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On the Future of Nuclear Energy and Climate Change: A Summary

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Abstract

Rising expectations best characterize the current prospects of nuclear power in a world that is confronted with a burgeoning demand for energy, higher energy prices, energy supply security concerns and growing environmental pressures. It appears that the inherent economic and environmental benefits of the technology and its excellent performance record over the last twenty years are beginning to tilt the balance of political opinion and public acceptance in favour of nuclear power. Nuclear power is a cost-effective supply-side technology for mitigating climate change and can make a substantial contribution to climate protection.

This paper reviews the current status of nuclear power and its fuel cycle and provides an outlook on where nuclear power in relation to climate change may be headed in the short-to-medium run, say 20 to 40 years from now.

Introduction

Meeting the growing demand for energy, and electricity in particular, while addressing the need to curb greenhouse gas emissions and to ensure security of energy supply, is one of the most difficult challenges facing thse world's economies. No single technology can respond to this challenge, and the solution which policy-makers are seeking lies in the diversification of energy sources.

Although nuclear energy currently provides a significant percentage of electricity, especially in developed countries, and does not emit any carbon dioxide during production, it continues to be seen by many as a controversial technology. Public concern remains over its safety and the management of radioactive waste, and financing such a capital-intensive technology is a complex issue. The role that nuclear power will play in the future depends on the answers to these questions.

1. Nuclear Safety

The safety of a nuclear facility depends on the engineered protection built into it, on the organization, training, procedures and attitudes of the operator, and on the verification and inspection activities carried out by an independent regulatory body with the powers to suspend the operation of the facility if necessary.

Radioactivity generated during nuclear power production has the potential to harm people and the environment if released accidentally. Thus, very high levels of safety are considered essential to the use of nuclear energy. The primary purpose of all nuclear safety measures is thus to ensure that radioactivity remains contained or, if released, then only in controlled amounts that ensure no significant harm is done. There nevertheless remains some degree of risk, which must be effectively managed by the operator with oversight by a strong regulatory body.

In general terms, the safety of a nuclear installation can be understood as the ability of its systems and personnel to first prevent accidents from occurring, and second to mitigate the consequences if an accident should occur. The overarching goal is that the radiological impact on people and the environment from nuclear installations remains as small as possible for both normal operation and potential accidents. To achieve this, technical and organizational measures are put in place at all stages of a nuclear facility's lifetime starting with its siting and design, through manufacturing, construction and commissioning, during operation, and finally during its decommissioning.

At every step, adherence to certain principles and practices which define what is known as safety culture is essential to ensure the safe operation of nuclear facilities.

It is vital to tress on safety considerations pertaining primarily to nuclear power plants including their installations.

2. The Future of Nuclear Energy

World energy demand is set to grow rapidly over the coming decades against a background of increasing concern about the environmental implications of energy use, especially the emission of carbon dioxide from burning fossil fuels. Rising demand also means that security of energy supply is becoming a major issue for many countries.
Nuclear energy has certain advantages in addressing both these concerns. It is an established source of low-carbon energy that can add to the diversity and security of energy supplies.

3. World Energy Demand and Security of Supply

3.1 Growing demand for energy

The world's demand for energy will continue to increase as a result of economic development and population growth. In addition, new uses of electricity are expected to emerge, for example, the more widespread use of electrically powered vehicles. The world faces several major challenges over the next four decades and beyond to provide secure and affordable energy supplies to a growing population, while avoiding unacceptable impacts on the environment. Achieving this will involve moderating energy demand growth and greatly improving the efficiency of energy production and consumption, as well as optimizing the mix of energy sources and technologies to meet the remaining growth in a socially and environmentally acceptable manner.

3.2 Security of energy supplies

The availability of adequate energy supplies at reasonable prices has long been a concern of many governments, especially where there is a high dependence on imports. Energy shortages and consequent high prices can have a devastating effect on a country's economy. These concerns have, in the past, related primarily to the supply of fossil fuels, oil and natural gas in particular. One reason for such concerns is that oil and gas resources and production are concentrated in a relatively small number of countries and global regions, some of them politically unstable. In the longer term, there are concerns that as low-cost fossil fuel resources are depleted, extraction will become costly and potentially more environmentally damaging.

Furthermore, the nature of the nuclear fuel cycle means that nuclear plants are not dependent on continuous deliveries of large quantities of fuel.

Nuclear fuel is a very concentrated energy source, and is easy to stockpile. Several years' worth of fuel can be kept in inventory at low cost. About 25 tonnes of fabricated fuel will provide a year's supply for a typical nuclear plant, while a coal-fired plant of similar output requires some three million tonnes of fuel annually. If increased reliance is to be placed on nuclear energy for the longer term, and given that the operating lifetime of a new nuclear power plant is expected to be around 60 years, then the continued availability of uranium and the adequacy of known uranium resources are important considerations.

Taking into account the progressively increasing efficiency with which uranium is being used in reactors and the fuel cycle due to technological advances, it can be concluded that uranium resources are more than adequate to support a significant increase in nuclear capacity by 2050. However, uranium production will clearly need to expand from its present levels, as will the capacity of other nuclear fuel cycle facilities.

For the longer term, the recycling of uranium and plutonium in fast reactors could potentially extend the lifetime of existing uranium resources for several millennia. Security of energy supply is also strengthened by increasing the diversity of energy sources, meaning that disruption of one source will have a smaller overall impact. Given most countries' heavy dependence on fossil fuels, nuclear and other alternative energy sources can provide valuable diversification. For these reasons, many governments view nuclear power as an important component of their strategy to increase the security of their energy supplies.

4. Energy use and Climate Change

It is widely accepted by the scientific community and by most governments that the increasing concentrations in the atmosphere of carbon dioxide and other greenhouse gases emitted as a result of human activities will, if unchecked, lead to a warming of the global climate. While uncertainties remain over the extent and speed of warming, and over its impacts, a broad global consensus has been reached that future emissions must be significantly reduced from projected "business as usual" levels.

Emissions from the burning of fossil fuels (coal, natural gas and oil) for electricity generation are the largest source of CO2 from human activities, accounting for about 40% of the total emissions. Fossil-fuelled power plants have also been the fastest growing source of CO2 emissions over recent decades. Reducing CO2 emissions from power plants, although challenging is expected to be less difficult than controlling some other sources of emissions, such as transport and deforestation. Hence, strategies to respond to the threat of global warming invariably include very large reductions in emissions from the power sector, with the goal of its near-complete "decarbonisation" by the middle of this century.

Although nuclear power plants themselves emit essentially no CO2, some indirect emissions from the complete nuclear cycle can be attributed to nuclear electricity production. Most of these arise from the use of energy from fossil fuels in uranium mining and enrichment. Their size varies considerably depending on the technologies employed and the sources of the electricity used.

Only nuclear and hydro-power currently provide significant amounts of low-carbon electricity, with over two-thirds of all electricity being produced by burning fossil fuels. Nuclear is thus one of very few established low-carbon energy sources and its expansion can make an important contribution to efforts to decarbonize electricity supply.

Nuclear power also avoids the emission of particulates and polluting gases such as Sulphur and nitrogen oxides produced by burning fossil fuels, especially coal. These have important local health and environmental effects, such as respiratory diseases and acid rain.

5. The Future Role of Nuclear Power

As noted in earlier, at the end of 2011 world nuclear generating capacity was about 369 gigawatts (GW), providing nearly 14% of global electricity supply. Most of this capacity had already been installed by 1990, with total capacity increasing only slowly since then. However, recent years have seen a significant increase in the construction of new nuclear power plants.

Since construction typically takes five to seven years this has yet to feed through to an increase in operating capacity.

On the basis of plants under construction and firmly planned, and allowing for the closure of some older units, as well as the phase-out policies of some countries following the Fukushima Daiichi accident, it can be expected that nuclear capacity in 2025 could be between 470 GW and 500 GW. This represents a decrease of about 8% compared to projections made before the Fukushima Daiichi accident.

Scenarios for the longer-term future of energy supply take into account population growth, economic growth, technological developments, government energy policies, fossil fuel prices and other factors. Very different scenarios can be produced by changing the assumptions for each of these factors. Scenarios can also be constructed to examine the steps necessary to produce a desired outcome, for example, to achieve a set reduction in CO2 emissions. The Baseline, or "business as usual", scenario illustrates the possible outcome if energy policies remain unchanged, given expected population and economic growth.

- Achieving such a large expansion of nuclear energy over the next 40 years will depend on successfully addressing issues that could limit its growth, many of which have been discussed in earlier chapters of this report:
- Making available adequate supplies of uranium, and in the longer term introducing advanced nuclear technologies to make more efficient use of the natural resource provided by uranium.
- Fully implementing plans for radioactive waste management and disposal, in particular opening the first deep geological repositories for spent fuel and high-level waste.
- Continuing to improve levels of safety at existing and new nuclear power plants.
- Achieving more widely the shorter construction times and resulting lower investment costs that have been demonstrated in a few countries, thus reducing financial risks and improving overall economics.
- Developing the skilled human resources and industrial capacities needed to build and operate nuclear power plants and fuel cycle facilities.
- Maintaining and strengthening where necessary the international legal framework for nuclear energy, notably the non-proliferation and liability regimes.

Strengthening acceptance by civil society of nuclear energy as part of an overall strategy to meet energy and environmental goals, based on a balanced assessment of the risks and benefits of different energy sources. This challenge has of course become much more difficult as a consequence of the Fukushima Daiichi accident. It is clear that a successful nuclear programme requires a clear and stable national commitment over the long term. On a practical level, a country pursuing a nuclear programme needs to develop an effective legal and regulatory framework, as well as its own skilled human resources and industrial capabilities. Even though in many cases the main expertise and components for a nuclear plant will be imported, there is usually significant local content. This has important economic benefits in the country concerned.

6. Developing Nuclear Technology for the Future

The present status of nuclear technology is the result of over 50 years of continuous development, making use of experience gained from nearly 15 000 reactor-years of operation. The latest designs of nuclear power plants that are available commercially, known as Generation III or III+ designs, incorporate the lessons learnt from this experience to enable more efficient construction methods, and offer higher levels of safety and performance, improved fuel efficiency and reduced radioactive waste production.

Altogether, several designs for large Generation III/III+ light water reactors have been fully developed, with the first examples of most designs now in operation or under construction in several countries. These designs and others resulting from continuous evolutionary development will be the mainstay of nuclear expansion for the next 20 years and beyond. Small modular light water reactors have also been developed though none has been licensed to this date. They compensate in theory for the lack of "economy of scale" Characterizing large light water reactors by modular design and construction, workshop assembly, faster construction time, and possibly incremental capacity adjustments. More importantly, their lower investment cost would make such reactors attractive to investors not able to finance the high overnight costs of the much larger reactors. For the longer term, more innovative nuclear energy technologies and fuel cycles, known collectively as Generation IV systems, are being developed through international co-operation.

The most mature Generation IV concepts are the SFR and VHTR, which are based on proven technology. These are the leading candidates for large-scale demonstration projects, the first of which could be in operation in the 2020s.

Other benefits of advanced fuel cycle technologies could include increased proliferation resistance by avoiding the separation of plutonium, and reduced volumes of long-lived radioactive waste requiring very long-term isolation in a repository. The latter could be achieved by either consuming ("burning") the long-lived isotopes by incorporating them into nuclear fuel, or by separating them chemically and then irradiating them in a nuclear accelerator to transform them into shorter-lived isotopes. The process of separating the long-lived elements of interest, so-called minor actinides such as americium, curium or neptunium, from the rest of the radioactive waste is called partitioning, and the process of transforming these elements into shorter-lived isotopes is called transmutation.

Hence the name P&T is given to this advanced fuel cycle research. Recent work on this subject has concluded that:

- P&T and cooling during interim storage prior to disposal can be effectively used to reduce decay heat in the corresponding waste by about a factor of 3 for a 50-year cooling time compared to the once-through fuel cycle.
- A more efficient utilization of repository space is expected, with a reduction of required gallery length of the order of 3.

In addition, the inventory reduction means that uncertainties in repository performance are reduced. Improved public acceptance of geological repositories is therefore expected if P&T can be implemented in future fuel cycles.

7. Additional uses for Nuclear Energy, Present and Future

To date, nuclear energy has been used almost exclusively for the production of electricity. As electricity gradually takes a larger share of final energy consumption, the relative importance of nuclear energy will therefore grow. In particular, the expected rise in the use of electrically powered vehicles over the coming decades will increase its importance in the transport sector.

In addition to its growing importance for electricity supply, there are potential uses of nuclear energy as a source of direct heat. These include:

- supply of process heat for use in industrial plants, including petro-chemical plants;
- production of hydrogen, which could itself then be used as a clean fuel for transport and other purposes;
- desalination of sea water, especially in dry, coastal regions;
- district heating of buildings.

While heat for some of these applications could in principle be supplied from existing reactor designs, the use of advanced reactors specifically designed as dedicated heat producers or as co-generation plants offers the greatest potential.

Medical applications include the detection of tumours and other ailments such as cardiological diseases through diagnostic gamma-imaging cameras, substituting for more invasive diagnostic procedures.

8. Challenges for the Nuclear Industry

The main challenges would be to ensure that nuclear power retains and improves its economic competitive position relative to alternative energy sources, and to enhance public understanding and acceptance of nuclear power.

Secondly, the nuclear sector will be challenged to meet the need for maintaining capabilities and know-how to ensure the safe decommissioning of nuclear units and final disposal of radioactive wastes. Nuclear industries in a number of Organizations for Economic Co-operation and Development (OECD) countries have demonstrated already that capability. This variant might exacerbate challenges within the non-nuclear energy sectors, in regard to long-term security of supply and meeting the United Nations Framework Convention on Climate Change (UNFCCC) commitments.

In addition, would challenge the nuclear industry to ensure that technical and economic preparedness would be maintained and enhanced during more than two decades of stagnation, in order to keep the nuclear option open. A revival of nuclear power by 2025 is assumed to be based upon technologies that are able to compete favorably with advanced fossil-fuelled technologies, renewable sources and other options for alleviating the risk of global climate change.

Conclusion

More than 55 years after the first commercial electricity production by a fission reactor, nuclear energy has come a long way. It developed quickly in the 1970s and 1980s in a large number of countries as a means to produce electricity on a large scale and with a technology that increased the security of energy supply compared to fossil-based technologies.

Over the last two decades, the use of nuclear energy has expanded quickly in Asia, and it is increasingly being considered by several developing countries across the world to meet their rising electricity demand.

Despite its importance, nuclear energy remains a controversial technology, characterized by public concern over its safety especially after the Chernobyl and Fukushima accidents, the issue of the management of its waste and the risk of proliferation of nuclear material.

Although the levelised cost of nuclear electricity generation has been shown to be competitive, especially in the presence of carbon pricing, investors also face the challenge of financing the large upfront construction costs, while seeking long-term stability and political commitment to ensure adequate returns on investment over several decades of operation.

- Clearly, nuclear energy is at a new crossroads, with possibilities of the start of a renaissance or a slow decline as existing reactors are gradually retired. Fundamental reasons to support the use of nuclear energy include the following:
- Nuclear technology has evolved continuously and improved from generation to generation.
- Generating electricity using nuclear power is generally cost-competitive, even in liberalized markets.
- Nuclear energy as part of a diversified mix can significantly improve the security of energy supply, since available uranium resources are sufficient to power fission reactors throughout the 21st century at least.
- It is necessary to invest in low-carbon electricity generation technologies, at a time when anthropogenic emissions of greenhouse gases are rising to levels beyond which the consequences of global warming are predicted to be economically and ecologically untenable.
- The technical issues of management of high-level radioactive waste have been solved, with the recommendation to implement deep geological disposal sites.
- Safety remains the priority of the industry and governments.
- Nuclear energy is also a key technology for producing isotopes for medical applications, diagnostic and therapeutic, food processing, sophisticated detection devices, and environmental and other scientific research.

Recommendations

Political decision makers wishing to use this technology have the responsibility to:

- engage in public dialogue about the use of nuclear energy;
- put in place and enforce the regulatory and institutional framework necessary to oversee the safe use of nuclear energy and the appropriate management of waste;
- make long-term commitments and implement energy policies able to provide a stable environment that minimizes investment risks for new nuclear build.

The further development of nuclear energy depends on these criteria being met. Doing so will enable nuclear energy to provide electricity in large amounts and at an affordable price, while contributing to the reduction of greenhouse gas emissions from the power sector.

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