THE FUTURE OF NUCLEAR POWER

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ABSTRACT

Energy production and use will contribute to global warming through greenhouse gas emissions in the next 50 years. Although nuclear power is faced with a lot of problems to be accepted by the public, it is still a significant option for the world to meet future needs without emitting carbon dioxide (CO_2) and other atmospheric pollutants.

In 2002, nuclear power provided approximately 17% of world energy consumption. There is belief that worldwide electricity consumption will increase in the next few years, especially in the developing countries followed by economic growth and social progress. Official forecasts show that there will be a mere increase of 5% in nuclear electricity worldwide by 2020. There are also predictions that electricity use may increase by 75%. These predictions require a necessity for construction of new nuclear power plants.

There are only a few realistic options for reducing carbon dioxide emissions from electricity generation:

- Increase efficiency in electricity generation and use;
- Expand use of renewable energy sources such as wind, solar, biomass and geothermal;
- Capture carbon dioxide emissions at fossil-fuelled electric generating plants and permanently sequester the carbon;
- Increase use of nuclear power.

In spite of the advantages that nuclear power has, it is faced with stagnation and decline today. Nuclear power is faced with four critical problems that must be successfully overcome for the large expansion of nuclear power to succeed. Those problems are cost, safety, waste and proliferation. Disapproval of nuclear power is strengthened by accidents that occurred at Three Mile Island in 1979, at Chernobyl in 1986 and at fuel cycle facilities in Japan, Russia and in the United States of America. There is also great concern about the safety and security of transportation of nuclear materials and the security of nuclear facilities from terrorist attack.

The paper will provide summarized review regarding cost, safety, waste and proliferation, but emphasis will be put on an investigation of assumptions of competitiveness of nuclear power plants with regards to options (thermal power plants (coal and oil) and combined cycle gas turbine).

1 INTRODUCTION

The generation of electricity from fossil fuels, notably coal, oil and natural gas, is a major and growing contributor to the emission of carbon dioxide-greenhouse gas that contributes significantly to global warming. Nuclear power is a significant option for the world to meet future needs without emitting carbon dioxide (CO_2) and other atmospheric pollutants.

In the year 2000, 442 commercial reactors were in operation in 31 countries. The United States has the largest deployment with 104 operating reactors producing 20% of the country's electricity, followed by France, Japan, Germany, Russia, and South Korea. If current polices continue, nuclear power is likely to decline gradually and conceivably disappear in this century from the world's electricity supply portfolio, no matter of its long-term contribution to reducing greenhouse gas emissions. Few nuclear power plants are under construction worldwide. It is assumed that there will be significant increases in nuclear generated electricity in China, Japan, South Korea and decreases in Western Europe and United States. There is considerable anti-nuclear sentiment in Europe: Belgium, Germany, the Netherlands and Sweden are officially commited to gradually phasing out nuclear power. There is public opposition to nuclear power in Japan and Taiwan. Several countries are on a path to construct new operating units, such as South Korea, Finland, India, Russia and China. In most developed countries, the use of nuclear power is not expected to expand and, in many of these countries, including the United States, nuclear power has been explicitly excluded from policies to stabilize and reduce carbon emissions. Removing nuclear power as a supply option would be a mistake at this time. The primary reason is that nuclear power is an important source of electricity that does not rely on fossil fuel and hence does not produce greenhouse gas emissions. Experts project worldwide electricity consumption will increase substantially in the coming decades, especially in the developing world, accompanying economic growth and social progress. However, official forecasts call for a mere 5% increase in nuclear electricity generating capacity worldwide by 2020 (and even this is questionable), while electricity use could grow by 75% (4). Growth in electricity use is expected especially in developing countries, as they strive to meet basic needs and to modernize and industrialize their economies.

Among the major developed countries, the United States is unique in having a projected large increase in population and a large increase in total electricity demand. If the global deployment of nuclear power is to grow substantially by mid-century, the United States almost certainly must be a major participant. Nuclear power growth is unlikely to be very large in other key developed countries, such as Japan (with an anticipated population decline) or France (with a stable population and a power sector already dominated by nuclear power).

More advanced developing countries such as China, Brazil, Mexico and Iran can reach 4000 kWe-hrs/person/year with annual growth rates of electricity consumption in the 2%-3% range (4). Although improved business, regulatory, financial, political and other conditions may be needed, these countries would likely be very important for an expanded nuclear power scenario. By 2050, they will have large urban populations (above 85%), an important factor that requires large base load plants. Those countries have relatively little nuclear power today but could turn to nuclear power to meet a fraction of their electricity supply needs, as South Korea has done.

Less advanced developing countries such as India, Pakistan, Indonesia, Philippines and Vietnam may, with considerable progress in their political, legal, financial and regulatory regimes and an associated increase in domestic and foreign investment in their energy sectors, reach 2000-3000 kWe-hrs/person/year by mid-century. Nuclear power may account for part of the dramatic increase in electricity supply called for in these countries, India is an exception (fourteen units).

Least advanced developing countries, a particular concentration in Africa, are not good candidates for nuclear power, barring an unforeseen breakthrough in technology and capital requirements.

If developing nations do adopt nuclear power, all nations of the world will have an interest in how these countries regulate their nuclear enterprise with respect to reactor and fuel cycle safety, transportation of nuclear materials, waste disposal and especially proliferation safeguards. These projections will result with growing anti-nuclear sentiment in key countries. The limited prospects for nuclear power today are attributable to four unresolved problems: cost, safety, prolifiration and waste. The nuclear power option will only be exercised, if the technology demonstrates better economics, improved safety, successful waste management low prolifiration risk and if public policies place a significant value on electricity production that does not produce CO_2.

This article analyzes what would be required to retain nuclear power as a significant option for reducing greenhouse gas emissions and meeting growing needs for electricity supply.

Unlike other energy technologies, nuclear power requires significant government involvement because of safety, proliferation and waste concerns. If in the future carbon dioxide emissions carry a significant “price”, nuclear energy will be an important option for generating electricity.

2 FUEL CYCLE AND URANIUM RESOURCES

A critical factor for the future of an expanded nuclear power industry is the choice of the fuel cycle-what type of fuel is used, what types of reactors “burn” the fuel and the method of disposal of the spent fuel. The choice affects all four key problems that confront nuclear power-costs, safety, proliferation risk and waste disposal. The once through cycle has advantages in cost, proliferation, fuel cycle safety and is disadvantageous only in respect to long-term waste disposal; the two closed cycles have advantages only in long-term aspects of waste disposal and disadvantageous in cost , short-term waste issues, proliferation risk and fuel cycle safety. Cost and waste criteria are likely to be the most crucial for determining nuclear power's future. It is not realistic to expect that there are new reactor and fuel cycle technologies that simultaneously overcome the problems of cost, safety, waste and proliferation.

Closed fuel cycles may have an advantage from the point of view of long-term waste disposal and, if it ever becomes relevant, resource extension, but closed fuel cycles will be more expensive than once-through cycles until ore resources become very scarce. This is unlikely to happen, even with significant growth in nuclear power, until at least the second half of this century and probably considerably later still.

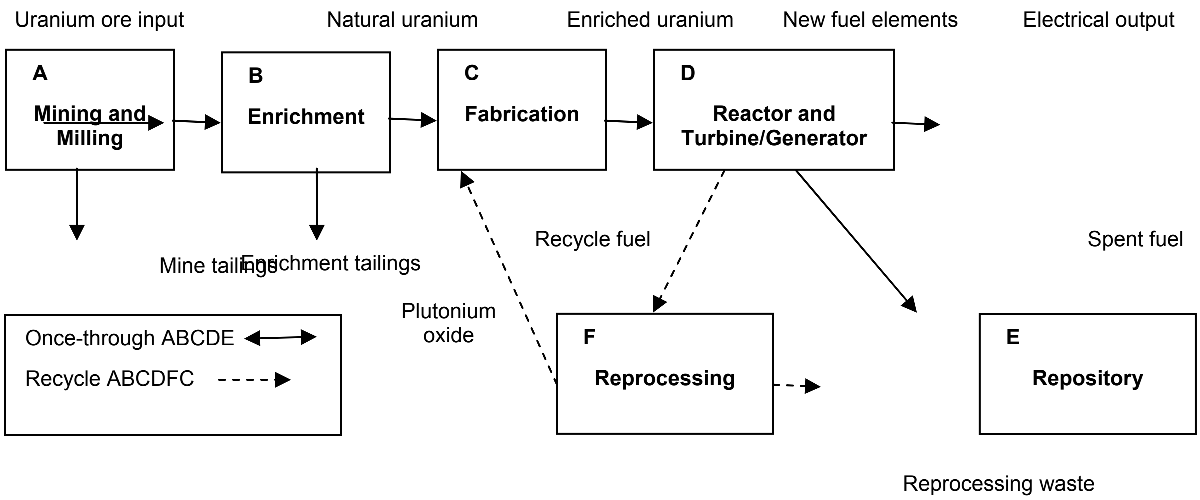

Figure 1. Fuel Cycle Diagram

Present data suggests the required resource base will be available at an affordable cost for a very long time. According to the NEA/IAEA, known resources recoverable at costs <$80/kgU and <$130/kgU are approximately 3 to 4 million tonnees of uranium. The amount of known resources depends on the intensity of the exploration effort, mining costs and the price of uranium.

According to the Australian Uranium Information Center, a doubling of the uranium price from its current value of about $30/kgU could be expected to create about a tenfold increase in known resources recoverable at costs <$80/kgU i.e. from about 3 to 30 million tonnes. By comparison, a fleet of 1500 1000MWe reactors operating for 50 years requires about 15 million tonnes of uranium, using conventional assumptions about burn-up and enrichment.

Since the cost of uranium represents only a small fraction of the cost of nuclear electricity, even large increases in the cost of uranium, as may be required to recover the very large quantities of uranium contained at low concentrations in both terrestrial deposits and seawater, may not substantially increase the cost of nuclear electricity. The resource utilization is not a pressing reason for proceeding to reprocessing and breeding for many years to come.

3 SAFETY

Safe operations of the entire nuclear fuel cycle are very important. It is assumed that there will be three-fold increase of nuclear fleet capacity by 2050 in the world. The goal should be to carry out this large expansion without increasing the frequency of serious accidents. This can be accomplished by means of both evolutionary and new technologies.

Three major reasons for reducing the frequency of serious accidents are: first, and foremost, they are a threat to public health. Reactor core damage has the potential to release radioactivity to air and groundwater. Second, an accident destroys capital assets. Loss of a plant costs billions of dollars and could restrict electrical generating capacity in the locality until replacement, thereby adding to the economic loss. Third, a serious accident erodes public confidence in nuclear generation, with possible consequences of operating plant shutdowns, and/or moratorium on new construction.

There are two ways to determine the frequency of accidents: historical experience and Probabilistic Risk Assessment. Expert opinion using PRA considers the best estimate of core damage frequency to be about 1 in 100 000 reactor years for nuclear plants in U.S. Although safety technology has improved greatly with experience, remaining uncertainties in PRA methods and data bases make it prudent to keep actual historical risk experience in mind when making judgements about safety.

Realization of the mid-century scenario has important implications for safety and especially in training and qualification of people competent to manage and operate the plants safely, including the supporting infrastructure necessary for maintenance, repair, refueling and spent fuel management. Development of competent managers and identification of effective management processes is a critical element in achieving safe and economic nuclear power plant operations. For developed countries that now operate nuclear plants, these tasks require attention to the rejuvenation of the entire workforce. The workforce has been aging for more than ten years due to lack of new plant orders and decline of industrial activity. For developing countries this challenge is much greater, because of the lack of workers in the many skills required in nuclear power plant construction, operations and maintenance.

Terrorists have demonstrated their ability to inflict catastrophic damage. Nuclear plant safety has considered natural external events, such as earthquakes, tornadoes, floods and hurricanes. Terrorist attack by fire or explosion is analogous to external natural events in its implication for damage and release of radioactivity. The strength of containment buildings and structures presents a major obstacle and hardened target for attack. EPRI (Electric Power Research Institute) carried out an evaluation of aircraft crash and NPP structural strength, concluding that U.S. containments would not be breached.

There is a concern about the safety of reprocessing plants, because of large radioactive material inventories and because the record of accidents, such as the waste tank explosion at Chelyabinsk in Russia, the Hanford waste tank leakages in the United States and the discharges to the environment at the Sellafield plant in the United Kingdom. Releases due to explosion or fire can be sudden and widespread. Although releases due to leakage may take place slowly, they can have serious long-term public health consequences if they are not promptly brought under control. There is a belief that there is no need for commercial reprocessing in the global scenario, but the subject requires careful study and action, if and when reprocessing becomes necessary.

4 WASTE MANAGEMENT

The management and disposal of high-level radioactive spent fuel from the nuclear fuel cycle is one of the most intractable problems facing the nuclear power industry throughout the world. Most countries with nuclear power programs and all the major ones have adopted as their preferred technical approach to the final disposal of high-level waste the emplacement of sealed waste bearing canisters in mined structures (“goelogical repositories”) hundreds of meters below the earth’s surface. Many independent experts have concluded that geologic respositories will be capable of safety isolating the waste from the biosphere. However, implementation of this method is a highly demanding task that will place great stress on operating, regulatory and political institutions. No country has yet successfully implemented an operating repository for high-level waste and all have encountered difficulties with their programs. In many countries public and political opposition to proposed nuclear waste facilities and to the transportation of nuclear waste by road or rail has been intense and public opinion polls reveal deep skepticism around the world about the technical feasibility of safely storing nuclear waste over the long periods for which it will remain hazardous. Many people think that no new nuclear power plants should be built until the waste issue has been resolved. In several major nuclear countries laws have been enacted whose practical effect will be to slow or even prevent the licensing of future nuclear power plants in the absence of demonstrable progress towards waste disposal.

Although geologic disposal is the announced technical strategy in almost every country, there are big differences in how countries are planning to implement it. So far only three countries, Finland, Russia and the U.S., have identified specific sites for their repositories.

For fifteen years the U.S. high-level waste management program has focused almost exclusively on the proposed repository site at Yucca Mountain in Nevada. Although the successful commissioning of the Yucca Mountain repository would be a significant step towards the secure disposal of nuclear waste, it is believed that a broader, strategically balanced nuclear waste program is needed to prepare the way for a possible major expansion of the nuclear power sector in the world.

5 NONPROLIFERATION

Nuclear power should not expand unless the risk of proliferation from operation of the commercial nuclear fuel cycle is made acceptably small. Nuclear power can expand as envisioned in global growth scenario with acceptable incremental proliferation risk, provided that reasonable safeguards are adopted and that deployment of reprocessing and enrichment are restricted. The nonproliferation issues arising from the global growth scenario are brought into sharp focus by assumption of deployment of nuclear capacity. If the proliferation regime is not strengthened, the option of significant global expansion of nuclear power may be impossible, as varios governments react to real or potential threat of nuclear weapons proliferation facilities by fuel cycle development. Responsible governments must control, to the extent possible, the know-how relevant to produce and process either highly enriched uranium or plutonium.The proliferation concern has led, over the last century, to many international institutions and agreements, none of which have proved entirely satisfactory.

Three issues are of particular concern: existing stocks of separated plutonium around the world that are directly usable for weapons; nuclear facilities, for example in Russia, with inadequate controls; and transfer of technology, especially enrichment and reprocessing technology, that bring nations closer to a nuclear weapons capability. An international respone is required to reduce the proliferation risk. The response should re-appraise and strengthen the institutional underpinnings of the IAEA safeguards regime in the near term, including sanctions and the response should guide nuclear fuel cycle development in ways that reinforce shared nonproliferation objectives.

6 PUBLIC ATTITUDES TOWARD NUCLEAR POWER

Expanded deployment of nuclear power requires public acceptance of this energy source. The public in the world is skeptical of nuclear power. A majority of Americans simultaneously approve of the use of nuclear power, but oppose building additional nuclear power plants to meet future energy needs. Since the accident at the Three Mile Island power plant in 1979, 60 percent of the American public has opposed and 35 percent have supported construction of new nuclear power plants, although the intensity of public opposition has lessened in recent years. In many European countries, large majorities oppose the use of nuclear power. Recent surveys show that 40 percent of Europeans feel that their country should abandon nuclear power because it poses unacceptable risks, compared with 16 percent who feel it is “worthwhile to develop nuclear power”. Should there be a public campaign to change perceptions about nuclear power? The evidence suggests that such a campaign may have only modest effect. Most of the change would come through education about the high price of alternative energy sources, such as solar and wind. The other possible source of change in public attitudes is the connection between global warming and fossil fuels. The typical person expresses concern about global warming, but it does not lead to higher support for carbon free electricity sources, such as nuclear power.

The surer way to cultivate public acceptance of nuclear power is through the improvement of the technology itself and choosing carefully what nuclear technology to use. Developing and deploying technology that proves uneconomical and hazardous will make the global growth scenario unfeasible. Technology choices and improvements that lower the cost of nuclear power, that improve waste management and safety and that lessen any environmental impact will substantially increase support for this power source.

7 ECONOMICS

A rigorous analysis of the economics of nuclear power should consider this energy source within the overall energy and economic development scenario of a country. Such a global assessment is very difficult to achieve, so normally a more modest approach is used, consisting of the economic analysis of the electric power-generating system expansion. This approach can provide a reasonably clear indication of the economics of nuclear power in the country.

A simpler approach consisting of a direct comparison between the economics of nuclear power plants and their competitors, thermal power plants-coal and Combined Cycle Gas Turbine (CCGT) could only provide rough indications regarding the economic competitiveness of nuclear power. Obviously, such an analysis would disregard the effects between the nuclear, coal and gas plants. In comparing electricity costs from nuclear, thermal plants and CCGT, the results depend on a number of factors and there is no single answer. The key economic factor for coal electricity is the cost of coal delivered to the power plant and for nuclear power the key factor is the total capital investment cost, which is significantly increased when interest rates are high and lead times long. For coal power plants stringent environmental protection regulations are expected to be applied in the future. These will increase their capital and operational costs, placing nuclear power in a more competitive position.

A model is constructed to evaluate and compare the real cost of electricity of nuclear plants, coal and natural gas plants over the economic and technical life that would be necessary to cover all costs (capital cost, operating and maintenance expenses and fuel costs). The economics may be defined as the period of time after which facility should be discarded or replaced because of its excessive costs or reduced profit. The economic life of a nuclear power plant does not necessarily coincide with the technical life, however, the time considered for the economic life of a plant does not exceed the technical life of the plant.

Table 1 illustrates some of the significant input parameters of the model.

Table 1 The Cost of Eectricity for Different Power Plants

The Cost of Electricity for Different Power Plants			
Input Parameter	Nuclear Power Plant	Thermal Power Plant (coal)	CCGT
Electric Power (Mwe)	1000	350	350
Overnight Cost ($/kWe)	2000	1500	750
Decommissioning Cost ($/kWe)	300	0	0
Fuel Cost ($/GJ)	0.5	2.115	5
Operation and Maintenance Cost %	4.5	4.5	4.5
Construction Period (years)	5	4	3
Project l Life (years)	40	30	30
Yearly Operation Period* (hr/year)	2000:8000	2000:8000	2000:8000
Discount Rate %	6	6	6
Interest Rate During Construction %	5	5	5
Inflation Rate %	2	2	2

** Assumption:, 2000 hr/y, 3000 hr/y, 4000 hr/y, 5000 hr/y, 6000 hr/y, 7000 hr/y, 7500 hr/y, 8000 hr/y.*

The model results for above input parameters make clear that electricity from new nuclear power plants today is not competitive with electricity produced from coal or CCGT plants (Figure 2).

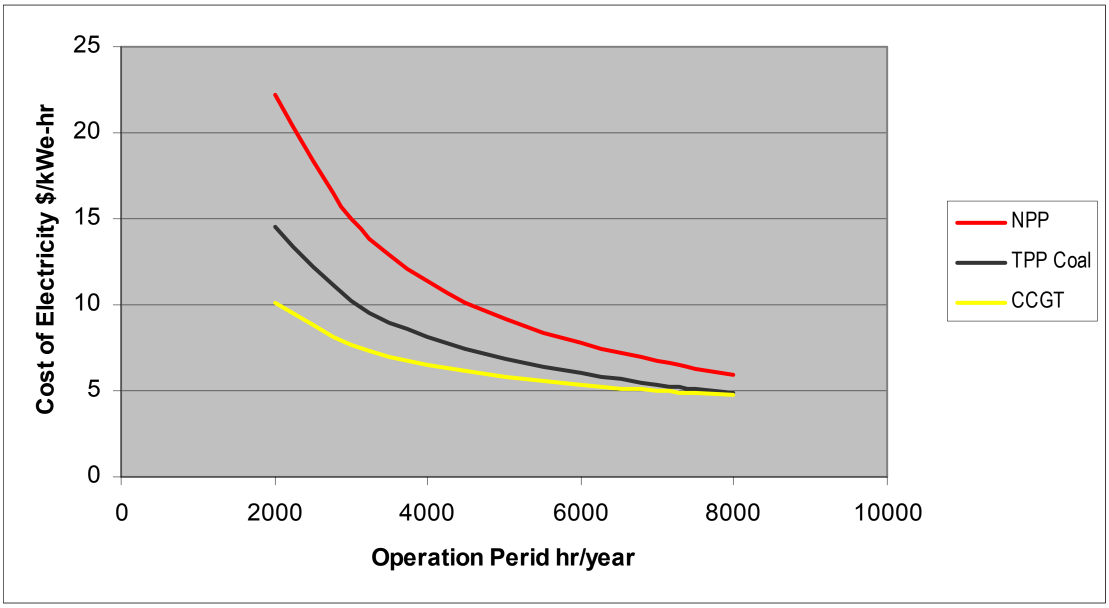

Figure 2. Cost of Electricity for Different Power Plants

Nuclear fuel 0.5$/GJ, Coal 62$/tonne coal-2.115$/GJ, Natural gas 176$/ 1000Nm^3-5 $/GJ

(Actual prices April 2004 (5,6,7))

It is examined how the cost of electricity generated by nuclear power plants would change if effective measures can be taken to reduce nuclear electric generation costs in several different ways.

First, it was assumed that construction cost of advanced nuclear plants will be reduced by 25% related to the existing concept of nuclear power plants (Figure 3). This brings the construction costs of a advanced nuclear power plant to a level more in line with the nuclear industry beliefs ($1500/kW). While this reduces levelized cost of nuclear electricity considerably, it is competitive with coal power plants over 6000 operation hours per year, and it becomes competitive with CCGT at 8000 hr/year.

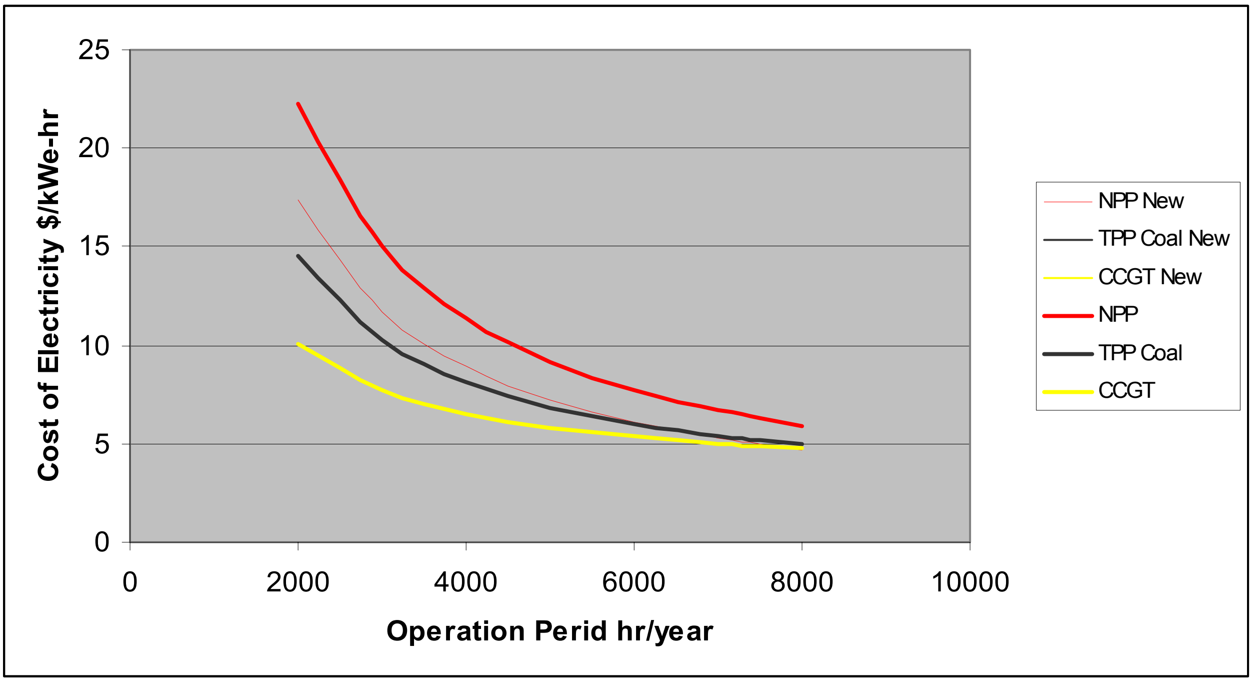

Figure 3. Reduction of NPP Overnight Cost (25%)

Second, if the construction time of nuclear power plants is reduced from 5 to 4 years, it makes nuclear power plants still uncompetitive with coal plants and CCGT plants (Figure 4).

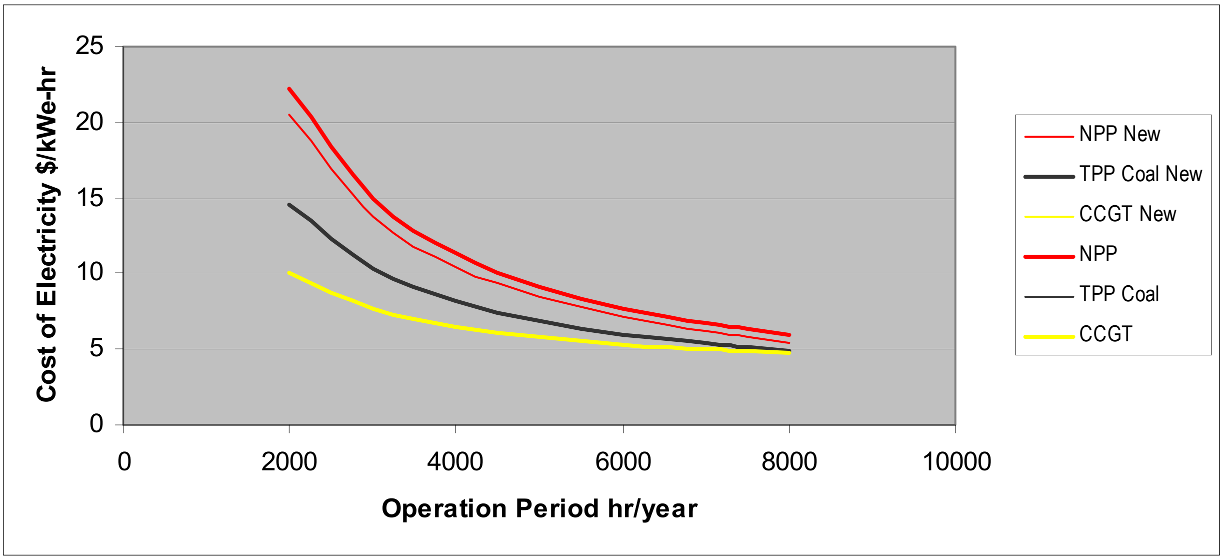

Figure 4 Construction Period from 5 to 4 years

Third, nuclear does become competitive with coal plants and CCGT plants in the case of combination of 25% reduction of NPP overnight cost and reduction of construction period from 5 to 4 years.

Forth, if only the social cost of carbon emission is internalized, (assuming the cost of 1.2 $/GJ (50$/tonne C) for coal and 0.6 $/GJ for natural gas), nuclear becomes competitive with coal plants at 8000 hr/year, and , if the 25% reduction of NPP overnight cost and reduction of construction period are also taken into account nuclear becomes competitive with natural gas over 6000hr/year (Figure 5).

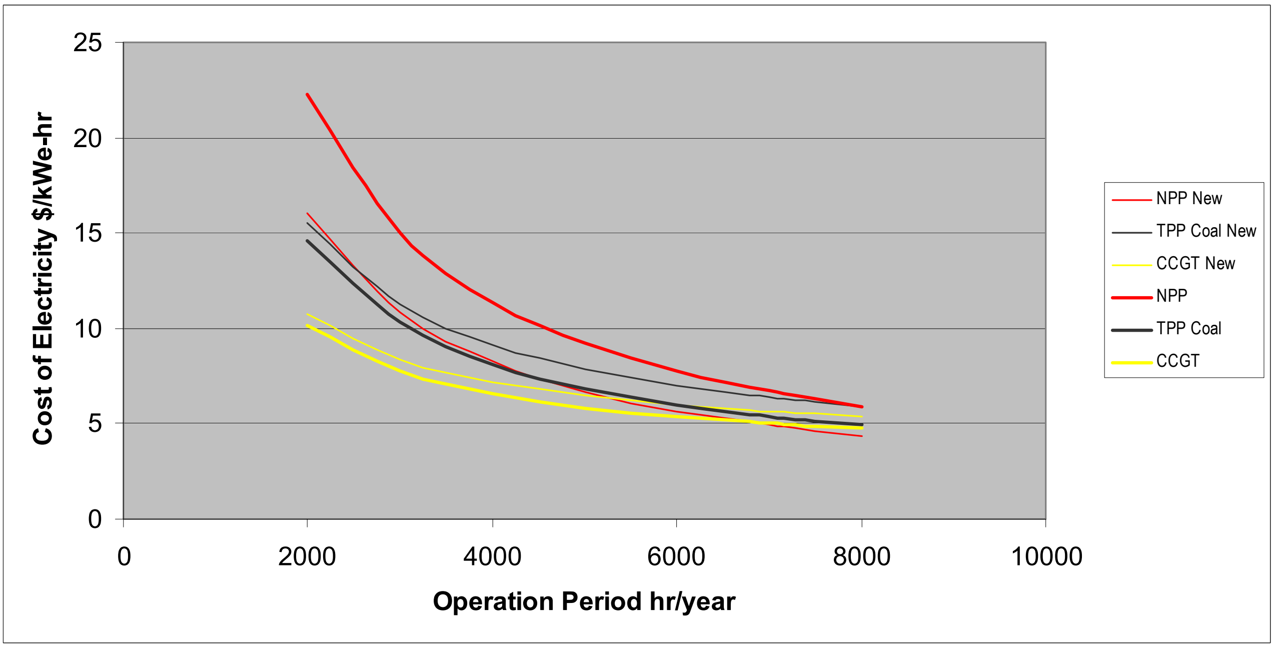

Figure 5 Reduction of NPP Overnight Cost, Construction Period from 5 to 4 years and inluded carbon taxes

The ultimate cost of carbon emissions will depend on both societal choices, such as how much carbon dioxide emission to permit, and technology developments, such as the cost and feasibility of large-scale carbon capture and long term sequestration.

However, if regulatory, construction, and operating cost uncertainties could be resolved, and the nuclear plant could be financed under the same terms and conditions (cost of capital) as a coal and gas plant, then the costs of nuclear power become more competitive, assuming that comparable improvements in the costs of building coal and CCGT plants are not achieved.

8 CONCLUSION

With significant improvments in the costs if building, operating, and financing nuclear power plants and continued excellent operating performance (85% capacity factor), nuclear power could be quite competitive with coal and with natural gas if gas prices turn out to be higher than most analysis now appear to believe. Obviously, there is some set of assumptions that will make nuclear cheaper than coal and natural gas. However, they basically require driving the construction costs and construction time profile to be roughly equivalent to those of a coal unit. It has not been assumed any improvements in construction costs or heat rates for coal units associated with advanced coal plant designs.

The cost improvements that are projected are plausible. During this analysis it is taken into account the fuel cost at the first quarter 2004 prices level. It should be emphasized, that the cost improvements required to make nuclear power competitive with coal are significant: 25% reduction in advanced nuclear power plants overnight cost, reducing the construction time form 5 years to 4 years and achieving investment environment in which nuclear power plants can be financed under the same terms and conditions as can coal plants. Nuclear looks more attractive when the cost of CO_2 emissions are also taken into account. If only the social cost of carbon emission is internalized, (assuming the cost of 1.2 $/GJ (50$/tonne C) for coal and 0.6 $/GJ for natural gas), nuclear becomes competitive with coal plants at 8000 hr/year, and, if the 25% reduction of NPP overnight cost and reduction of construction period are also taken into account nuclear becomes competitive with natural gas over 6000hr/year. Unlike coal and gas plants, nuclear plants produce no carbon dioxide during operation and do not contribute to global climate change.

The Finnish parliament in May 2002 approved construction of a new nuclear power plant based in part on the economic analysis of generation options.The economic analysis supporting the decision to build a fifth nuclear reactor compares the economics of a new nuclear plant to a coal plant and a CCGT plant. Low nuclear construction and operating costs, high plant performance, and a 6% real discount rate contributed to nuclear power being the superior choice not taking into account the carbon taxes.

The nuclear future depends on overcoming the four challenges described above-cost, safety, proliferation and wastes. All improvements are required whether nuclear technology expects expanded deployment. Without public acceptance of nuclear power as one of the energy sources, there is no bright nuclear future.

This analysis presents that it would be eligible to consider all mentioned solutions in order to meet most of the future Croatian energy needs. This indicates the absurdity of the Croatian parliament decision from 1999 that prohibited any research of potential locations for construction of new thermal and nuclear power plants until 2015.

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