NUCLEAR POWER PROSPECTS IN THE CONTEXT OF ENERGY TRENDS

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In order to put the prospects for nuclear energy development into perspective, I wish to briefly present the overall trends in energy demand and supply world-wide. I will highlight the key issues and the factors affecting energy policies and choices between alternative sources with emphasis on the electricity sector which is the main market for nuclear energy in the short and medium terms. I will elaborate on the role that nuclear energy could play in future energy mixes and on the opportunities and challenges for nuclear energy development. This presentation draws on statistical data and analytical work published by my own organisation, the OECD Nuclear Energy Agency, as well as by other authoritative international sources such as the International Energy Agency (IEA), the World Energy Council (WEC), and the International Institute of Applied Systems Analysis (IIASA).

ENERGY DEMAND AND SUPPLY

A snapshot of the present energy demand situation in the world indicates a sharp contrast between different regions of the world in terms of per capita energy consumption, with OECD countries consuming on average some nine times more energy per inhabitant than developing countries. This signals the likely evolution of demand in the coming years and decades. The trends in energy consumption and use over the last decades show the links between social and economic development on the one hand and adequate access to energy and electricity supply on the other. Economic growth will remain a major goal especially in non-OECD countries and adequate energy supply will be essential to meet this objective.

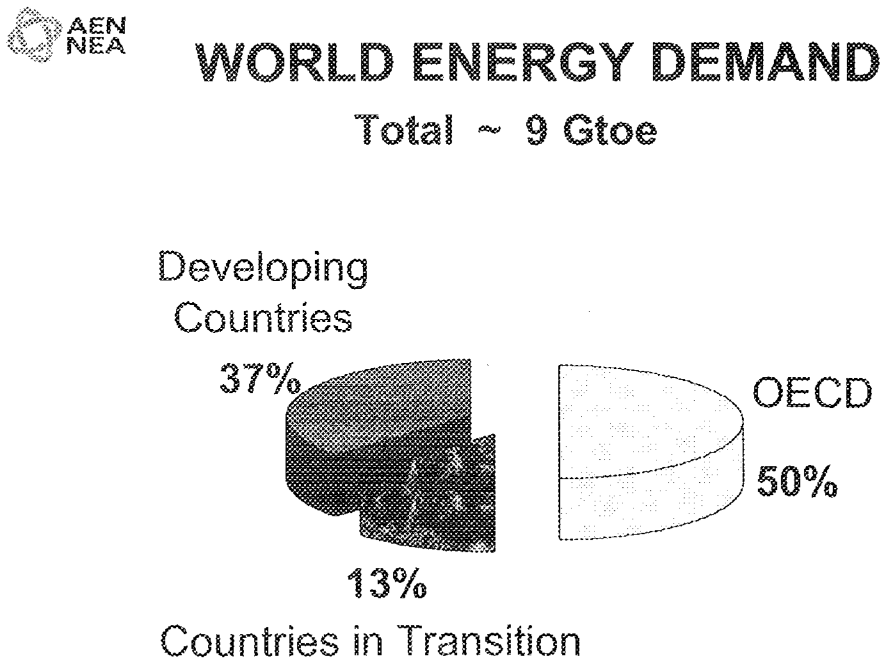
Roughly 20% of the world population consumes 80% of the world energy production at present. At the same time, one-third of the six billion world population is denied access to any form of commercial energy. Most of this population is in developing countries which account for some 90% of current population growth. By 2020, world population will have increased by two billion and world energy consumption at that time will have increased by 50% from present levels.

Total primary energy consumption world-wide exceeds 9 Gigatonnes of oil equivalent (Gtoe), of which around 50% is consumed by OECD countries, 13% by countries in transition, including Eastern Europe and the former Soviet Union, and 37% by the rest of the world, essentially developing countries including the People's Republic of China [1]. The average energy consumption per capita varies from less than 0.6 tonnes of oil equivalent (toe) in developing countries, to around 3 toe in countries in transition and more than 4.5 toe in OECD countries.

[1] International Energy Agency, World Energy Outlook, OECD, Paris (1998).

WORLD ENERGY DEMAND

Total ~ 9 Gtoe



Turning to electricity demand, a steady increase has been noted, showing a more rapid progression than either GDP or primary energy demand. While energy demand for stationary uses in the industrial, agricultural, commercial and residential sectors tends to remain stable, electricity demand is increasing steadily with income. Electricity intensity has increased practically everywhere in the world, in spite of efficiency gains, owing to electricity being substituted for other direct energy sources, in particular for direct fossil fuel burning.

Between 1971 and 1995, the average electricity demand growth rate in the world has been 3.8% per annum, as compared with 2.2% per annum for primary energy demand. In developing countries the annual growth rate was 7.5% for electricity compared with 5.5% for primary energy. Moreover, in those countries, electricity consumption is currently constrained by supply and would grow more rapidly if adequate capacity was to be available. In OECD countries, electricity demand grew by 3.1% per annum as compared with 1.4% per annum for primary energy; however, as possible substitutions are progressively exhausted, electricity intensity is tending to stabilise. Further substitutions remain possible in developing countries.

Practically all studies on future energy demand foresee continued growth. The expected increase in total and per capita energy consumption in developing countries, driven by their population and economic growth during the next century, will be key driving forces for future energy demand. The IIASA/WEC study [2], for example, points to significant energy demand growth for several decades even in ecologically driven scenarios. Although energy intensities (i.e. energy requirements per unit of gross domestic product, GDP) decrease when income increases, intensity improvements cannot be gained indefinitely.

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[2] International Institute for Applied Systems Analysis, Global Energy Perspectives, Cambridge University Press, Cambridge, UK (1998).

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DEMAND GROWTH RATES 1971-1995

	Energy	Electricity
World	2.2%	3.8%
OECD	1.4%	3.1%
Developing Countries	5.5%	7.5%

On the supply side, fossil fuels remain by far the largest contributors to energy supply world-wide although nuclear and hydro powers provide significant shares of the total. Other renewable energy sources, in spite of noticeable recent technology progress for some of them, are only marginal in the overall basket of supply sources. The status and trends in energy supply also highlight the growing importance of electricity as an energy carrier.

At present, fossil fuels (i.e. coal and hydro-carbons) represent more than 80% of total world primary energy supply. Oil is the largest contributor (some 36%), owing mainly to its currently non-substitutable uses in the transport sector. Coal and other solid mineral fuels, such as lignite and peat, supply some 25% of the world primary energy supply but their share exceeds 60% in China and some other developing countries. Renewable energy sources, mainly hydro power and traditional biomass, account for some 12%. Nuclear energy represents some 7% at the world level and more than 11% in OECD countries where some 85% of the nuclear power capacity is concentrated.

There is a wealth of accessible energy resources and technologies available on our planet and these are more than adequate to meet the expected demand, even in the very long term. Coal, gas and oil proven reserves are estimated to represent respectively more than 200, some 65 and some 40 years of present annual production [3]. Known uranium resources recoverable at costs lower than 130 $/kgU represent around 80 years of present consumption. However, resources of nuclear fuel, including uranium, thorium and recycled fissile materials, are sufficient to support large-scale nuclear power use over hundreds of years. Resources are sufficient for longer if mineral extraction activities were to be developed or if breeder reactor technology were to be widely deployed. Finally, renewable energy sources are by definition non-exhaustible and could, in principle, contribute to meet demand if and when technological progress would allow their economic exploitation. However, economic, technical and

[3] British Petroleum, BP Statistical Review, BP, London (1998).

environmental challenges will have to be faced in order to make those resources available.

Factors Affecting Energy Policies

The evolution of energy supply mixes and the rate of change between alternative sources or technologies, including demand side management, have been driven by a number of factors that vary from region to region and country to country over time. Although energy policies differ in specific situations and contexts, driving factors are similar in all countries.

Competitiveness remains the established cornerstone in policy making but the framework within which comparative economic assessments are conducted is evolving. In the electricity sector, economic deregulation, privatisation and the introduction of competition are changing the landscape and criteria of choice. Also, the increasing awareness of environmental issues and more broadly the sustainability goals, including long-term security of supply and protection of people and eco-systems, are giving a stronger weight to non-economic criteria in energy policy making.

Today, energy policy making is characterised by an emphasis on market mechanisms for promoting optimised energy supply mixes, in particular for electricity generation. The introduction of a competitive market to the electricity sector is expected to yield higher economic efficiency as costs previously supported by taxpayers or captive consumers will be shared by shareholders and by consumers who will be able to choose between alternative suppliers. At the same time, explicitly integrating the concept of sustainable development in energy policies is calling for strategies that preserve natural resources and the environment, reduce regional disparities and give equal opportunities to present and future generations world-wide.

The key factors affecting the economics of electricity generation sources and technologies are essentially fossil fuel prices, total capital costs and expected rates of return on investments, and technological performance, e.g., thermal efficiency, availability factor and technical lifetime of power plants.

At present, low fossil fuel prices are challenging the economic viability of nuclear and renewable energies for new electricity system projects. For example, the competitive margin of new (to be built) nuclear units versus gas-fired power plants, which was quite significant until the mid-1990s, has disappeared in most countries at present gas prices. In a long-term perspective, however, energy policies have to take into account uncertainties over future fossil fuel prices as compared with stability of nuclear generated electricity costs.

Economic deregulation in the power sector reduces and should eventually eliminate captive markets upon which utilities enjoying a monopoly used to rely for guaranteed future demand. This increases the financial risk associated with capital intensive technologies. The main alternatives for base-load electricity generation, namely coal-fired, gas-fired and nuclear power plants, have different costs structures with relative shares of capital costs varying widely from technology to technology. For nuclear power plants, investments account for some 65% of total levelised costs of electricity generation while operation, maintenance and fuel costs together represent some 35%. Gas-fired power plants, at the other extreme of the range, have low capital intensity, with investment costs representing around only 15% of electricity generation costs, while fuel with operation and maintenance costs account for some 85%. In a fully competitive market with uncertain future demand, gas-fired power plants are attractive because of their relatively small size, short construction time and low investment costs that can be amortised quickly reducing significantly the financial risk supported by the generating company shareholders.

The cost of capital depends largely on the rate of return expected by investors. The global financial market generally requires higher financial returns than governments accept and the acceptance of these may modify the ranking of electricity generation options. For capital intensive technologies such as nuclear power, the impact of higher rates of return on total generation costs is adverse and very significant.

The trend to higher profitability and an emphasis on the short-term conflicts with many of the policy issues with which governments are primarily concerned in overseeing competitive energy markets. These are the trade balance considerations, security of supply, environmental and social issues which would favour the use of a lower discount rate than that sought by the world's financial markets.

Security of supply has been an explicit objective of energy policies in many countries since the early 1950s. In many countries, this led energy policies to aim at diversification of supply with emphasis on substituting alternative sources, preferably domestic, to imported hydro-carbons. For example, in countries such as France and Japan where indigeneous fossil fuel and hydro power resources are very limited, energy independence and security of supply were key factors in the decision to implement nuclear power programmes. Although recently concerns over security of supply seem to have vanished, balanced and diversified energy mixes remain a relevant goal for national energy policies.

The extent to which higher priority on environmental protection and long-term sustainability will affect energy and electricity policies is difficult to predict and the outcomes are likely to differ from country to country and over time. Uncertainties over the impacts of energy-related environmental burdens remain quite large, in particular with regard to greenhouse gas emissions and the threat of global climate change. However, as a clear trend emerges at the international level to tackle ways to control CO_2 emissions from industrial activities, energy sources having lower emissions are likely to be chosen whenever technically feasible and economically competitive. From this point of view, the incorporation of externalities associated with, for example, impacts of carbon dioxide and other atmospheric emissions, in the costs borne by electricity producers and passed along to consumers, offers particular opportunities to reinforce the competitiveness of nuclear power and renewable energy sources.

OPPORTUNITIES AND CHALLENGES FOR NUCLEAR ENERGY

According to the IIASA/WEC study [2], a 1.5 to 3 fold increase in primary energy demand is expected by 2050. The increasing demand for energy, in particular electricity, creates opportunities for all energy sources and technologies, including fossil fuels, nuclear and renewables. However, each source and technology will have to face specific challenges to realise its potential and be part of the energy mixes of choice for the next century.

In only a few decades, nuclear energy has reached the status of a mature technology, representing a 7% share of world primary energy consumption and 17% of world electricity supply. However, most of the nuclear energy capacity (i.e. 85%) is located in the OECD area where the industrial infrastructure is in place for supporting nuclear power programmes. Since the demand for additional power capacity mainly will come from non-OECD countries, there are opportunities for the development of nuclear energy in those countries, provided technology adaptation and transfer will occur timely. Also, in 11 OECD countries, the nuclear share of electricity production exceeds 20% of the total, with the share in some of them like France, Belgium and Sweden peaking at 78%, 60% and 46% respectively. This shows that there are opportunities for nuclear power to substitute other generation sources and increase its share of total generation in many countries.

Nuclear energy enjoys favourable conditions in terms of resources. The raw material for present nuclear fuel, uranium, is relatively abundant and widely distributed on the planet and has no other possible use. Although with current technologies, known uranium resources would not be sufficient to support significant development of nuclear power beyond the first half of the next century, additional resources can be expected to be discovered and economically exploited in the long term. Furthermore, improved fuel design and management, and advanced reactors, offer ways to reduce significantly the amount of natural uranium required per unit of electricity generated. In the long term, thorium fuelled reactors and fusion could enlarge even further the nuclear resource base. The wide geopolitical distribution of uranium-producing countries is also a positive factor for importing countries in terms of diversity and security of supply.

Another favourable characteristic of nuclear power attracting attention from public and policy circles is its absence of CO_2 emissions and other atmospheric releases. Two countries with large nuclear programmes provide highly illustrative examples. In France, between 1980 and the mid-1990s, emissions were reduced by a factor of four for carbon dioxide, nine for sulphur dioxide, and ten for particle emissions from the power sector. In Sweden, energy-related CO_2 emissions have been reduced by more than 40% between the early 1970s and the early 1990s, owing essentially to a switch from oil to nuclear and hydro power for electricity generation.

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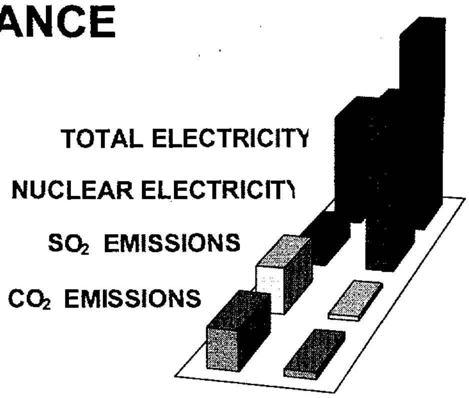
NUCLEAR POWER AND ATMOSPHERIC EMISSIONS

FRANCE



As already mentioned, the competitive edge of nuclear power has been impaired by the dramatic decrease in the cost of fossil fuels in recent years. On the other hand, the cost structure of nuclear electricity includes a large part of capital investment, which by itself is a factor of long-term stability in electricity production costs. For existing nuclear power plants, once capital costs are largely amortised, competitiveness based on marginal cost of production is generally largely ensured.

For new nuclear units, technology progress leading to enhanced economic performance may be expected in the light of the positive feedback from experience. Over the last decades, nuclear electricity generation costs have been reduced continuously. Uranium prices and fuel cycle service costs have decreased [4] while efficiency gains in reactor operation have lowered operation and maintenance costs. The experience of countries such as France, Japan or the Republic of Korea shows that nuclear power plant investment costs can be reduced by standardisation and efficient management. Extension of plant lifetime from 30 to 40 years or more is now considered to be safe and feasible in most OECD countries. Additionally, new reactor designs are being developed which aim to reduce the capital costs of plants while increasing safety.

Increasing pressure for "getting the prices right", in particular by internalising externalities such as costs associated with environmental impacts from burning fossil fuels, offers an opportunity for nuclear energy to regain its competitive margin. External costs from nuclear electricity production do not exceed 1% of direct costs, and greenhouse gas emissions from the overall nuclear cycle are minimal. On the other side, allocating a value to carbon would immediately increase the cost of fossil-fuelled electricity generation. The last OECD study on projected costs of generating electricity [5] shows that the cost ratio between nuclear and gas generated electricity does not

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[4] Nuclear Energy Agency, The Economics of the Nuclear Fuel Cycle, OECD, Paris (1994).

[5] International Energy Agency, Nuclear Energy Agency, Projected Costs of Electricity Generation: Update 1998, OECD, Paris (1998).

exceed 1.5, except in the United States with a discount rate of 10%. In this context, a carbon value of 100 $/tC or more would make nuclear power cheaper than gas practically everywhere.

While there are opportunities, the actual role of nuclear power in global energy supply to 2050 and beyond will depend on the ability of governments and the nuclear industry to address a number of challenges, including to maintain the nuclear option for the long term in spite of an expected slow-down in the next two decades and to enhance public acceptance by addressing in a credible way concerns on safety, radioactive waste disposal and nuclear weapon proliferation risks.

Since the late 1980s, nuclear development has reached a plateau and the number of nuclear units under construction or planned has decreased steadily. Today, while there are more than 400 reactors in operation in the world, less than 40 are under construction. As a result, taking into account the ageing of existing units, five were shut down in 1998, the installed nuclear capacity world-wide will not increase in the short term. The International Energy Agency foresees a mere 0.6% growth of nuclear electricity world-wide until 2010, falling to zero growth at the 2020 horizon [**Error! Unknown switch argument.**]. This trend will be even more visible in OECD countries, with only the Asia-Pacific region expanding its nuclear electricity capacity during this period.

Maintaining adequate infrastructures during the stagnation period is essential to support a successful revival of nuclear power programmes beyond 2015-2020. Continued research and development efforts is needed not only to ensure the safe and economic operation of existing nuclear power plants but also to prepare the next generation of nuclear reactors. The educational framework to provide suitably qualified manpower in sufficient quantity is a prerequisite to continued R&D, development and implementation of advanced nuclear technologies.

Safety remains a challenge although the level of safety of existing plants, particularly in OECD countries, is very high and the safety record of nuclear power has generally been satisfactory [[6]]. Key issues in this regard include maintaining nuclear safety research and regulatory effectiveness in a context of deregulation and privatisation, addressing specific problems related to the ageing of existing plants, ensure that new reactor designs meet increasingly stringent safety standards while achieving good economic performance. Also, organisational issues, such as preserving and enhancing safety culture, and maintaining an adequate level of competence and capability need to be adequately addressed. Safety standards in non-OECD countries have not always measured up to standards in OECD countries. However, international co-operation and assistance programmes put into place since the Chernobyl accident, the broad adoption of safety culture world-wide, and the entry into force and implementation of the Nuclear Safety Convention have improved the situation considerably.

Another challenge is to demonstrate that all radioactive waste can be disposed of without causing detriment to humans and the biosphere in the distant future. Considerable experience has been gained in recent years in the industrial conditioning, storage and disposal of low and medium-level radioactive waste. Experts are confident that safe solutions exist for the management of high-level, long-lived waste; however,

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[[6]] Nuclear Energy Agency, Derestriction of a Collective Opinion by the Committee on the Safety of Nuclear Installations (CSNI) on Nuclear Safety Research in OECD Countries, NEA/NE(96)7/REV1, Paris, France, 1996

for this latter category, demonstration that solutions can be implemented, that are scientifically sound, technically reliable, and socially and politically acceptable, has not yet been fully achieved.
Nuclear fission, being a high density energy source, generates less solid waste than most alternatives. One kilogram of uranium produces more than 10 000 times more electricity than one kilogram of fossil fuels or biomass. Therefore, solid waste arising from the nuclear chain represents small volumes as compared with those produced by most alternative generation sources. A 1 GWe coal-fired power plant generates some 350 000 tonnes of solid waste per year, including chemicals that remain toxic indefinitely. A nuclear power plant of the same capacity and its supporting fuel cycle facilities generate each year some 500 tonnes of low-level waste, 200 tonnes of intermediate-level waste and 25 tonnes of high-level waste when operated once through.

Owing to its small volume, nuclear waste can be isolated from the biosphere. A collective opinion published by the NEA, the European Commission and the IAEA in 1991 [7] confirms that safety assessment methods are available to evaluate the potential long-term impact of radioactive waste disposal systems on humans and the environment, and that appropriate use of such safety assessment methods, coupled with sufficient information about proposed disposal sites, can provide the technical basis to decide whether specific systems offer a satisfactory level of safety for current and future generations. A second collective opinion published by NEA in 1995 [8] addresses, specifically, the strategy for the final disposal of long-lived waste from both an environmental and ethical perspective, including considerations of equity and fairness within and between generations. It concludes that the geological disposal strategy can be implemented in a manner that is sensitive to fundamental ethical and environmental considerations, and that it is justified to continue development of geological repositories for such waste; indeed, the bottom line is that the implementation of high-level waste repositories is regarded by many as a prerequisite to demonstrating the sustainability of nuclear power.

While there is no doubt that nuclear power development would reduce the emissions of greenhouse gases and other atmospheric pollutants, radioactive emissions may raise concerns. However, the small quantities of radioactive materials released by nuclear reactors and fuel cycle facilities in routine operation are monitored and limited to levels believed to cause insignificant environmental and health damage on the basis of the recommendations from the International Commission on Radiological Protection as interpreted by national regulations. The collective doses resulting from nuclear industry emissions of radioactivity are monitored and assessed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). In its 1994 report [9], the UNSCEAR assessment showed that the collective effective dose committed to the world population by a 50-year period of operation of existing nuclear power facilities, i.e., power plants, uranium mining and other fuel cycle facilities, is 2 million man-Sieverts (man-Sv) as compared with 650 million man-Sv committed by natural background radiation. That is, the dose commitment from natural background radiation is 325 times higher than that from the world's entire nuclear power industry. Therefore, even if it is assumed that there would be no reduction in the nuclear industry's

[7] Nuclear Energy Agency, et al., Disposal of Radioactive Waste: Can Long-Term Safety be Evaluated? An International Collective Opinion, OECD, Paris, France, 1991

[8] Nuclear Energy Agency, The Environmental and Ethical Basis of Geological Disposal: A Collective Opinion of the NEA Radioactive Waste Management Committee, Paris, France, 1995

[9] United Nations Scientific Committee on the Effects of Atomic Radiation, Ionising Radiation: Sources and Biological Effects, UNSCEAR, New York, USA, 1994

radioactive emissions per kWh (even though at present there is a trend towards decreasing emissions per kWh), nuclear electricity generation could reach 750 thousand TWh per year as compared to less than 2.5 thousand TWh per year in the late 90s without leading to a population dose higher than that from the natural background.

Concluding Remarks

In order to meet growing energy and electricity demand, sustainable energy supply systems relying on a mix of available sources and technologies will need to be developed. The share of nuclear energy, currently contributing 17 per cent of the electricity supply world-wide, could be increased significantly thereby contributing significantly to reducing the carbon intensity of energy supply systems. Scenarios developed by my Agency and the IAEA as well as those published by IIASA/WEC show that it is technically and economically feasible to reach nuclear capacities exceeding 1 000 GWe in the world by 2050 and that nuclear electricity generation growth would reduce carbon dioxide emissions.

However, the current drive for competition in electricity markets is emphasising short-term direct cost considerations, rapid return on investments and flexibility of supply systems. This context is not favourable to capital intensive technologies not to large size power plants such as most nuclear units presently available on the market.

In the longer term, the combination of the desire to conserve fossil fuels, which are valuable raw materials, the commitment to keep carbon dioxide emissions below specified levels, according the decisions taken within the UNFCCC, will provide a stronger incentives for the development of nuclear power.

The challenge is to maintain the nuclear option available for the longer term, which means keeping alive nuclear infrastructure, and, in particular, the ability to develop new reactors and fuel cycle technologies in spite of the expected short-term stagnation of nuclear power programmes in most countries.