however, still result in changes in the competitive position of different fuel/technology combinations to provide the same energy-related service. For example, coal would bear a heavier economic burden in all sectors. Carbon value would be implicit and would vary, perhaps greatly, by sector and by end-use.

On the other hand, if emissions limits were implemented in a market-based system, carbon value would be determined by the balance of market supply and demand forces. It would be uniform among all end-uses, drawing first on those end-uses having the least cost to reduce carbon emissions. As the requirement for emissions reductions grew, more expensive options could be called upon. The carbon value would rise accordingly. On the demand side, increases in the cost of energy-related services would also have an effect. As the cost of reducing emissions were included in prices to end users, consumption would decrease and contribute to restraining emissions growth.

Certain fuel/technology options would establish limits on carbon value until the full extent of their supply could be absorbed. They would depend on local market conditions, including fuel supply. For example, replacing heat-only heating systems by cogeneration heating systems might provide a supply of relatively inexpensive carbon dioxide reductions without necessarily switching the primary energy input. In a heavily urbanised area or cold country, this could conceivably supply emissions reductions equal to, say, several percent.

A more expensive source of emissions reductions might be industrial or power generation fuel switching in existing plants. In this source, the least expensive switch would be from oil to gas, since the difference in their prices is small in many markets. A more expensive switch would be from coal towards oil or gas. Switching away from coal is a much larger potential source than switching away from oil. Switching from coal to oil alone accounts for a 20% reduction in carbon dioxide emissions assuming the same efficiency of energy use. Switching to natural gas results in about a 40% reduction in carbon dioxide emissions. However, the carbon value at which switching would be economic from the energy user's point of view would correspond to the price difference between the two fuels without the carbon value. Coal prices would effectively double with a carbon value that made switching economic in existing plants.

In new industrial or power facilities, where the capital cost must be taken into account, the choice of natural gas is often the most economic even without a carbon value. As old facilities are replaced by new ones, natural gas may provide a larger share of energy supply. This would provide a relatively inexpensive source of carbon reduction. The relevant calculations for new power generation are illustrated in Figure 3. In summary, switching to lighter fossil fuels represents a relatively large source of potential reduction in carbon dioxide emissions. In a market-based approach to limiting carbon dioxide emissions, fuel switching could be expected to set a series of limits on carbon value until most fuel switching opportunities were exhausted.

The economics of fuel switching described above suppose that adequate supplies of lighter fuels are available in local markets. This may not necessarily be the case during transitional periods. Particularly in the case of natural gas, rapidly increasing demand could lead to bottlenecks as in the development of infrastructure and markets. If the capacity of existing production and supplies could not keep pace with demand, gas prices could rise, at least for a period, and diminish the economic advantage derived from the carbon value.

In the long run, continued world-wide economic growth could be expected to lead to substantial increases in energy demand. As energy consumption increases in end-uses that do not have close economic substitutes for fossil fuel use — among which transportation figures most prominently — the need for deeper reductions in carbon dioxide emissions in other end-uses would grow. Carbon-free energy sources would ultimately provide a technically limitless source of carbon dioxide reductions. They would also set the economic limit to carbon value.

The largest sources of carbon-free energy are presently concentrated in electricity production: nuclear power and power generation from renewables. Any future carbon value would not itself alter the economic competition between them. Rather, technological development is the route by which their relative competitiveness will change. On the basis of today's estimates of costs, nuclear power has an advantage compared to renewables in many markets. Nuclear power could, by providing the limit to carbon value, grow to meet the requirements of less carbon dioxide emissions in energy use.

This conclusion supposes that economics would be the deciding factor in the selection of nuclear power in future energy development scenarios. This is not by any means a supposition that will hold true. Nuclear power faces challenges beyond economic competitiveness which must be met before it can contribute to the world's future energy supply, with or without the effects of restrictions on carbon dioxide emissions.

A Potential Decline in Diversity of Energy Supply?

Since the oil shocks governments have been particularly concerned about energy security. Their general concern has been to reduce the potential economic consequences of a disruption in energy supply. The factors seen as having the potential to cause supply disruptions include technical failures, such as the rupture of a pipeline, failure to mobilise long-term investment at a rate commensurate with demand growth, or political disruptions of fuel supply. A fundamental measure to promote security is to diversify energy sources such that each provides a smaller proportion of supply and, hence, has a smaller effect if disrupted. Diversity may refer to the number of producers, the number of transport options, the number of supplying countries, or the number of different fuels.

It is the latter that might cause concern if energy use shifted towards lighter fossil fuels in order to reduce carbon dioxide emissions. If, for example, coal use diminished substantially and primary energy use shifted towards oil and natural gas, the diversity of fuel inputs would be decreased. The potential effects of a disruption in oil or gas supply could be potentially greater for regions heavily dependent on these fuels as their primary energy sources. In the long term, reliance on renewable energy could raise similar concerns. Nature's supply of energy is not always constant, as droughts may reduce hydroelectric output, winds may calm, or insects may devour an energy crop. Whether the result of restrictions on carbon emissions resulted in a shift to lighter fossil fuels or carbon-free sources of energy, there is the potential concern that energy diversity could be reduced.

The desire for energy security could give some advantage to nuclear power. In fact, the desire for energy security was an important force in the rapid development of nuclear power after the oil shocks of the 1970s. Energy security continues to be factor motivating nuclear programs today in some countries, such as Japan, Korea, Chinese Taipei, China, Indonesia, and Turkey. Nuclear fuel is unique in its high energy density and slow rate of energy release when in use. Refuelling is needed infrequently and many years' supply for an individual plant can be stockpiled on site. Stability of fuel supply for an individual plant can be assured over several years without exceptional measures. Considering the supply of uranium to be sufficiently diversified that its supply should not be subject to long-term interruption, countries have tended to regard nuclear as an "indigenous" energy supply which contributes to diversification of energy supply. In the past this meant diversification in relation to fossil fuels, and in the future this role could be accentuated by a concentration in lighter fuels. Could it also mean diversification in relation to renewables? If fossil fuel use diminishes in the future as carbon dioxide emissions are limited, or if fossil fuel use is concentrated in lighter fuels, could nuclear help to contribute to the diversity, and hence security, of energy supply? If these questions are answered positively by market forces or by government action, the economic position of nuclear power could be strengthened if carbon emissions are limited in the future.

NUCLEAR CHALLENGES BEYOND CLIMATE CHANGE

Although nuclear power now supplies about 7% of world total primary energy and one quarter of input energy to electricity (11% and one third in the OECD), it is not clear today that these shares can be expanded or even maintained in the future. Nuclear power has, in the last decade, seen a considerable change in its public perception, economics, and technical challenges. The period of nuclear power development from 1950 to 1980 might be characterised as one primarily of technical and commercial development of the power generation technology itself. The front end of the fuel cycle, that is enrichment and fabrication, were also developed in parallel.

The 1979 accident at the Three Mile Island Plant in the United States and the 1986 explosion of the Chernobyl plant in Ukraine substantially altered the pace and focus of nuclear power development. Safety in generation, always seen as of fundamental importance, took on even greater prominence. Costs of safety-related modifications to plant design and operation increased production costs, as did increased regulatory oversight in some countries. Competition from economical gas-fired combined cycles and improved coal-fired plants also appeared. In parallel, as the quantity of spent fuel increased from operating commercial reactors, the need for development of the back end of the nuclear fuel cycle became more apparent. The approaching retirement of some of the early plants also cast light on the need for more specific planning and substantial expenditures for plant decommissioning. Finally, baseload power growth has been relatively limited in the countries where nuclear power has heretofore developed the most. As a result of these trends, today only three OECD countries, Korea, Japan and France, have active nuclear power programs which at present expect new plants to be constructed after 2000.

The previous chapter outlined three key political challenges to the potential of nuclear power to contribute to a sustainable energy supply. These are public acceptance, disposal of high-level wastes, and non-proliferation of nuclear weapons. These challenges are equally relevant in considering the narrower question of nuclear's potential role in reducing carbon dioxide emissions from energy use.

Although the discussion on carbon value indicates the potential economic advantage that might accrue to nuclear power if carbon emissions are firmly restricted, particularly in the long term, the movement towards competitive markets in power generation poses additional challenges for both nuclear power and renewable power in the near term. These challenges are described in Chapter 4. Nuclear power has been developed throughout the world in regulatory regimes which have allowed utilities to fully recover costs of nuclear power programs from electricity consumers. In addition, civilian nuclear technology development has been aided by government programs in research and development, fuel enrichment, reprocessing, and storage. That certain nuclear power plants may not have been the most economic generation choices, seems, in hindsight, to be borne out by discussions of stranded costs in electricity supply systems that are contemplating the introduction of competition in generation. Renewable energy today is heavily subsidised in many countries around the world. It faces the same issue of competitivity that nuclear power does in relation to fossil fuels. In the future it might also be drawn into a debate on stranded costs if renewable energy subsidies were to be removed. So while both nuclear and renewable power could become more competitive with carbon dioxide restrictions, long before fossil fuels decrease significantly in use they must demonstrate economic viability, without government subsidies, in more competitive power markets.

CONCLUSIONS FOR CLIMATE CHANGE

Past patterns of energy use in OECD countries and the world show the strong links between economic growth and energy use. Policies to address climate change concerns cannot ignore these links. Any measures taken to curb carbon dioxide emissions from energy use must also recognise that each energy-related service sector and individual end-uses will have different options available to reduce carbon dioxide emissions. Each sector and end-use will have different costs associated with emission reductions.

The IEA believes that open, undistorted markets are the best means to ensure the efficient use of energy both now and in the future. This remains true for climate change policies. Thus, if firm restraint is agreed upon by parties to the climate treaty, the advantages of market-based policies to restrain carbon dioxide emissions are evident. Further, they will be most cost-effective if applicable across all sectors and for all countries, developed and developing. Regardless of the form of policies ultimately devised, restrictions on carbon dioxide emissions will lead to the development of a carbon value, or a value to reducing emissions.

A carbon value will change the results of interfuel competition, tending to favour lighter fossil fuels and increased energy efficiency. In some end-use sectors, particularly transport, there are few alternatives to liquid petroleum fuels, and a carbon value would have minimal effect on the immediate prospects for economical fuel or technology switching. In other sectors, particularly electric power, production processes can take advantage of fuel switching to lower carbon dioxide emissions while minimising final cost increases. Natural gas is favoured in the near term, but higher carbon values could ultimately make nuclear power and renewables less expensive options compared to fossil fuel.

Because of their potential for economical fuel switching, power generation and some industrial energy uses are likely to offer sources of carbon dioxide reductions at lower cost than other energy uses.

The competitive position of nuclear power might be strengthened if market forces or government policy were to give energy security a renewed importance. A shift towards lighter fossil fuels, particularly a decrease in coal's share of primary energy, would tend to reduce the diversity of fuel supply and raise concerns about the potential for its disruption. Nuclear power and renewables could be used to help respond to those concerns. In the long term, a concentration on renewable energy, which has a natural component of variability, could tend to give a value to the improvement in diversity attainable using nuclear power.

A carbon value determined by market forces would be limited by sources of carbon dioxide reduction obtainable from various fuel/technology options. In the near term such limits would relate to fuel switching among fossil fuels. In the long-term, carbon-free energy sources such as nuclear power and renewables provide an upper limit for carbon value.

Nuclear power faces political obstacles that must be overcome if it is to provide such a limit on carbon value. Public concerns about safety, waste storage or disposal, and non-proliferation are critical areas that must be addressed. Neither the nuclear industry nor governments should look to the climate change debate to ensure the future of nuclear power. The desire to reduce carbon dioxide emissions will not lead to greater use of nuclear power, even if it may be an economic solution, if some of the non-economic impediments to its use are not removed in the coming years.

Should these obstacles be overcome, nuclear power could make an important, positive contribution to reducing carbon dioxide production from energy use. A co-operative international framework will inevitably be a part of it sharing the expense of meeting commitments to restrain carbon dioxide emissions. In developing countries, where electricity growth is strongest, nuclear power could grow within this framework and help in the search for a model of sustainable development.

4

ELECTRICITY MARKET COMPETITION

Throughout OECD Member countries and the world, governments are promoting competitive electricity markets. In particular, there is a move away from administrative price setting by government institutions to market price setting through the introduction of competition. Today this is often focused on competition in generation. However, competition among final electricity suppliers and distributors to provide effective consumer choice is a further step that governments are likely to pursue as experience with market reform grows.

The basic objective of all efforts to reform electricity markets is to improve the economic efficiency of a secure electricity supply and pass through the benefits to consumers through lower prices. Other objectives, however, remain very important. As electricity markets are changed, some of these policy objectives constrain the range of available choices for the new market structure. The most important examples are the policy objectives to maintain security of fuel supply, system reliability, and environmental performance.

Broad Influences of Competition on Generation Plant

The single most important influence of competition on electricity supply systems will be the greater emphasis on cost efficiency by utilities. This is one of the fundamental benefits competition is intended to promote. Competitive markets provide incentives, in a way that no other approach can, to reduce costs and increase productivity.

Electricity market competition is expected to:

- concentrate efforts to reduce expenditure on generation and maximise returns by plant owners
- re-orient decision making to incorporate private rather than public costs and benefits
- lead to more transparent and effective pricing to better reflect costs.

Utilities will seek new methods and technologies to ensure that they are able to provide secure and clean electricity at the lowest possible cost in comparison with their competitors. A recent IEA study identifies the specific utility strategies to minimise costs in generation (IEA, 1998). Utilities have always pursued cost-effective operation through “technical” approaches related to improvements in plant investments, operations and maintenance, and fuel efficiency. The ultimate scope for further cost reductions in specific utilities from competition will depend on how successful, or not, regulators and governments were at maximising commercial efficiency under former, monopoly supply conditions.

Utility responses to competition are not restricted to improvements in generation plant and operations, although these areas are fundamental. Business practices in general will become more oriented towards profitability. As monopoly supply rights disappear, marketing will grow in importance. Marketing and pricing will increasingly be tailored to user needs in all respects: avoidance or tolerance of supply interruptions, seasonal or daily variations in demand, power quality, related services such as customer system maintenance, green pricing, and other areas.

Competition and Nuclear Power

Nuclear power cannot remain isolated from electricity market competition. Table 3 summarises the status of electricity market reform in OECD countries with nuclear power plants. Both existing and future nuclear power plants will be affected by competition. Ultimately nuclear power, in fact all power generation technologies, will be increasingly subject to market requirements that may not have been foremost under traditional, monopoly supply arrangements. Nuclear plant operators will increasingly be left to fend for themselves in electricity markets.

Table 3

Status of Electricity Market Reform in OECD Countries with Nuclear Power Plants (mid-1998)

Country	*Current Status/ Policy Orientation*[1]	*Year*	*Comments*
Belgium	EU Directive	1999	
Canada	provincial-level competition	2000	in Ontario, to be first competitive province out of 3 provinces with nuclear power plants
Czech Republic	privatisation	1997	
Finland	**competitive market**	1997	member of NordPool market
France	EU Directive	1999	emphasis on "public service"
Germany	EU Directive[2]	1998	negotiated network access model
Hungary	IPP programme	1994	60% privatised since 1995
Japan	IPP programme	1996	
Korea	IPP programme	1993	privatisation programme starting 1998
Mexico	IPP programme	1997	
Netherlands	**competitive market**	1999	network access model, pool possible
Spain	**competitive market**	1997	
Sweden	**competitive market**	1996	member of NordPool market
Switzerland	under discussion	n.a.	network access model
United Kingdom	**competitive market**	1990	privatised nuclear plants in 1996
United States	**state-level competition**	1998	federal law under development

Notes: 1) "EU Directive" indicates that country has not yet fully defined the legal framework for implementing the EU Electricity Directive, which requires the introduction of some competition in generation, network access, and end-user choice. Independent power producer (IPP) programme defined as procurement of new generating capacity by long-term purchase agreements. This is not a competitive form of electricity market. 2) German law transposing EU Directive currently under legal challenge.
Source: IEA

Structure of Discussion

The impact of electricity market competition on nuclear power generation is discussed under the following headings:

- energy policy issues
- operating nuclear power plants
- nuclear utility business structures
- new nuclear plants
- safety and safety regulation
- plant closure and waste disposal
- other nuclear activities.

Several key transitional issues for the nuclear industry when moving to competition are also addressed.

ENERGY POLICY ISSUES

Transparency of Policy Measures Improves

An important change in the framework for nuclear power development under competitive markets will be the clearer separation of commercial and government decision-making. Under non-competitive supply systems, governments had available a number of mechanisms to pursue public policy objectives without any easily identifiable public or private expense. The essential arrangement was to assign the responsibility for executing policies to utilities. Through state ownership, regulation, or in a "co-operative" spirit, utilities could be used to bear the costs. These expenses could be passed on quietly and diffusely to electricity ratepayers.

The list of such policy objectives pursued through electric utilities is long and extends well beyond energy-related policies. Among others, it includes support for domestic coal mining, support for domestic power equipment suppliers, regional development, consumer protection, rural electrification, employment, environmental objectives, and promotion of energy security. Seemingly every type of generation technology/fuel combination has been promoted or discouraged in one country or another in support of various policy objectives. Governments followed this approach because they felt that least-cost development of electric supply might not have resulted in the same business choices.

In markets where electricity supply becomes open to competition, individual investment and operational decisions will no longer incorporate non-economic requirements unless they are made explicit by government action. Investment decisions will also reflect commercial reality more closely in, for example, projected investment costs or fuel price escalation rates. Policy costs previously borne by monopoly utilities will be made transparent by the arrival of competition. This forces governments to either make their policies and policy instruments transparent or to abandon them. Governments must establish a democratic consensus for policies affecting electricity markets and demonstrate that they are best pursued through the electricity sector rather than through other areas of the economy.

In particular, government support for specific generation sources must become open. The cost of support policies will become apparent and brought to the attention of consumers. For example, in the United Kingdom and Spain, competition in electricity supply has highlighted the cost of policies to support domestic coal mining. In the Netherlands and other countries, support for renewable electricity production has been a particular issue. In Germany, support for combined heat and power systems was extensively debated during their reform of the electricity market.

In every country with nuclear power plants, there has been strong government funding for their development. Research and development of nuclear technology has perhaps been the most visible component of this support. Governments have also built specialised facilities such as enrichment plants, fuel re-processing facilities, and radioactive waste dumps. In the countries with nuclear weapons (United States, United Kingdom, France), military programs supported the development of civilian nuclear power plants.

The past arrangements for government support of nuclear power perhaps contribute to public mistrust of it. Past government support may contribute today to the sentiment that the choice of nuclear power was not made openly and democratically, but secretly, and with financial support that has not been fully justified or accounted for. In some countries there seems to be a strong public sentiment that the true costs of nuclear power are still unknown because of secretive or unquantified government support. The implication is that nuclear power would not be sustained if left to rational economic choice in open markets.

Competition in electricity markets, and the increased policy transparency it brings, could be an important means to erase this element of mistrust. To the extent government financial support for nuclear power continues, especially for the construction of new plants, it will become more explicit for both market participants and the public. Owners of power plants in competition with nuclear power plants will not hesitate to bring to the attention of the public and competition authorities those support measures that they believe to be unfair or not justified by public benefits. The perception of nuclear power as a fully democratic and market-based choice will be strengthened. Competition could, in this respect, help to strengthen public acceptance of nuclear power.

Special Public Policy Concerns Can Be Accommodated, if Politically Sought

There is no fundamental incompatibility of competitive markets and the pursuit of government policy objectives of any kind, as the long experience of OECD governments shows. Countless social, economic, defence, and other policies have been implemented through mechanisms that allow markets to function while still taking into account public objectives. The essential requirement is to translate policy decisions into constraints and costs that markets can assimilate. For example, environmental policies can be implemented as technical limits on emissions of pollutants or tradable pollution permits. Owners of industrial and power plants must then pay for pollution control equipment or permits, thus incorporating the cost of the policy measures in their commercial decisions.

There are numerous market-compatible policies and measures that may be used to implement public policy choices. Tonn, Hirst and Bauer (1995) list 31 “enabling mechanisms” suitable for use in a restructured electricity industry. For example, governments can require non-competitive parts of the electricity supply system to bear the costs of some policies. Charges on the use of the network can include such a policy-related component. Taxes, investment support, special-purpose markets, and government research and development are potential measures. Nuclear power can be supported, if governments so desire, by these and many other mechanisms.

The change from monopoly to competitive electricity markets forces governments to adapt policies and subject them to the rigours of public debate, often for the first time. There is no technical reason why policies designed to support nuclear power cannot be transposed to competitive markets, but this will require governments to clearly spell out the costs and benefits of these policies, and to put them to the test of public debate. If public views on the support of nuclear power have changed since the existing policies were put into place, there is a risk that their transposition to a competitive market will not succeed politically. It is this risk that some governments seem to fear, but it is one that must be taken if nuclear power is to be effectively integrated into competitive markets and if it is to secure a soundly based future.

Energy Security Is Still a Valid Objective

The goal of preserving energy security has always been one of the primary public policy reasons for supporting nuclear power. Countries with limited domestic fossil fuel resources, notably Japan, Korea and France, have always emphasised energy security in their support for the development of nuclear power. As with other policy objectives, however, the pursuit of energy security is compatible with electricity market competition.

If nuclear power is the most economic alternative in a given market, there is no need for government action to encourage it. If it is not, then the challenge for governments wishing to support it is to find a politically acceptable balance of cost and benefit for supporting energy security through the use of nuclear power, among other potential energy sources. An IEA analysis shows the difficulty of this exercise (OECD, 1998: Annex 9), especially in quantifying the value of energy security and the contribution to it that non-fossil energy sources can bring. Robinson (1994) argues forcefully that over-riding the market in the case of nuclear power runs the risk of undermining the objective of market reform itself. Since economic efficiency is a primary object of electricity market competition, it would be counterproductive for governments at the same time to supplant the role of the market by substantially altering what would otherwise be the market choice. Still, it is clear from the past, very strong support for nuclear power, and the current support for renewables, that political support can be found for specific generating sources when their perceived societal benefits are clear.

EFFECTS ON OPERATING NUCLEAR PLANTS

Whereas monopoly supply systems can pass along the cost of operating generation plants to electricity customers regardless of cost, in systems with competitive generation this will no longer be the case. The marginal cost of production (also known as the short-term variable cost) of individual power plants is what sets the bulk price of electricity in systems with competition among generators. That is, plant owners will be willing to sell electricity from individual plants as long as the price they receive is greater than their marginal costs of production. Expenses for fuel and operations and maintenance (O&M) are the components of short-term cost.

In the short-term, economic viability is ensured if production costs can be kept below the market price. In the medium term, prices must be sufficiently high to pay for debt repayment and capital improvements. In the long term, for investments in new power plants, the market price must provide a sufficient margin to pay both production costs and the full capital costs. For existing nuclear plants, the implications are as follows.

Low-Cost Plants Will Thrive; High-cost Plants Will Shut

Existing nuclear plants with low marginal production expenses will thrive in competitive markets, while those with high marginal costs will either innovate to reduce them, or will cease operation. This is the essence of what changes for existing nuclear power plants under competition. This provides strong incentives to reduce costs and will lead to changes in the way existing nuclear plants are operated and managed. Their output will be maximised and extended in time to maximise revenues. These are well established results in countries with electricity market competition.

Marginal production costs are generally low in nuclear plants, although this can vary considerably. On the basis of marginal production costs, it appears that the majority of existing nuclear plants operating throughout the OECD will be able to compete with their fossil-fuelled rivals.

There is, however, some debate about the size of this majority. The outcome of fossil versus nuclear competition is difficult to predict with confidence because the costs of both types of generation will decrease in response to competition. Wholesale electricity market prices will decrease as well. The presence of low-cost hydroelectric power plants in some regions will also affect the relative economic competitiveness of nuclear plants compared to others.

The fraction of US nuclear plants that will fare well in competitive markets has been extensively analysed. The United States has the largest and most diverse set of nuclear power plants, and performance varies greatly among them. The best performing nuclear plants have marginal expenses of 11 to 15 $/MWh, and the average for all US nuclear plants was 21 $/MWh in 1996 (EIA, 1997). In comparison, average production cost was 21 $/MWh for US fossil-fuelled, steam electric plants. Although average expenses do not indicate the individual plants that may face economic difficulties, they do suggest that a large group of US nuclear plants would be able to match competition from coal-fired plants and recover their costs of operation in a competitive electricity market. The best performers would do quite well initially, since their production costs are well under today's typical wholesale electricity prices of 25 $/MWh.

On the other hand, two studies, much disputed by the nuclear industry, state that up to 40% of US nuclear plant capacity could have marginal expenses higher than competitive market prices if the plants remain at their current levels of performance (WIEG, 1998; Ryan, 1997). The majority of the potentially uncompetitive plants are located in the Northeast and Midwest. It seems likely that the estimate of 40% is too high. It is clear that some fraction of nuclear plants will face difficulty, as shown by the permanent closure of 8 800 MWe nuclear capacity from 1997 to mid-1998. The owners of the shut plants cited economic reasons, in some cases the need for refurbishment that could not be justified in light of expected plant revenues. To date, only a few nuclear power plants in several states have been subject to true competition, though all are preparing for it in the expectation that most states will introduce competitive electricity markets in the coming years.

In France, the government-owned utility Electricité de France (Maclachlan, 1996) states that its nuclear power plants are currently competitive with fossil fuelled alternatives on the basis of 22 US$/MWh marginal costs (0.13 FF/kWh).

About 10% of OECD nuclear power plants are already operating in competitive electricity markets and are generally faring well. The oldest example is given by

British nuclear plants, which have been able to compete on the basis of price in that country's electricity pool since 1990[1]. Nuclear power plants in Finland and Sweden have been operating successfully within the Nordic electricity market, and Spanish nuclear power plants have competed successfully in the competitive market introduced at the beginning of 1998. The single operating nuclear plant in the Netherlands anticipates no problem competing under the new competitive system agreed in 1998. The total capacity of nuclear power plants in the United Kingdom, Finland, Sweden, Spain, and the Netherlands is about 30 GWe and represents over 10% of OECD nuclear capacity.

Although competitive marginal costs of production will allow many nuclear plants to continue operation, this assumes that outstanding plant debt does not pose a cash flow problem. This will be the case if there has been a sufficient period of amortisation or if there were explicit payments for transition costs included in the change to competitive markets (see below,"Transition Issues in Moving to Competitive Markets").

Performance Improves and Operating Costs Decrease

Nuclear plants will compete not only on the basis of their typical "historical" costs before introduction of competition. They will obtain lower unit costs through performance improvements and increased plant output. There has been a world-wide trend towards improved nuclear plant technical performance since the late 1980s. Learning must account for a good part of this as the industry has matured. Competition or the expectation of competition has also played a role, particularly in the United States. Many indicators of performance and safety are likely to further improve under competition:

- decreased corporate and plant-level overhead
- decreased duration for plant refuelling
- increased time between refuellings
- higher energy utilisation of nuclear fuel
- higher plant utilisation rate (capacity factor)
- reduced staffing
- fewer unplanned plant shutdowns
- lower collective radiation exposure of workers.

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[1] British nuclear generators received, effectively, lump-sum payments through the Non-Fossil Fuel Levy from 1990 to 1996. This was to enable them to meet unavoidable long-term liabilities that were not matched by assets. These liabilities included costs for plant closure, waste management, and reprocessing of fuel already used. According to the UK Department of Trade and Industry, the payments were specifically designed to avoid giving the generators incentives to increase output behond the level indicated by their marginal costs of production and the market prices of electricity, including the Pool price. In practice, nuclear generating marginal costs at existing stations have been below pool prices. Upon privatisation of the modern nuclear plants in 1996, payments to nuclear generators from the Levy were stopped, except for those accrued in earlier years but not yet made.

The UK nuclear generator British Energy (and its predecessor Nuclear Electric) has operated under a competitive market longer than any other generator in the OECD and has shown significant cost improvements in its new environment. From 1992 to 1997 staffing decreased from 8 200 to 5 000 while total plant output increased 64%, from 41 TWh to 67 TWh. The company improved operations as measured by capacity factor, decreased industrial accident frequency, decreased worker radiation exposure, and other technical indicators. Overall, production costs decreased from 80 US$/MWh to 33 US$/MWh (0.02 £/kWh) (Marshall, 1994; Marshall, 1998). It should be noted that the starting point for technical and economic performance indicators of British nuclear plants was relatively poor among OECD countries in 1990.

The United States has shown substantial improvement in nuclear plant performance in the 1990s. Since 1992, when the Energy Policy Act opened access to wholesale electricity markets, the prospect of electricity market competition has been an important driver of this improvement, though certainly not the only one. From 1990 to 1996, plant thermal efficiency increased by 0.2 percentage points, the volume of low-level wastes generated decreased by almost two-thirds (NN, 1997), nuclear plant staffing decreased by 7% (Martin, 1996), and times required for refuelling dropped by over one-third. Overall, nuclear plant production costs decreased from 23 $/MWh to 21 $/MWh according to US Department of Energy data.

Upgrades and Longer Lives will Provide New Capacity

Increasing the capacity of existing plants and extending their lifetimes are likely under competition (Harrison, 1998) because they can provide "new" capacity without incurring the full costs that would be required for a complete facility. In Spain, for example, an extra 4% (220 MWe) nuclear plant capacity was added between 1995 and 1997 from steam generator and turbine upgrades. An additional 7% is expected to be added by 2004. Swedish boiling water reactor power plants using nuclear systems designed by the company ABB have been upgraded to provide a total additional capacity of 600 MWe (Olsson and Haukeland, 1997). US plants designed by Combustion Engineering have increased their capacities by 2.5% to 15%. Capacity upgrades are likely to be pursued further under competition.

The competitive advantage of owning depreciated nuclear plants with low marginal costs, combined with the difficulty in siting and building new plants of any type, is likely to lead many utilities to extend the lives of their nuclear plants. This may entail additional investments to bring plants up to current safety requirements. Two of the earliest reactors built in the United Kingdom applied for and received permission (1998) to operate an additional 10 years beyond their initial 40 years of operation, contingent upon further safe operation. The first US plant to seek licence renewal expects to invest more than $ 300 million for equipment and safety upgrades (Weil, 1998a). If a 20-year extension to its licence is granted, the plant will operate for 60 years. With continued investments and refurbishment, current nuclear plants should be able to operate 60 years, or even longer (Ryan and Hibbs, 1997). As long as the expected value from continued operation exceeds the cost of capital improvements and refurbishment needed to operate safely, individual owners will seek to continue operating their plants. Competitive markets are likely to test the limits of economic lifetimes for the current generation of nuclear plants.

EFFECTS ON NUCLEAR UTILITY BUSINESS STRUCTURES

In addition to improvements in plant performance and operation, competition is likely to bring improvements to the management and business arrangements of nuclear utilities. This is already beginning to be seen in the United States, where a diverse group of nuclear utilities is seeking ways to improve the organisation of nuclear generation businesses as competition develops.

Re-organisations and Consolidations

Corporate re-organisations are often legally required when electricity market competition is introduced. Accounting or legal separation of generation, transmission, and distribution activities are typically specified so that there is a sound basis for competition in generation and other segments. Among utilities with nuclear plants, utility corporate structures may be re-organised to better manage the special requirements of nuclear power generation. Corporate entities may be created to manage special risks or funds related to nuclear power activities.

Consolidation of nuclear power activities is likely. Single-unit nuclear power installations generally have higher fixed operating costs per unit of electrical output because of the specialised infrastructure, staff, and regulatory activities required for nuclear installations, regardless of size. A likely strategy for owners of single-unit nuclear power plants will be to consolidate the business operations of their units with other plants through mergers. Other small or less successful nuclear utilities may decide to hire an operating company to run their nuclear plants. Mergers and operating agreements allow companies to share nuclear-specific expertise and facilities and to spread the fixed costs of some nuclear activities over a larger total output. Consolidation could extend quite far according to some. The head of a major US nuclear utility suggested that the number of nuclear utilities in the United States could drop from around 50 today to ten or fewer (Weil, 1998b).

Utilities may also wish to sell their nuclear plants or shares in nuclear units. The companies that purchase nuclear units or shares in them, as in the case of a merging companies, will be able to reduce the per-unit overhead costs of nuclear generation, bring new expertise to the operation of their plants, share specialised staff, and negotiate contracts with suppliers from a stronger position.

International activity of this type is likely to grow as well as competition is introduced into other OECD markets. Companies wishing to conclude business transactions with foreign companies are likely to press for the removal of restrictions on foreign ownership of nuclear power plants and other facilities, such as still remain in the United States.

Competition Law Limits Consolidation and Special Support

Nuclear generators will lose their exemptions from general competition law they have enjoyed under monopoly supply arrangements. Competition authorities will have an important role in ensuring that utility consolidation (not just among nuclear utilities) does not lead to abuses of market power in competitive markets. They can act to prevent anti-competitive contracts, mergers, or joint ventures between nuclear generators. Competition law will therefore provide some limits to the new business freedom of nuclear utilities in competitive markets.

Competition authorities will also act to eliminate preferential government support for particular generators. Subsidies, transfers, or special privileges such as tax exemptions or procurement set-asides will come under scrutiny. Nuclear utilities that benefit from such support are likely to see it come under pressure.

Contrasting Strategies are to Focus on Nuclear or to Diversify

Some companies with good records of nuclear plant operation will seek opportunities to expand their activities through operating agreements or acquisitions of nuclear generation and related companies. For these companies, the basic strategy is to develop and take advantage of their strengths in nuclear power. As with consolidation, a benefit to the nuclear industry will be the transfer of superior operating, safety, and management practices from the industry’s best performers to others. British Energy has formed a joint venture company AmerGen with an US nuclear utility to explore possibilities to acquire and operate nuclear generating power plants. Entergy is focusing its growth strategy on nuclear operations, and was among the first US utilities to seek contracts for operation of nuclear plants (Newman, 1996; Entergy, 1996).

A contrasting strategy is to diversify activities into other types of generation or entirely new business areas. Utilities who consider that their activities are too highly concentrated in nuclear power generation, or those with poor records of nuclear plant management, may favour this strategy. Some US nuclear utilities have increased their shares in gas-fired power generation outside their service areas through subsidiaries. The nuclear industry is likely to benefit from increased interaction with businesses and industries outside the nuclear area.

The strategies are not mutually exclusive. Electricité de France has been preparing itself for competition in 1999 by, among other actions, investing in non-nuclear generating plant and electricity distribution companies around the world (Blanc, 1997). But it is also pursuing nuclear plant opportunities in China, Turkey, and elsewhere.

Bankruptcy May Contribute to Change

Bankruptcy will be a new potential option that some nuclear utilities may turn to if, ultimately, they are not able to compete successfully. That a nuclear plant be bandoned because of the financial failure of its owner is effectively impossible, in OECD countries. It is most likely that bankruptcy would facilitate sales of plants to more successful nuclear utilities. It could provide a means to reduce unsustainable debt on nuclear plants if arrangements for the transition to competition do not do so.

EFFECTS ON NEW NUCLEAR PLANTS

Current Prospects for New Nuclear Plants are Limited Regardless of Market Type

An issue of concern to the nuclear industry and to some governments is the prospect for new nuclear power plant construction when there are competitive electricity markets. Today, this is a largely theoretical concern because, under any electricity market system, monopolistic or competitive, the prospects for nuclear power are very limited in OECD countries. The introduction of competitive electricity markets should not be confused with, or be held responsible for, the pre-existing prospects for nuclear power in the near term.

There are likely to be few, if any, new commitments to build nuclear power plants anywhere in the OECD, except Japan and Korea, in the next 10 to 20 years. This assessment is common, both within the nuclear industry and in the electric utility industry in general. It assumes that fossil fuel prices do not increase greatly in price and that environmental protection regulations do not become significantly more stringent. The reasons why few new plants are expected are well known:

- in many markets, there are power generation alternatives with lower total generation costs;
- there are no fully developed, politically accepted plans and facilities in place today for disposal or re-use of nuclear plant high-level wastes, including used fuel;
- there remain public concerns about what constitutes an acceptable level of operating plant safety in new plants; nuclear plant siting is especially difficult because of this;
- there remain concerns about use of nuclear materials from power plants for nuclear bombs or terrorist actions;
- in many markets, the need for new baseload capacity in the near term is limited because of existing reserves of generating capacity and moderate electricity demand growth rates.

In any type of electricity market, the weak economic position of nuclear power today limits prospects for new plants. Nuclear power is not necessarily more expensive than alternatives in every market, especially in those with high fossil fuel prices and where nuclear plant capital costs can be kept low. However, a joint study by the International Energy Agency and OECD Nuclear Energy Agency (OECD, 1998) shows that in a majority of countries, and under various financial evaluation conditions, fossil fuelled power generation is less expensive for meeting baseload demand than nuclear power generation. Competitive markets will provide options for meeting demand with plants other than the large, centralised ones common today. In most markets then, competition will merely confirm the humble economics of nuclear power today.

The issue of how to deal with used nuclear fuel has taken on increased importance. Temporary storage plans and facilities have been stretched to accommodate delays in developing permanent solutions, but the issue has not been resolved. Only a small fraction of commercial nuclear power plants have permanently ceased commercial operation, so there are few actual examples to confirm cost estimates for final closure. These are elements of uncertainty which compound the tenuous economic case for nuclear power in many markets.

There has been little economic driving force for new nuclear power plants in recent years, so there has little driving force to resolve some of the non-economic issues which restrain nuclear plant development for the future. The improved policy transparency that competition brings should help to resolve some of these issues and reduce mistrust in nuclear power.

In some countries, there are formal or de-facto prohibitions on the construction of new nuclear power plants. This is the case in Australia, Austria, Denmark, Greece, Ireland, Italy, New Zealand, Sweden, Switzerland, and Portugal, among other OECD countries. Regardless of electricity market arrangements or nuclear power's economic competitiveness, no nuclear power plants will be built in countries or states where there is a political impasse on the use of nuclear power. This political impasse, and the issues that must be resolved before there could be new political decisions in support of nuclear power, are far more important to the future of nuclear power than the introduction of competitive markets.

In the long term, there is every reason to expect that nuclear power's economic competitiveness could improve, depending on a host of factors. A penury of fossil fuels could finally arrive in the next century, driving up their prices and improving the relative position of nuclear power. Removal of production subsidies from domestic fossil fuels could increase their prices in some countries. Stricter regulations on emissions of pollutants from non-nuclear power plants could have the same effect by increasing the cost of pollution control. Nuclear power proponents today pin great hope on the commitment to reduce emissions of greenhouse gases as the decisive factor in nuclear power's future. Since nuclear power produces no carbon dioxide, it could enjoy an economic advantage if there is a value to not producing the gas (see Chapter 3). On the other hand, lower limits on radioactive releases permitted by nuclear plants or nuclear fuel cycle facilities, more stringent or different safety regulations on the disposal of nuclear wastes, or other changes in the regulation of nuclear material could equally worsen nuclear power's economic competitiveness.

Such changes in the economics of nuclear generation are unrelated to competitive electricity markets. The examples merely suggest that today's economics situation for nuclear power is not necessarily tomorrow's.

Competition is Compatible with New Nuclear Plants

Some suggest that competitive electricity markets are inherently incompatible with decisions to build new nuclear power plants. They argue that competitive markets favour investments with low capital costs, short construction periods, and short payback periods, none of which do nuclear plants have. According to this line of reasoning, high discount rates that do not reflect the "societal benefits" of a long-term supply of electricity will lead utilities in competitive markets to select only gas-fired combined-cycles and other plants with low capital cost: new nuclear plants will never be built. A parallel argument is also made by some worried about the fate of coal-fired power plants in competitive markets.

The argument presents an incomplete model of competitive markets. Companies do not make decisions on investments based upon initial cost alone. Rather, they weigh the cost of investment against the prospect of a stream of revenue extending into the future. If an investment, even a heavy one, offers the prospect of steady profits because its ongoing costs are low compared to alternatives, there will be an adequate incentive to make the investment. Considering a specific case for baseload power production makes the point clearer. If a gas-fired combined cycle is less expensive to build, but has much higher operating costs than a nuclear plant, its electricity will be too expensive to compete with that from the nuclear plant. Over time the nuclear plant would be able to sell its power on the electricity market while the combined-cycle sat idle, or earned a smaller amount due to its higher running costs. The "advantage" of lower capital cost would be of no use without an adequate revenue stream to repay that lower investment. There will be a strong incentive to invest in the plant with the lowest total cost of generation. In summary, if the balance of capital, operating and fuel costs gives a lower total cost of generation to a nuclear plant, or any capital-intensive plant, there should be no economic impediment, and every economic advantage, to investing in that plant in a competitive market.

Some governments have taken a cautious approach when introducing competitive electricity markets by providing a mechanism to pay power plant owners for capacity separately from electricity. This was the case in the United Kingdom, though these capacity payments are to be eliminated. The markets in Spain, Portugal, and Argentina also provide capacity payments to generators. The payments are designed to provide a steady incentive for investment as prices and demand vary. Capacity payments could help to smooth the transition to competitive markets and reduce investment uncertainty. The need for them in the long term is, however, much debated. Other industries, such as the petrochemicals or the liquefied natural gas industries, demonstrate that markets can mobilise heavy investments, even without such a "structural" market guarantee.

The most important factor determining the balance of capital, operations and maintenance, and fuel costs is the discount rate, or opportunity cost of capital. It implicitly sets the relative importance of many factors involved in an evaluation of total power generation cost and profitability, including initial capital cost, construction time, operating lifetime, fuel costs, operations and maintenance costs, plant salvage value at the end of its lifetime, plant closure costs, and future revenues.

The argument that discount rates will be "too high" in competitive markets reflects a misunderstanding of the role of markets in allocating capital to productive enterprises. The discount rate used by privately owned companies in any industry reflects a broad societal weighting of the relative importance of saving money (investing) for creating future income versus spending money now. Private investors have a choice of what to do with their money, and by providing equity or lending to a company that invests in power generation, automobile manufacturing, or any other commercial venture, holders of private capital, as a whole, allocate money efficiently to activities society deems valuable. The allocation takes into account the potential value to society, that is, the productive output of the enterprise that society wishes to buy, as well as the cost of producing that value and the possibility that the investment may fall below expectations, that is, the risk.

The possibility that discount rates used by generating companies may change in competitive markets does not mean that the use of capital in power production will be worse than under monopoly markets. Rather, it will simply mean that there will be a better allocation of capital between electricity generation and other productive activities. In many electricity markets, the discount rate may increase when competition is introduced because uncertainty for utilities will increase. After a transition period, perhaps lasting up to a decade, the cost of capital will decline again and reach a stable value.

If the final average discount rate used by generating companies increases in a specific electricity market as compared to the former monopoly regime, this would suggest that, previously, capital was used less efficiently. Like many other products and services in modern society, such as telecommunications, automotive fuels, or industrial-scale food production and distribution, electricity generation is an essential part of the fabric of daily life. Modern society could not be organised as it is without electricity. However, like other essential products and services, there is no compelling reason to reserve a special allocation of societal capital to electricity generation compared to other activities. In fact, the move to competitive electricity markets reflects the broader recognition of the idea that electricity generation is not such a unique commercial activity after all.

An IEA analysis confirms that investment in generating capacity can be efficiently governed by competitive markets (IEA, 1998). There is little to suggest that inadequate investment or systematically incorrect plant choices will be made by utilities in competitive markets.

Competition will Improve Economic Prospects for New Nuclear Plants

The same forces that shape the operation of existing nuclear power plants will inevitably improve the economic performance of new nuclear power plants. Improvements in operating practices, plant technical performance, administration, and many other areas at existing plants should be largely applicable to new plants. The costs of operating and maintaining a new nuclear plant, like existing plants, are likely to decrease as a result of the efficiency improvements from electricity market competition.

The capital costs of building new nuclear plants are likely to decrease as well. As utilities seek ways to gain competitive advantage, there is no economic reason why they should exclude considering improved nuclear plants. Power plant owners seriously evaluating new nuclear plants will identify improvements that plant manufacturers and designers may have missed in the absence of specific market applications for their designs. Furthermore, if the economic promise of improved nuclear plant designs can be demonstrated in the markets where they are economically feasible (though seemingly quite limited today), competitive markets are more likely to risk a new plant design as long as it has prospects for substantial benefits. The nuclear industry itself is beginning to recognise the potential of competitive markets to improve upon and move beyond the first generation of nuclear plant designs (Lacy, 1997; Timbers, 1997).

At least four major new nuclear plant designs have been developed in recent years: the Advanced Boiling Water Reactor, the AP600, the System 80+, and the European Pressurised Water Reactor. Competitive generation markets will establish how competitive these plants are, particularly in relation to plant size. But the designs exist and the first three have already passed many regulatory hurdles in the United States. Two units of the Advanced Boiling Water Reactor went into operation in Japan in 1996 and 1997. These updated designs, among others, will thus provide reference points for further improvements in plant economics.

Finance Can be Found for Economic Plants

Bankers and financial markets in general have sometimes been blamed for stifling investment in capital intensive power projects. They are often said to be hostile to nuclear power and financing an obstacle to nuclear power development. If there is some "unwillingness" to finance nuclear projects, past experience would certainly explain some of it. Surely only foolhardy financial managers would knowingly provide money to projects, in any industrial sector, whose technical characteristics were not fully determined at the outset, whose times to completion could be doubled or tripled, whose costs were subject to substantial increases, and whose output might never be sold. These were the characteristics of some nuclear projects in the 1970s and 1980s (though certainly not in all countries).

In fact private capital markets have financed a large proportion of nuclear power plants in the OECD, just as they have financed a large proportion of conventional power plants. They are not hostile to capital-intensive projects, just capital-intensive projects that lose money. They evaluate projects, typically with the support of independent technical evaluators, to ensure that:

- project design constraints and technological choices are well-known and fixed
- the project cost estimate is not likely to be exceeded
- there are no large, unforeseen future liabilities
- there are no external legal or regulatory factors which could jeopardise the investment
- the investment is competitive with others in the same sector
- the investment will provide an adequate return.

Given these conditions, money can be found for any project. The fundamental condition for a nuclear plant investment, as for any project, is that the plant provide a profit on the money invested. Large investments are often handled by involving many institutions.

Under monopoly supply conditions, financial markets did not need to pay as much attention to the fundamental economics or competitiveness, because the utility had a guaranteed market to absorb any cost overruns. In competitive electricity markets, however, minimising financial risk by ensuring both cost control and revenue potential are fundamental to attracting investors.

Today the nuclear industry states that nuclear plant technology is mature and proven, the safety regulatory framework is well established and stable, and therefore total costs are known with certainty. However, if past experience with nuclear plant construction costs provides a lesson, it is that changes in political attitudes towards nuclear power, and the corresponding approach to safety regulation, can have huge effects on nuclear project costs. The value of future liabilities could be affected similarly by changes in public attitudes towards plant safety or radioactive waste. Therefore, financing of nuclear projects will depend on prospects for a stable political climate for nuclear power, and a stable, consistent regulatory environment.

EFFECTS ON SAFETY AND SAFETY REGULATION

Governments of OECD countries have historically attached an absolute priority to the safe operation of nuclear power plants. For example, the Shared Goals of the International Energy Agency notes the desire of countries to use nuclear power "at the highest available safety standards." Energy ministers from the G-8 countries, at their meeting in April 1998, committed themselves to "keeping safety as [their] absolute priority in the use of nuclear energy" while at the same time recognising that competitive pressures in the electric sector are growing. Given the long-standing commitment to safety within the OECD at the highest levels of government, competition should not weaken the ability of nuclear safety authorities to monitor and ensure the safe operation of nuclear power plants. Rather, its most likely effect will be to create new challenges for nuclear safety regulators. Competition will alter the way in which safety regulation is developed and applied.

Monitoring and Incentives for Safe Operation Remain

The argument that competition will lead to lower levels of nuclear plant safety has been advanced by, among others, nuclear plant worker trade unions (Reuters, 1995; Launet, 1996). In OECD countries, nuclear plant safety is assured by independent authorities who are, in principle, outside the control of nuclear plant operators and independent of short-term political influence. Nuclear safety regulators are required to ensure compliance with regulations regardless of the business consequences on the companies affected by their actions. In short, if a plant is not safe, it will not operate. Environmental regulations, airline safety, food processing hygiene, and a host of other regulations are enforced in a similar way throughout the OECD.

Furthermore, nuclear safety regulations themselves are largely independent of the organisation of the electricity sector since they concern individual plants and the procedures in place in individual companies for ensuring that safe plant operation is maintained. The introduction of competitive electricity markets should therefore have little impact on the application of existing nuclear safety regulations by safety authorities.

Competition should not lead individual companies to give a lower priority to plant safety either. In fact, many in the nuclear industry argue that it is likely to have the opposite effect. Competition will magnify the cost implications of failing to comply with nuclear safety regulations. Plants which cannot operate due to safety problems represent an enormous loss of revenue. The cost of bringing plant equipment or procedures to acceptable safety levels after a period of neglect can also be very large. Although the ongoing costs of ensuring safety can be large, there are also potentially huge costs of not complying with regulations and a high likelihood that deficiencies will be noted by safety regulators. One potential benefit of nuclear industry consolidation is that the best safety practices of successful companies will be made available to all their operating units. As long as nuclear safety regulations are applied consistently to all nuclear operators, their cost is simply a normal cost of doing business.

This reasoning is confirmed by recent experience in the United States. The US Nuclear Regulatory Commission "has not found a consistent relationship between a licensee's financial health and general indicators of safety such as the NRC's Systematic Assessment of Licensee Performance" (NRC, 1997). The US nuclear industry emphatically states that competition is likely to improve plant safety rather than the opposite (Lacy, 1997). The Nuclear Energy Institute, a US trade association, has noted a positive correlation between good plant economic performance and good plant safety performance (Colvin, 1997). That is, plants with the lowest operations and maintenance expenses, and those with the highest utilisation rates, are also the plants with the best scores on the Systematic Assessment of Licensee Performance. The safety of US nuclear plants, as evaluated by the Nuclear Regulatory Commission, has increased since the early 1990s, at the same time as nuclear utilities have begun to prepare for electricity market competition.

The example of British and Nordic electricity market liberalisation also confirms the view that competition does not compromise nuclear plant safety. The UK Health and Safety Commission, when giving evidence to the team responsible for the 1995 Nuclear Review, stated (DTI, 1995) "the system of nuclear regulation in the UK ... is essentially sound, and there is no reason to change it in any fundamental way to deal with whatever [electricity market] structure emerges." No special changes were thought necessary to Swedish or Finnish safety regulation as competition has been introduced in those countries.

Vigilance and Independence of Safety Regulators Are Crucial

Business priorities may change for companies operating nuclear power plants, but it should not affect their systematic compliance with nuclear safety regulations. This is not to deny the likelihood that some companies in financial difficulties or with poor management will inappropriately reduce spending on safety, just as they have in monopoly supply systems. As has always been the case, governments must make sure that nuclear safety regulators ensure safety at the level of individual nuclear plants, and not rely simply on the good faith and past performance of plant operators as a whole. Whether utilities are operating in monopoly or competitive environments, there will always be, unfortunately, some whose operations slip towards minimally acceptable levels of plant safety. Adequate regulatory strength and vigilance is a pre-requisite under any electricity market system.

Governments must also make absolutely certain that nuclear safety authorities are able to act independently of short-term influence by both nuclear utilities and political authorities. There is a real danger that safety regulators too sensitive to either could let safety levels drop in a newly competitive market. Adequate regulatory independence is also a pre-requisite under any electricity market system, but even more so in a competitive one.

Because of the financial impact of the decisions of regulatory authorities, competitors to nuclear power generators may put pressure on governments to ensure the functional independence of nuclear regulatory authorities, to the extent that this independence is not already fully established. If safety authorities are subject to influence or informal control by the government, competitors may see them as providing a means to support nuclear power through unfairly favourable treatment. In this respect, competition will help to improve the transparency of safety regulation, just as it does for energy policy.

Safety Regulators Face New Challenges

The advent of competition does bring many new challenges to safety regulators. A comprehensive review of future challenges, including those related to electricity market liberalisation, is given in a report by the OECD Nuclear Energy Agency (NEA, 1998b). They include:

- changing plant technical operation made in response to the desire for improved economic performance (extension of plant operating lifetimes, greater operational flexibility, higher energy utilisation of nuclear fuel, longer periods between refuelling, etc.)

- resolving differences in point of view with plant operators regarding the need for and cost of improved safety
- developing ways to monitor the adequacy for safety of new working arrangements
- maintaining access to research results while guarding regulatory independence
- moving towards risk-informed, performance-based regulation

The latter is perhaps the most important when considering the economic future of nuclear power. Competition will reinforce the existing trend towards more careful analysis of the cost-effectiveness of safety regulation. In non-competitive electricity markets, safety requirements could be implemented without regard to cost because costs could be passed on to consumers. In competitive markets, there is a much stronger incentive for utilities to critically evaluate the potential benefits of safety requirements to make sure that the costs of implementing them are warranted. In other words, plant operators are more likely to openly question the need for some safety actions. Regulators will be asked to pay ever greater attention to the cost implications of their actions. The risk to plant owners from abrupt changes in plant safety regulations is likely to go down, because of the greater incentives for owners to resist and protest against such changes unless they are clearly beneficial.

As in other areas of nuclear plant operation, it is likely that the cost of complying with safety regulations will decrease due to competition's spur to innovation, assuming a stable political environment. Owners are likely to be more insistent that safety authorities consider changes to plant and operation that do not fit within pre-established regulatory guidelines, as long as the changes maintain or improve plant safety. Outdated or procedural regulations may be dropped in favour of performance-based rules.

Inefficient regulatory practices may be exposed as international competition reveals differences between neighbouring countries. An example is given by a study comparing maintenance costs of a German and a Swedish utility (Brocker and Hanson, 1996). The German utility was thought to have higher costs due primarily to differences in safety regulation, including requirements on testing, the use of outside technical experts, working methods, and inspections. The safety of Swedish and German plants, however, appear to be the same. The study concluded that German regulatory requirements should "give greater credit to the utilities' own sense of responsibility for the safety of their plants." In another similar study (Hibbs, 1997), operations and maintenance costs of German utilities were found to be about three times greater than for the French utility Electricité de France. If the cost of reserves for waste management and decommissioning are included, the total cost of German nuclear generation is twice that of Electricité de France. The study concluded that "politically imposed burdens" account for much of the difference. In general, competition will put pressure on nuclear safety authorities to set framework and performance conditions, while allowing utilities themselves decide how to apply the safety requirements.

Other Safety Issues

Adaptation to New Network Operation

All plans for introducing competition in electricity supply have involved, at the least, the separation of generation from transmission and distribution. Typically an independent operator of the network becomes responsible for plant dispatch and ensuring network stability. Political considerations as well dictate that grid reliability not degrade significantly with the arrival of competition. Ultimately, the quality of institutional arrangements for the independent operator will be one of the most important factors in ensuring a high level of network reliability. Although it has not been seen in practice, it is possible that network reliability could be lowered. The period of transition to competitive arrangements is likely to be the period of greatest uncertainty in ensuring stable network operation.

Nuclear safety authorities have an interest in ensuring that potential decreases in network reliability do not affect the safety of nuclear plants. More frequent network blackouts could increase the estimated danger from plant accidents if on-site backup generators failed during a plant malfunction. Another potential concern is that the independent network operator might not adequately take into account operational constraints of nuclear power plants such as rates of increase or decrease in plant output.

If there is a transitional risk of lower reliability, nuclear safety regulators can play a role in helping network operators and electricity regulators to understand the safe interaction of nuclear plants and the electricity grid. No amount of nuclear regulatory action is likely to reduce the transitional risk of lower grid reliability. (Otherwise, the nuclear regulatory authority would be in the unusual position of being able to ensure network reliability better than the operator itself.) Furthermore, the network operator would generally not place costly constraints on the network for one specific plant type, either for reliability or plant dispatching, unless they were part of the commercial arrangements for purchasing electricity from those plants. Therefore, the actions taken by nuclear safety authorities to adapt to new network conditions, should they arise, will be focused primarily on nuclear plants themselves.

Pressure to reduce safety regulators' role in financial oversight of nuclear utilities

Safety regulation is likely to become confined more strictly to safety and not to business matters. As nuclear utilities participate in the competitive market, they will seek to minimise the influence of nuclear safety authorities on matters which are not directly related to plant safety. These include, for example, general financial requirements, restrictions on ownership, or restrictions on asset sales. In the United States, sales of nuclear plants are a particular issue because of the financial reviews required for approval of the licence transfer by the safety authority (Avery, 1997).

PLANT CLOSURE AND WASTE DISPOSAL EXPENSES

An important issue regarding nuclear plants operating in competitive markets is how to ensure that they will accumulate enough money over their operating lifetimes to pay for plant closure and waste disposal expenses. Ensuring adequate reserves under any electricity market system has two important components:

- Establishing the technical requirements for plant closure and the corresponding sum of money needed to meet those requirements.

- Setting the financial arrangements for accumulating that money over the lifetime of plant operation. This includes managing any funds held in trust.

The first component is one that must be done by nuclear regulatory authorities. They must define exactly the standards, methods, and timing of plant closure. From these definitions they and the plant owner can estimate the amount of money needed to close the plant. The nuclear industry believes that, with clear definitions, costs are reasonably well known, despite variability among different plants in different countries of up to a factor of six in estimated plant closure costs. Reports by expert groups convened by the OECD Nuclear Energy Agency and UNIPEDE both address the question of why plant closure costs are so variable (NEA, 1991; UNIPEDE, 1998). They confirm that waste disposal requirements account for much of the difference, apart from plant technical factors such as type and size of reactor and apart from differences in the scope of cost estimates. Today the closure requirements and sums of money needed seem quite uncertain because few plants have actually been fully decommissioned. There is little actual experience to go by. Furthermore, there is a risk that closure requirements may become more stringent due to changes in political views or the availability of new technical or scientific information. This makes it difficult to fix the cost of plant closure or waste disposal with great confidence.

The second component is primarily a financial oversight function. There must be an agreed way to collect and manage money over an extended period of plant operation. A report by the OECD Nuclear Energy Agency (NEA, 1996a) summarises current requirements in OECD countries for meeting future liabilities. The financial management of money collected is a key question, since it must not take excessive risks with the funds, while still earning a return on them to minimise cash requirements. The latter is especially important when regulations allow for a long period of radioactive decay before final plant closure and plant owners wish to take advantage of this period. The principles behind financial regulation of plant closure funds are little different than regulation of pension or insurance funds.

Competition will affect both the technical and financial aspects of plant closure funding. It should put pressure on governments and regulators to establish plant closure requirements that limit open-ended risk in the future. Utilities will strongly resist requests to bear the cost of any stricter closure standards applied retroactively. Regulators may tend to increase the total money collected for plant closure since they cannot rely on automatic pass-through of the costs to electricity consumers. They may also consider faster accumulation of funds. Owners of nuclear plants may wish to proceed more quickly with plant closure than required by regulation in order to limit future liabilities and cost uncertainty.

To the extent that nuclear safety regulators are responsible for financial oversight of decommissioning funds, that role is likely to come under pressure. Utilities will seek changes to the financial management of plant closure funds to reduce their total cash outlays, and may see safety regulators as overly conservative, since they are not specialised in financial matters. Competition could tend to shift oversight of decommissioning funds to specialised financial regulators.

The introduction of competition requires some consideration by regulators (energy and financial, not just nuclear) of how to make up any shortfalls in plant closure and waste disposal funds once a plant has been closed. Assuming the owner is still in business, this does not pose a special problem, since the operator will normally be held responsible for the full cost. However, if the plant operator goes out of business, regulators will need to decide who should fund the shortfall. As in the past, they may ask electricity consumers to pay via a surcharge on electricity consumption or electricity supply services. Or they may ask the general taxpayer to pay, as typically has been the case for unfunded environmental cleanup projects.

Shortfalls of plant closure funding can be precipitated by the introduction of competition. Nuclear plants in a newly competitive environment may shut due to economic reasons before they have accumulated enough money to pay for proper plant closure. This would create unfunded liabilities which cannot simply be written off. The transition mechanisms used to pay for stranded assets can be used for these unfunded plant closure costs as well, according to the political choice.

EFFECTS ON OTHER NUCLEAR ACTIVITIES

As nuclear plant operators face competition, they will turn to their suppliers and business associates to seek sources of cost reduction. The effects of electricity market competition will thus extend beyond nuclear utilities to:

- suppliers of nuclear fuel and nuclear fuel services
- suppliers of equipment and plant services
- co-operative organisations for plant operations
- research and development organisations.

The pressures on nuclear suppliers have already developed due to the stagnation of nuclear power growth and consequent overcapacity among suppliers. Competition among nuclear generators is therefore unlikely to drastically affect nuclear suppliers, but it could accentuate the pre-existing tendencies.

Nuclear Fuel Suppliers

Nuclear fuel is a major component in the marginal cost of operating nuclear plants, so fuel suppliers will be pressured to increase their efficiency and reduce prices. Utilities may be more willing to seek fuel fabrication services from companies other than those responsible for the plant design, and to seek foreign fuel supply services. As with other aspects of market competition, this will probably put pressure on governments to liberalise the supporting nuclear sectors as well, some of which have strong administrative restrictions or are government-owned.

Services for handling, processing, and storing used nuclear fuel should be pressured to improve efficiency and cost. Historically the arrangements for dealing with used fuel have been driven by political, administrative and regulatory considerations. Cost is likely to become a more important consideration. Regulators may be pressured to consider alternative means of dealing with waste, and governments pressed to complete administrative planning for waste disposal. Electricity market competition will tend to accelerate the process already underway towards establishing more complete plans for high-level nuclear waste disposal.

Suppliers of Equipment and Plant Services

Among nuclear equipment suppliers and plant architect-engineers, the reduced level of nuclear construction long ago increased their attentiveness to prices. The days of contracts based on cost-plus-profit disappeared in the 1980s for most companies. Unless competition forces the early closure of a large fraction of plants (as noted early, this seems unlikely), pressures on nuclear plant suppliers and designers should not unduly increase. However, utilities may enter into new types of business relationships with them, for example, to take advantage of technical innovations developed within utility companies. Another example might be more creative use of consortia to pursue improvements to specific classes of power plant. Strong national links to domestic suppliers may weaken as utilities seek the lowest prices anywhere in the global nuclear engineering market.

Co-operative Organisations

Nuclear plant owners participate in co-operative organisations for sharing information and experience on nuclear plant operations. The Institute of Nuclear Power

Operations in the United States and the World Association of Nuclear Operators in the United Kingdom are two of the key organisations facilitating this co-operation. There are also owners' groups for the plants designed by the main nuclear plant vendors. These organisations have played an important role in improving practices for ensuring nuclear plant safety and improving economic performance.

Competition is not likely to harm their role in improving safety practices. Although some of the information shared may be commercially sensitive, there is a strong commercial incentive to maintain high-standards of plant safety. National safety authorities are also likely to support continued, strong participation in the groups.

There is the potential that co-operative sharing of operating information for primarily economic improvements could be reduced as companies seek to maintain competitive advantages. Another possibility is that, if nuclear operating companies grow in size through consolidation, sharing of information within these larger companies will fulfil some of the role formerly played by co-operative organisations. The outcome is today difficult to predict, but it seems unlikely that these organisations will be much weakened by the arrival of competition in national markets.

Research and Development

The fate of research and development in competitive markets is a much debated subject (see IEA, 1996). The main debate is whether or not competitive markets will provide an "adequate" level of money to ensure a reliable, long-term supply of electricity. It is often said that competitive markets will lead to short-sightedness in research and a drop in long-term research projects. The question in the nuclear field is particularly difficult to analyse since governments historically have spent enormous amounts of money that were never borne directly by electricity ratepayers. Nuclear research institutes already face many challenges, even without changing electricity markets (NEA, 1996b). Many involved in nuclear research apparently fear that the difficult environment caused by decreases in government research and development funds will be compounded by "inadequate" money from utilities.

There is quite a bit of confusion regarding the link, if any, between less government support of nuclear research and the introduction of competition. Although the two may be related by the increasing acceptance of governments to rely on markets to produce efficiency and innovation, competition itself is not responsible for decreasing government research and development.

Regardless of the "adequacy" debate, it is clear that competition leads companies to re-orient their research and enhance its effectiveness (Hirsch, 1996; Power, 1996). Utilities will tend to reduce research into generation technologies and instead focus on improvements to plant operations and in-plant technologies. "Public-goods" research projects with no commercial benefits will be dropped. It is likely that nuclear utilities will participate in collaborative research programs more than in the past.

There remains a strong incentive for power generators to continue industrial research programs. There also remains a role for government funding of research programs that provide an element "public goods." Some public funding may be warranted for pilot projects of unproved technologies, but most agree that governments should not try to "pick the winners." Co-operative arrangements between industry and government, such as those developed in the IEA Technology Implementing Agreements, can help to combine private and public research efforts. International co-ordination of nuclear research through organisations such as the OECD Nuclear Energy Agency will take on added value from the introduction of competition.

TRANSITION ISSUES IN MOVING TO COMPETITIVE MARKETS

Stranded Assets

Stranded assets often confuse discussions of nuclear power economics. They are essentially irrelevant to the question of operating expenses at existing nuclear power plants. They relate only to the transition from monopoly to competitive electricity generation markets.

Stranded assets may be defined as those unamortised costs of prior investments that would be recovered by monopoly supply utilities but which would not be recovered under competition due to lower electricity prices. The main source of stranded nuclear assets is high investment costs, typically due to cost overruns on plant construction, cancellation of partially finished nuclear plant projects, or prohibitions on the operation of functional plants. The existence of nuclear plant stranded assets indicates that some investments made in the past are uneconomic or even non-productive today. The debt incurred for these investments would be recovered only over a longer period than originally expected (if at all). However, stranded assets relate to past investments or commitments. They do not correlate with ongoing costs of operation, nor do they necessarily indicate future investment costs of nuclear power plants. Table 4 summarises estimates of stranded nuclear assets in four OECD countries.

The treatment of stranded assets is important to the operation of individual utilities. Plant owners may face cash flow problems if they must continue to pay

Table 4

Estimates of Stranded Nuclear Plant Assets

Country	*Estimated Stranded Nuclear Assets*	*Stranded Assets per Unit Total Nuclear Capacity (US$/kWe)*	*Source*
United States	US$ 24 to 56 billion	240 to 550	EIA, 1996, assuming 1/3 of total stranded costs from nuclear
Spain	Pesetas 0.730 billion	700	CSEN, 1997; base value of nuclear moratorium payments
Italy	Lire 3 trillion	1400	Sabotino and Vercellese, 1998
Switzerland	SFR 2.6 billion	580	EER, 1998

Notes: All figures are rounded. Estimates of stranded investment vary considerably among national sources. Italian nuclear capacity taken to be 1.3 GWe, none of which is in service.

interest on investments which do not generate adequate revenue. Stranded assets can be, therefore, very important to the financial situation of individual utilities, who might be unable to continue in business even if individual plants could continue to operate economically based on marginal costs.

Governments may choose to compensate utilities explicitly for stranded assets when the electricity market is reformed to avoid placing individual utilities in difficult financial situations. Allowing recovery of stranded assets also removes an incentive for an incumbent utility to abuse its market position in order to improve the chances of recovering its stranded assets on its own. As an issue of fairness, it is often argued that governments must take responsibility for ensuring recovery of stranded assets because it is governments who create them by changing the electricity market framework. In the United States, the Federal Energy Regulatory Commission has accepted the general principle of stranded cost recovery in the transition to competitive markets. The European Union Electricity Directive also recognises the importance of transitional costs. The Spanish electricity restructuring law made arrangements for stranded assets.

For government-owned utilities, the state may accept a lower value for the assets than their book value. For example, the 1996 privatisation of British Energy brought in £1.4 billion, even though the company’s newest generating station, Sizewell B, was completed in 1995 at a total cost of over £3 billion. Prior to its privatisation, British Energy’s capital accounts were strengthened through a levy on electricity sales, the Non-Fossil Fuel Levy.

The transition to competitive markets both creates and exposes the value of stranded assets. However, not all markets making a transition from monopoly to competitive generation will reveal stranded costs. This has been shown already in

Finland, the Netherlands, and Sweden. Based on the evaluations of Electricité de France, France would not have stranded nuclear assets.

Last-minute Utility Decisions

Nuclear plant owners expecting electricity market competition have incentives to recover as much capital investment as possible under monopoly supply arrangements before they disappear. In order to improve their competitive position, they may be tempted to make plant investments to improve safety or increase capacity before competition arrives. Authorities responsible for overseeing the transition to competitive markets will therefore need to be attentive that investment decisions made by incumbent utilities are sound. Investments should not thwart or unduly delay the onset of competition.

Some owners might be tempted to opt for the path of least resistance and uncertainty by closing nuclear plants even though the plants might be economically viable. This might allow the owners to recover their plant investment through a transition cost arrangement while avoiding the struggle to adapt in a new competitive environment. Here again, competition authorities and electricity regulators will need to make sure that stranded costs are truly stranded, and not just inconvenient.

Transitional Uncertainty

As competition is introduced in an electricity market, there will be a period of considerable business and regulatory uncertainty. All the individuals and organisations involved will require a period of learning and adaptation stretching over many years. Sellers and buyers in the electricity market will need time to understand how electricity prices vary in response to demand and competitive pressures. Utilities will require time to enter into new commercial structures. Safety regulatory authorities will need time to adapt their methods of monitoring and ensuring nuclear plant safety. Other government institutions must adapt to the new market structure.

During the period of transition, the final outcome of many developments will be unknown for a period. This introduces uncertainty that affects decisions on new investments or new undertakings in the electricity industry as a whole. The pace of plant building may slow and those plants that are built are likely to be smaller and less expensive. Nuclear plants, coal-fired plants, and others that require heavy capital investments are disadvantaged relative to less capital-intensive options. New nuclear power undertakings do indeed face a difficult transition period because of their high capital costs. As noted earlier, however, the limited near-term prospects for new nuclear power plants in the OECD, and a number of important non-economic roadblocks to nuclear power development, make this a largely theoretical issue.

If special transitional issues related to nuclear power are resolved as quickly as issues for other forms of generation, beyond the electricity market transition period there should be no effect on nuclear power investments compared to others. However, if the transitional issues specific to nuclear power do take longer to resolve than those of electricity market in general, these could delay investments in nuclear power that would otherwise be chosen in a competitive environment. The nuclear-specific transitional issues of greatest importance relate to the adaptation of:

- nuclear safety regulations
- nuclear safety institutions
- regulations on ensuring adequate provisions for decommissioning and waste disposal expenses

Experience in countries with nuclear power where the transition to competitive markets has already taken place suggests that adaptation in these areas need not be lengthy at all. However, if there is any question as to ensuring the safety of nuclear plants during the transition period to competitive markets, clearly this will take precedence. The United States' nuclear regulatory system presents a special case because of its sheer size, complexity, and federal versus state structure.

Governments have every interest in making the transition period as short as possible. Transitional uncertainty can also be reduced when governments provide clear statements of their ultimate objectives and the likely features of the market in the long-term.

CONCLUSIONS FOR COMPETITION

Competition provides an opportunity to re-invigorate nuclear power. Nuclear plants with low operating and fuel costs will thrive in competitive markets. All nuclear plants will improve their technical and economic performance beyond what has been seen in recent years. The strong economic performance of nuclear plants will result in many of them lasting longer than originally expected. Plants with high operating costs that cannot be reduced to competitive levels are likely to be a small fraction of the total, but they will be shut sooner than in non-competitive markets.

Competitive markets will improve the transparency of energy policy making and the policy framework for nuclear power. It will provide a clearer separation between commercial and government decision-making and help to reveal the true costs of nuclear. These changes will help to dispel the notion of nuclear power as an energy choice made secretly or un-democratically. Competition could very well help to reduce public mistrust of nuclear power and clarify what the real issues of public concern are.

New nuclear power plants face a difficult near-term future in the OECD with or without competition because of high total generating cost, the lack of waste disposal plans and facilities, and other impediments. A political impasse to the use of nuclear power exists in many OECD countries. But competition's spur to innovation in existing plants will help economic prospects for new plants.

Safety has always been given the highest priority in nuclear power development in OECD countries This will not change under competition. Safety regulators will continue to have the authority and ability to ensure safety, though they will face new challenges to adapt to the changing commercial environment. Safety regulators must make an effort to adapt to competitive markets, just as plant operators must. Competition is likely to improve the regulatory process.

Stranded nuclear assets reflect some of the past difficulties of building nuclear power plants, and are embarrassing to the nuclear industry as it makes its case for continued development. They arise because of the transition to competitive markets. But stranded nuclear assets do not reflect the economics of running existing plants or, necessarily, of building new ones. There are other transitional challenges in moving to competitive markets that take time to resolve.

Governments who wish to "keep the nuclear option open" should make sure that the government institutions involved in nuclear power, especially and foremost nuclear safety institutions, adapt to competitive markets as quickly as nuclear utilities. Competition will reveal if the economic outlook for new nuclear plants is really as difficult as it appears to many today. Regardless of current evaluations of nuclear power's economics, competition will provide a strong impetus for cost reduction and innovation, perhaps laying the economic foundation for a stronger nuclear power industry in the future.

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