NUCLEAR ENERGY IN FUTURE SUSTAINABLE, COMPETITIVE ENERGY MIXES

Luis Echávarri, Director-General, OECD/NEA

It is a pleasure for me to participate in this Conference and to share with you some views and findings drawn from the work of the Nuclear Energy Agency of OECD (NEA) on the future of nuclear energy. This meeting "ENC 2002" is a very timely event that offers a forum to investigate new opportunities and challenges for nuclear energy at the turn of the millennium. I am sure that presentations and discussions among experts during the coming days will enhance international co-operation in the field of nuclear energy, an objective which is central to the NEA mandate and scope of work.

The present energy policy landscape can be characterised, in particular in OECD countries, by economic deregulation and the emerging importance of sustainable development goals. These trends are affecting already technology choices and will continue to modify the attitude of the public and decision makers towards nuclear energy. Simultaneously, the signs of a nuclear energy renaissance worldwide, on which I will elaborate later with a few key examples, provide confidence that nuclear energy technology will be up to the expectations of society in the 21st century.

As an introduction, I would like to remind you of some facts and figures illustrating the present role and status of nuclear energy in OECD countries and worldwide. Nuclear energy is now an established component of electricity supply in OECD countries where it provides nearly a quarter of electricity supply [1]; worldwide nuclear energy represents 16% of total electricity consumption. More than half of the OECD countries – 17 out of 30 – rely on nuclear energy for part of their electricity supply and in 10 of these countries the nuclear share in electricity generation exceeds 30% (Figure 1).

The maturity of nuclear energy technology is based upon extensive experience with more than 8 000 reactor years of cumulated operation in OECD countries and nearly 10 000 reactor years worldwide. The continued increase in average availability factor of nuclear power plants is a good indicator of the steady progress of nuclear performance. In 2001, for all 438 nuclear power plants in operation, the average availability factor exceeded 83% (Figure 2) and in several OECD countries, including the United States where more than 100 units are in operation, it was close to or above 90%.

The excellent safety records of nuclear power plants and fuel cycle facilities demonstrate the effectiveness of stringent regulations in place in OECD countries and of the concerted effort of industry and regulators to implement a robust safety culture. As a consequence of this effort and of technology progress, the impacts of nuclear energy facilities on human health and the environment are kept extremely low. The data collected through the joint NEA/IAEA Information System on Occupational Exposure (ISOE) illustrate this point with regard to workers in the nuclear energy industry [2]. They show a steady decrease of occupational exposures in nuclear power plants and fuel cycle facilities since the late 80s (Figure 3).

The technical progress achieved by the nuclear industry through scientific research and feedback from experience covers a wide range of issues such as increasing fuel performance and burn-up, enhanced plant reliability, reduction of radioactive waste volumes and toxicity, capacity up-rating and life extension. Regarding reliability for example, the latest statistics from the World Association of Nuclear Operators (WANO) [3] show that since 1997 the number of unplanned automatic scrams per 7 000 hours critical has remained equal to or below 0.9 for the more than 420 units reporting this information (Figure 4).

Nuclear power plant lifetime extensions are in the process of licensing or already authorised in many countries, including the United Kingdom and the United States, where the safety authority, the US Nuclear Regulation Commission (NRC), has authorised several life extensions up to 60 years. With more than half of the reactors in operation worldwide being less than 20 years old (Figure 5), it means that nuclear energy will continue to play a role in electricity supply for several decades.

Although technical performance is essential for the future development of nuclear technology, it is economic competitiveness, the central theme of this afternoon session, that is the real key for nuclear energy renaissance to become a reality. In this connection, I would like to stress that existing nuclear power plants are an economic asset and perform well in deregulated electricity markets. Indeed, nuclear power plants in operation are competing successfully with alternatives even in countries, such as the United Kingdom, where the electricity market has been fully liberalised.

Nuclear power plants are characterised by low marginal production costs and high reliability that give them a robust advantage on open markets. In addition, market competition has led operators to enhance their efficiency and resulted in many cases in significant decrease of marginal production costs of nuclear units. This trend may be illustrated by the data published in the United States [4] indicating that average marginal production costs of nuclear power plants have decreased by some 50% in constant terms since the end of the 80s (Figure 6).

In the long run, once the capital costs, that represent some 60% of their levelised generation costs, have been incurred, nuclear units become the cheapest electricity source in most networks. This is an incentive for plant owners and operators to invest in refurbishment, upgrading and life time extension, which often are the most cost effective means to increase their power capacity and electricity generation. Examples are provided by utility policies and decisions in a number of OECD countries such as Spain, Sweden, Switzerland, United Kingdom and the United States.

The competitiveness of nuclear energy depends not only on its own performance but also on how alternatives perform. While low fossil fuel prices have reduced the competitive margin of nuclear energy in recent years, the volatility of oil and gas prices over several decades has demonstrated the advantage of nuclear energy for electricity generation cost stability. A doubling of gas price, that may happen anytime as shown by past experience in international hydrocarbon markets, would add 70 to 80% to the cost of electricity generated by combined cycle gas turbines. On the other hand, a doubling of uranium price, a very unlikely event in the present market conditions, would only increase the cost of nuclear electricity by some 5%.

Last but not least regarding competitiveness, external costs and subsidies raise economic and environmental issues that will have to be addressed by policy makers in a sustainable development perspective. The internalisation of external costs, or benefits, are a prerequisite for ensuring that price signals to consumers are correct and that market mechanisms operate according to global social optimisation. Removal of subsidies and internalisation of external costs likely would affect adversely the competitiveness of most alternatives versus nuclear energy as illustrated on Figure 7.

The historical government support to nuclear power development no longer exists in OECD countries where applied nuclear energy R&D is financed mainly by the industry. Safety and radiation protection norms and regulations internalise *de facto* the cost of health and environmental protection in the case of nuclear power plants and fuel cycle facilities. Also, the costs of plant decommissioning, and radioactive waste management and disposal, are internalised in the prices paid by nuclear electricity consumers as a charge (fee or levy added to direct costs) that feeds into the funds established for discharging in due course future financial liabilities.

Furthermore, with the prospect of implementing the Kyoto Protocol, reducing greenhouse gas (GHG) emissions may become a key objective of energy policies in OECD countries, and carbon emitting technologies might be penalised accordingly. Nuclear energy, on the other hand, is a nearly carbon free source that contributes to alleviating the risk of global climate change. Worldwide, GHG emissions from the energy sector are already 8% lower than they would be without nuclear energy (Figure 8).

A report prepared by NEA on nuclear energy and the Kyoto Protocol [5] was published by OECD in connection with the World Summit on Sustainable Development, held in Johannesburg (South Africa) from 25 August to 4 September 2002 [5]. It stresses that the Kyoto Protocol incorporates conditions that effectively exclude nuclear energy as an option under two of the flexible mechanisms that can be used by Annex I Parties to the United Nations Framework Convention on Climate Change. However, the benefit that nuclear energy brings in terms of reducing carbon dioxide emissions can help countries that will construct new nuclear power plants to meet their Kyoto targets through domestic measures.

While the entry into force of the Kyoto Protocol enhances the immediate relevance of nearly-carbon free technologies such as nuclear energy, the possibility for nuclear energy to make a significant contribution to the reduction of GHG emissions will be more important after the Kyoto Protocol compliance period (2008-2012). In the longer term, as the demand for energy will increase, nuclear energy may increase its supply share and its role in sustainable energy mixes.

The achievements of nuclear power plants in operation today are contributing to the credibility of nuclear energy as a major option for the future. We know already that, up to 2010-2020, nuclear energy will maintain its role in energy supply mainly through capacity upgrade and lifetime extension of existing plants. In addition some new units are being or will be built in the very near term; their construction and operation is bringing additional experience on advanced evolutionary nuclear systems and paving the way for the renaissance of nuclear power.

Recent trends, illustrated by the willingness of the Finnish industry to launch a 5th nuclear unit, show the viability and competitiveness of nuclear energy. Other speakers this afternoon will elaborate on the progress made and the reasons why new reactor designs ready to be commercialised are expected to compete favourably with alternatives. I'd like to look a bit farther down the road focusing on reactors of the 4th generation, since the role of intergovernmental organisations like mine includes working on long-term options.

In order to meet the requirements of 21st century society and markets, nuclear energy systems of the future should have high potential for: economic competitiveness; sustainable use of natural resources including the environment; proliferation resistance and physical protection; and safety and reliability. The goals fixed by the Generation IV International Forum (GIF) [6] for the next generation of nuclear energy systems illustrate the key objectives of ongoing R&D in several countries and within international initiatives (Figure 9).

The industrial nuclear power plants and fuel cycle facilities that today generate cheap, safe and reliable electricity are based upon scientific research and technical development undertaken as early as the beginning of the 20th century. The future of nuclear energy in the 21st century and beyond depends on research programmes that are undertaken today. There is a wealth of potentials offered by nuclear energy that could become a reality in the 21st century, provided that adequate scientific research is undertaken and timely technological development is carried out.

Ongoing R&D programmes on nuclear energy systems for the future are focusing on responding to society needs and concerns. Accordingly, efficient use of natural resources, reduction of volumes and toxicity of radioactive waste, safety systems minimising the risk of off-site impacts of accidents are key goals of innovative nuclear reactors and fuel cycles.

R&D efforts under way on nuclear energy systems cover a broad range of reactor technologies and fuel cycle options and rely on a wide variety of evolutionary and innovative approaches (Figure 10). Concepts considered by research teams range from classic water cooled reactors incorporating innovative options, such as the integral pressurised water cooled concepts, to radically non-classical approaches such as vapour core, molten-salt cooled reactors, through high temperature reactors and liquid metal cooled reactors with advanced fuel cycle options such as pyroprocessing technologies.

While planning and implementing new nuclear R&D programmes, it is important to recognise that the capability to provide energy products, such as domestic and industrial heat, desalinated water and eventually hydrogen, will be essential for the successful deployment of new nuclear energy systems. The possibility to supply a range of energy services in addition to electricity will open additional market shares and enhance the competitiveness of nuclear energy systems.

The ongoing R&D programmes on high temperature gas-cooled reactors are illustrative of some prospects for innovative technologies to penetrate the markets of the new century. Gas cooled reactors offer significant advantages in terms of thermal efficiency and may be used for high temperature process heat applications and direct hydrogen production as well as for electricity generation. Major technological progress in process and component design have led already to promising development during recent years in terms of their economics and safety features.

The use of nuclear reactors for heat applications is especially favourable in the case of high temperature reactors but is possible also with other reactors. However, the viability and economics of those applications will depend on the adaptation of nuclear technologies to the constraints of heat markets. For example, nuclear district heating may be considered, as demonstrated by experimental projects in some countries, but will require the development of economically competitive small and medium size reactors, a few hundreds of MWth, with safety characteristics allowing their construction close to urban areas.

In order to address new challenges of deregulated markets, innovative reactor designs should enhance economic competitiveness and reduce financial risks of nuclear energy. This implies significant capital cost reduction as compared with the present generation of reactors and enhanced flexibility, that could be obtained for example by modular units better adapted to decentralised electricity supply and uncertainties in demand.

Improved thermodynamic efficiency, provided for example by high temperature reactors, can contribute to better economic performance through higher total energy output per unit of fuel. The implementation of passive safety systems based upon natural convection circulation of fluids such as air, lead, molten salt or water for the transfer of decay heat to the environment under postulated accident conditions may bring significant economic savings.

Several innovative designs take advantage of supercritical conditions in the secondary system in order to increase thermodynamic efficiency and reduce costs. The design of reliable primary heat exchangers for operation under supercritical conditions, and the establishment of appropriate chemistry conditions and process control, will require significant development work but is expected to bring important performance enhancement.

The breeding capability of fast neutron reactors is extremely attractive in terms of natural resource utilisation and management; it may be exploited in the long term to secure energy supply when uranium resources will decrease leading to higher costs and eventually larger environmental impacts when lower grade ores will have to be extracted. Furthermore, liquid metal cooled fast reactors offer opportunities to manage plutonium and radioactive waste. They may be used for burning actinides and thereby reducing the burden of long-lived radioactive waste for future generations as well as reducing the stock of fissile materials (plutonium) when their core geometry and composition are set up for a conversion ratio lower than one.

The perception of civil society on nuclear energy and its risks as compared with alternatives is not only a driving factor in choices between different sources and technologies but has direct and indirect impacts on the economics of nuclear energy systems. Addressing public concerns about nuclear risks requires research in the fields of nuclear safety and radioactive waste disposal. Progress towards the implementation of deep geological repositories (e.g., Yucca Mountain in the United States, Olkiluoto in Finland) and research on innovative fuel cycles aiming at partitioning and transmutation of minor actinides are helpful in this regard.

In concluding my presentation, I would like to stress again that nuclear energy has very large potentials to supply increasing quantities of competitive and environmentally friendly energy services. It can provide a significant share of the energy products that people will need, such as heat, electricity, hydrogen and potable water, at affordable costs and without jeopardising natural resources and the environment. Realising the potentials of nuclear energy, however, will require sustained R&D efforts covering a wide range of disciplines and technologies.

International co-operation is essential for a successful renaissance of nuclear energy in the competitive context of the new millennium. Sharing experience, expertise and know-how across countries offers unique opportunities for synergy and cost effectiveness. Pooling resources together and carrying out jointly capital or manpower intensive studies not only reduces the cost for each participant country but also offers opportunities for creating more dynamic scientific teams in a multi-cultural environment.

The role of intergovernmental organisations such as the NEA is important in this regard. Given its experience in joint projects and its structure adapted to international co-operation, the NEA can play an important role as a catalyst in support of ambitious R&D endeavours for a successful future of nuclear energy. The expertise and management skills available within the NEA secretariat can provide interested Member countries with a robust and flexible framework to efficiently carry out background studies and co-ordinate research projects undertaken by various national teams and laboratories.

References

[1] Nuclear Energy Agency (2002), *Nuclear Energy Data*, OECD, Paris, France.

[2] International Atomic Energy Agency and Nuclear Energy Agency (2001), *Occupational Exposures at Nuclear Power Plants: Tenth Annual Report of the ISOE Programme*, 2000, OECD, Paris, France.

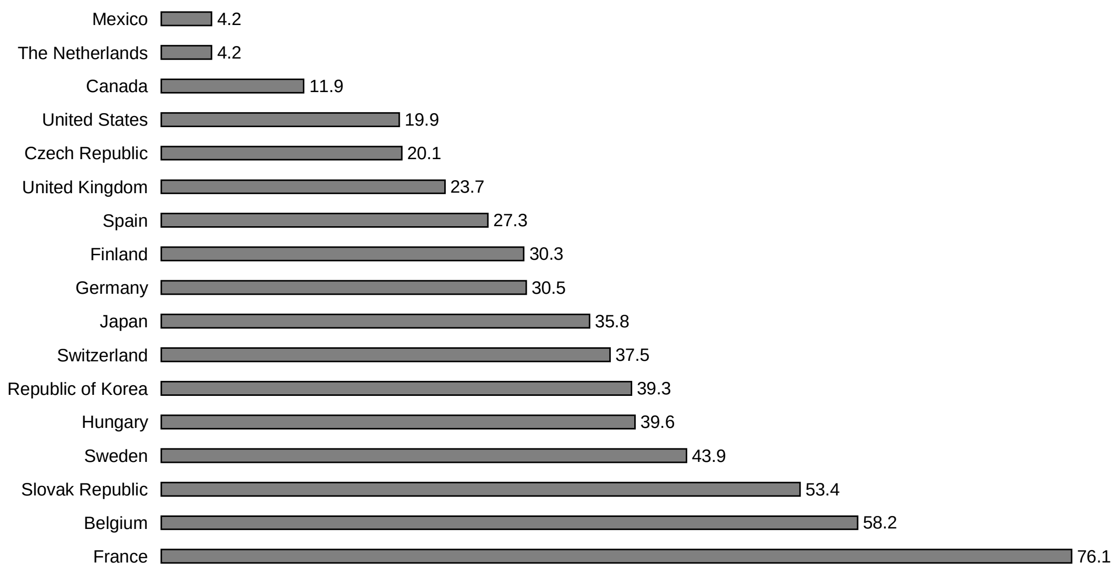
[3] World Association of Nuclear Operators (2002), website: http://www.wano.org.uk/index.asp

[4] Nuclear Energy Institute (2002), website: http://www.nei.org/default.asp

[5] Nuclear energy Agency (2002), Nuclear Energy and the Kyoto Protocol, OECD, Paris, France.

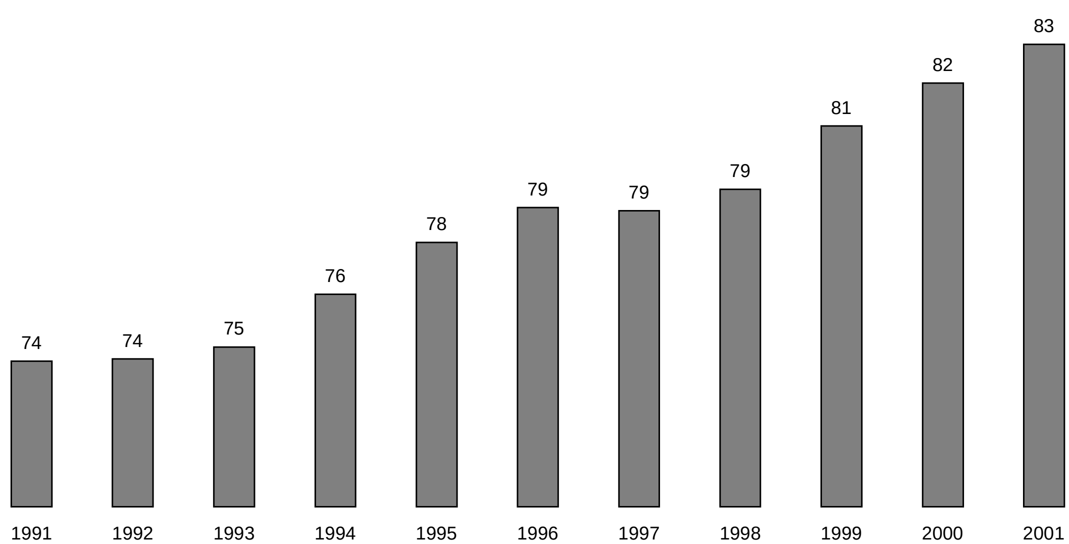
[6] Generation IV International Forum (2002), website: http://gen-iv.ne.doe.gov

Figure 1. Nuclear Share in Electricity Generation of OECD Countries in 2001 (%)



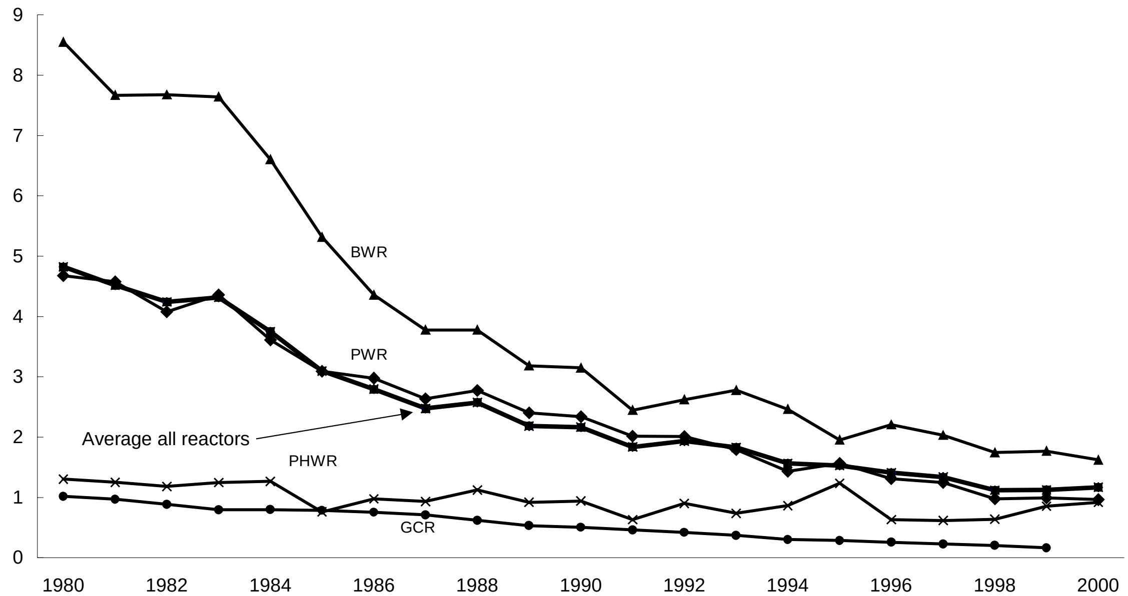
Source: OECD/NEA 2002

Figure 2. World Average Nuclear Power Plant Availability Factor (%)



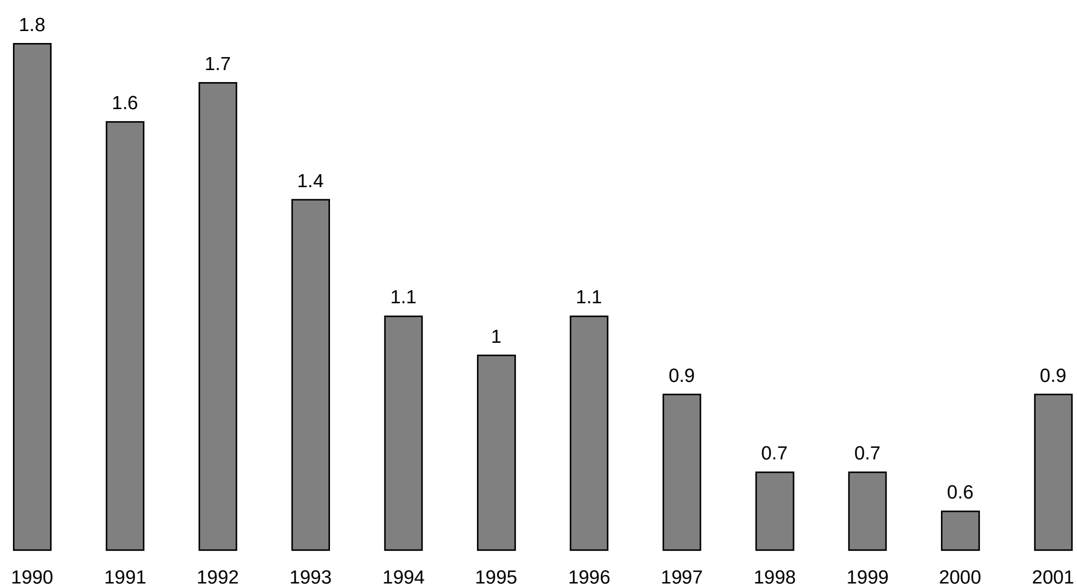
Source: IAEA/PRIS 2002

Figure 3. Average Occupational Dose per Reactor (man.Sv)



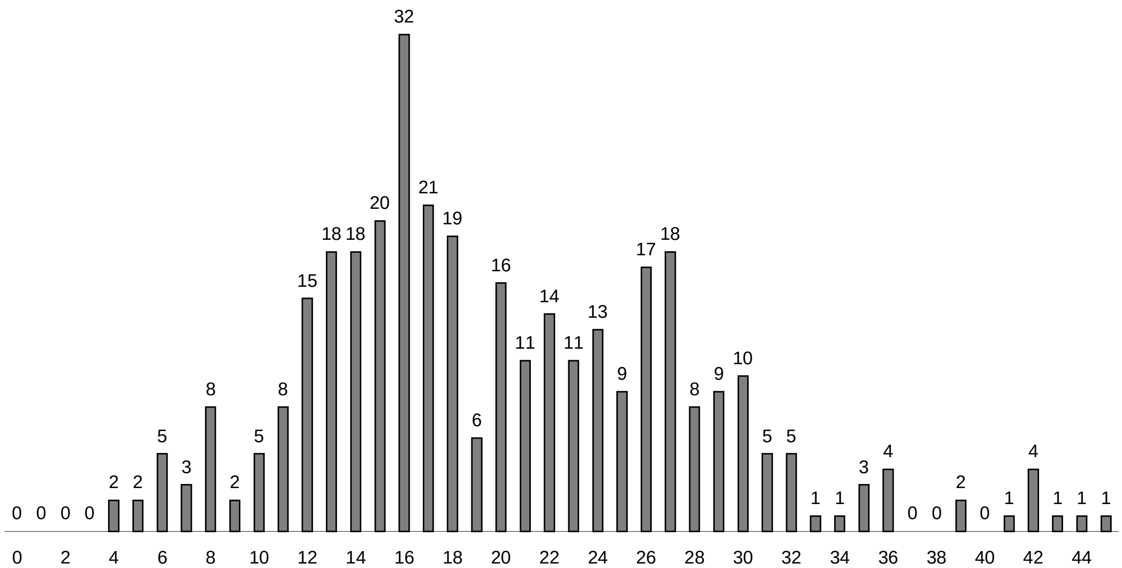
Source: ISOE 2001

Figure 4. Unplanned Automatic Scrams per 7000 Hours Critical



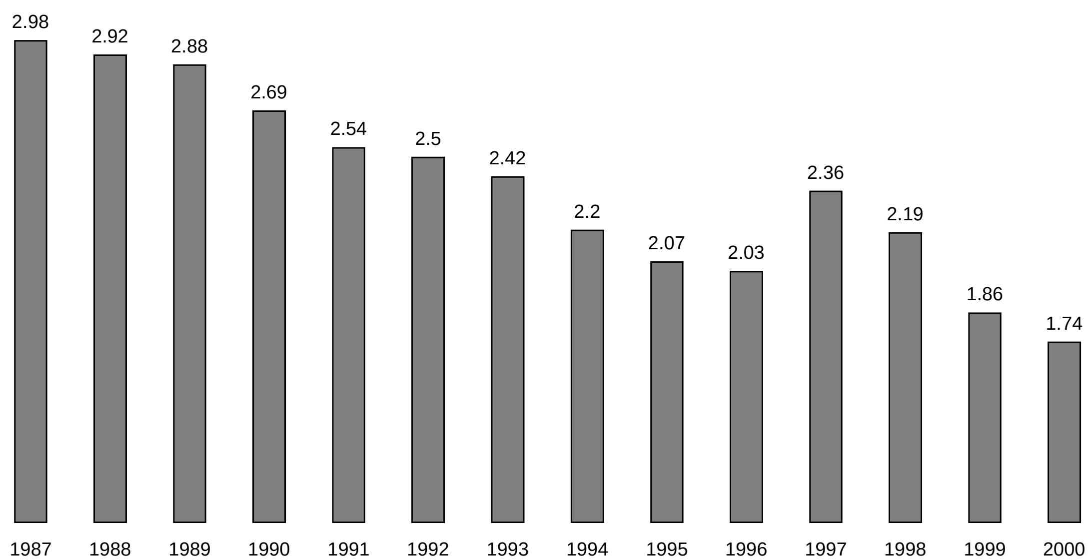
Source: WANO 2002

Figure 5. Number of Reactors in OECD countries by Age as of 1 January 2002



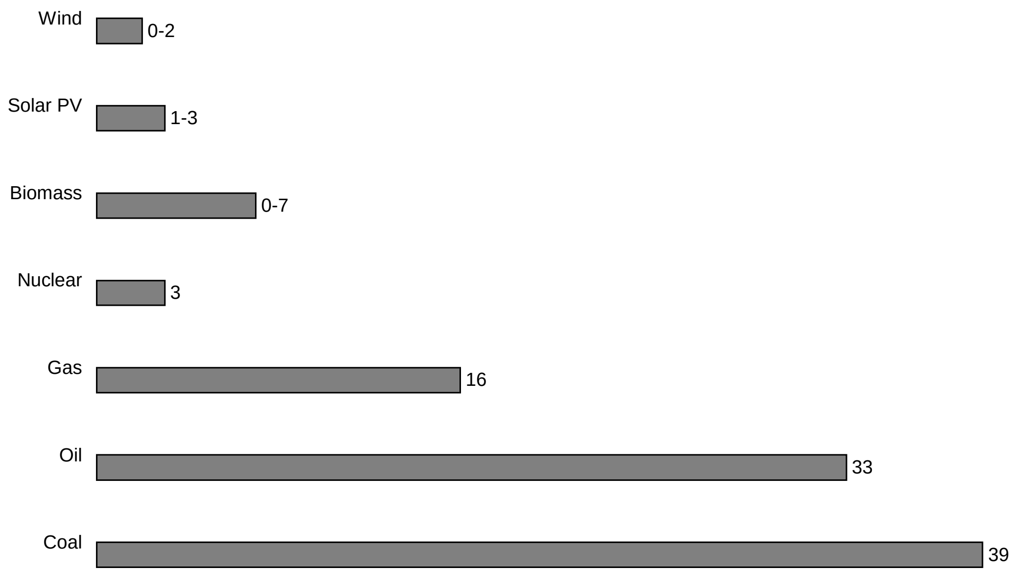
Source: OECD/NEA 2002

Figure 6. Average Production Costs (O&M + Fuel) of Nuclear Power Plants in the United States (UScents 2000/kWh)



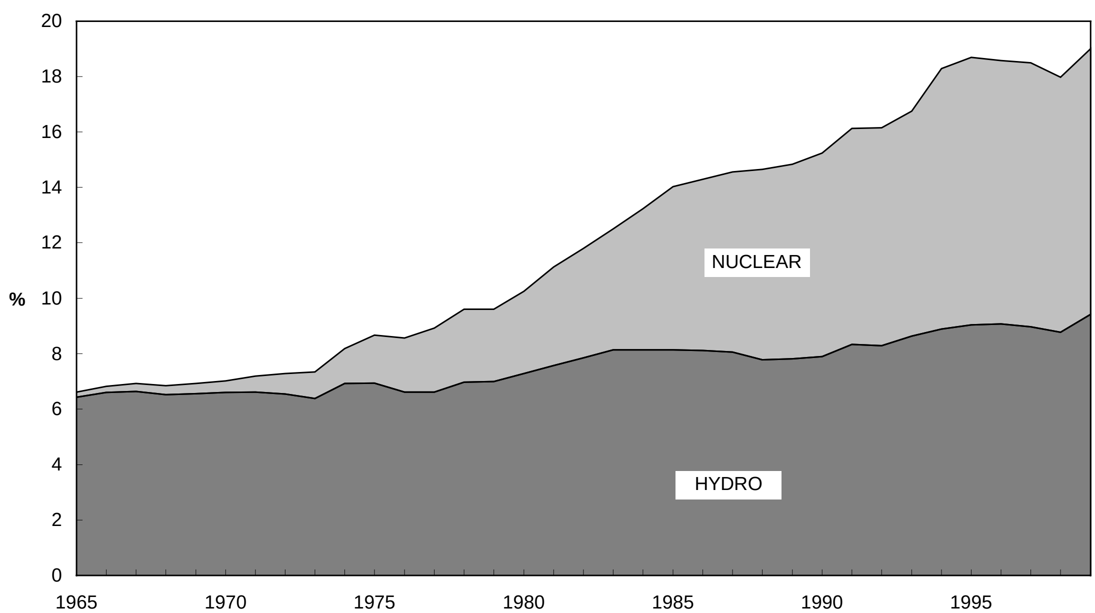
Source: NEI 2002

Figure 7. External Costs of Electricity Generation (m€/kWh)



Source: ExternE 1999

Figure 8. CO_2 avoided by hydro and nuclear energy (% of total CO_2 emissions from the energy sector)



Source: OECD/IEA Statistics

Figure 9. GIF ROADMAP GOALS

- Economics
  - Lover life-cycle cost than alternatives
  - Financial risk similar to alternatives
- Sustainability
  - Better use of natural resources
  - Reduced environmental burden
- Proliferation Resistance & Physical Protection
  - Minimise life-cycle susceptibility to diversion of weapon-usable materials
  - Minimise vulnerability to theft, acts of terror or sabotage
- Safety & Reliability
  - Excel in safety & reliability
  - Very low likelihood and degree of core damage
  - Eliminate the need for off-site emergency response

Figure 10. EVOLUTION OF NUCLEAR ENERGY SYSTEMS

CURRENT GENERATION	GEN III+	GEN IV
BWR PHWR PWR	ABWR Ad. CANDU APWR IPSR	SCWR
AGR	MHTGR	VHTR GFR
LMFBR		LMR-Na LMR-Pb alloy
		MSR