
The Future of Nuclear Power: A Global and Regional Outlook

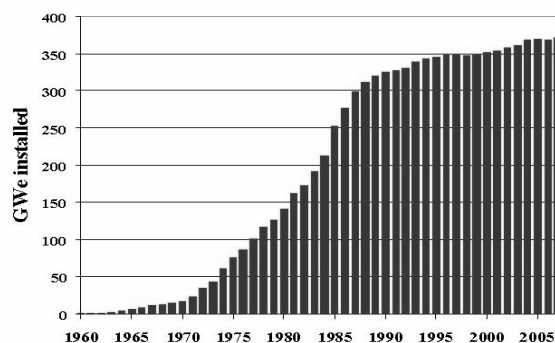
H-Holger Rogner and A. McDonald

Nuclear Power Today

A Brief History

At the beginning of 2008 there were 439 nuclear power reactors in operation worldwide, totaling almost 372 GW_e of generating capacity (see Table 1) up from 325 GW_e in 1990. Since 1990, global nuclear power capacity has grown at only one quarter the rate of total generating capacity and its share has slipped from almost 12 percent in 1990 to less than 9 percent in 2007. Figure 1 depicts this slowdown after the mid-1980s, and were it not for developments in Asia, there would have been hardly any growth in nuclear generating capacity during this period (see Figure 2).

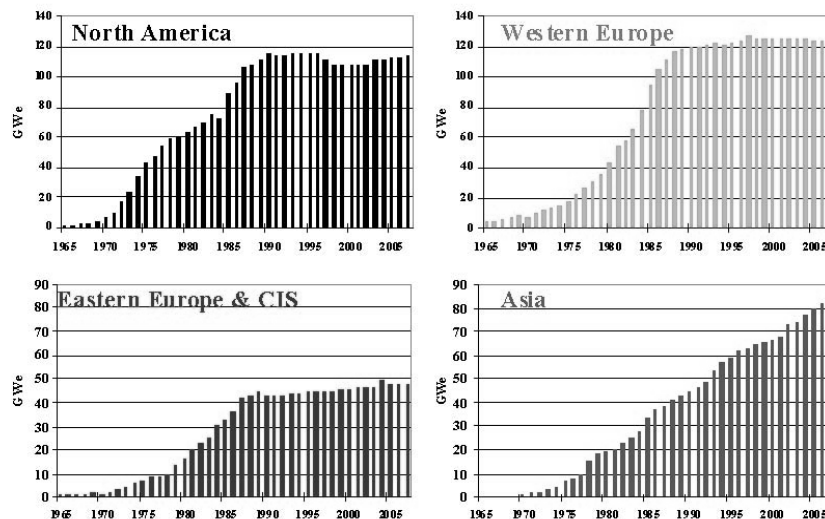
Figure K.1
Historical Development of Global Nuclear Generating Capacity (1960–2007)



There are several factors that contributed to the quasi stagnation in Europe, North America, the Russian Federation and the Commonwealth of Independent States (CIS). Electricity demand growth dropped significantly after the mid-1980s. In the wake of the oil price crises of 1973/4 and 1979/80, governments imposed efficiency standards, industry shifted production to less energy intensive products and processes, and consumers, at least temporarily, tightened their belts. The pattern of a doubling of demand every ten years (or a seven percent annual growth rate) was history, and annual demand growth in these regions was closer to 2 percent than 3 percent per year.

Because of the long lead times from planning to grid-connection associated with power plants, there was more capacity nearing completion than there was demand. Despite the cancellation of numerous nuclear and coal power projects, electricity markets in North America and Europe had to cope with excess generation capacity.

Figure K.2
Global Nuclear Generating Capacity by Region (1960–2007)



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The economic transition that followed the break-up of the Soviet Union and its satellite states led to drastically reduced economic activity, and high rates of unemployment and migration. Many energy intensive industries closed for good due to lack of competitiveness. The net effect was a precipitous drop in energy and electricity demand and thus excess generating capacity. Excess generating capacity and regionally varying electricity rates based on the traditional cost plus rate setting in regulated markets, together with a lack of competition between generators were seen as systematic inefficiencies. Market liberalization and the unbundling¹ of generation and transmission were therefore hailed as universal remedies.

Table K.1
Nuclear Power Reactors in Operation and Under Construction in the World (April 14, 2008)^a

Country	Reactors in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2007		Total Operating Experience through 2007	
	No. of Units	Total MW(e)	No. of Units	Total MW(e)	TW(e)*h	Percent of Total	Years	Months
Argentina	2	935	1	692	6.72	6.2	58	7
Armenia	1	376			2.35	43.48	40	3
Belgium	7	5,824			45.85	54.05	219	7
Brazil	2	1,795			12.37	2.84	33	3
Bulgaria	2	1,906	2	1,906	13.69	32.1	143	3
Canada	18	12,589			96.52	16.02	478	8
China	11	8,572	6	5,220	62.60	1.92	77	3
Czech Republic	6	3,619			24.62	30.25	98	10
Finland	4	2,696	1	1,600	22.50	28.94	115	4
France	59	63,260	1	1,600	418.60	76.85	1,582	2
Germany	17	20,470			133.21	25.86	717	5
Hungary	4	1,829			13.89	36.81	90	2
India	17	3,779	6	2,910	15.91	2.52	284	4
Iran, Islamic Republic of			1	915				
Japan	55	47,587	1	866	266.39	27.54	1,331	3
Korea, Republic of	20	17,373	3	2,880	136.60	35.34	299	8
Lithuania	1	1,185			9.07	64.36	41	6

FUTURE ARABIAN GULF ENERGY SOURCES: HYDROCARBON, NUCLEAR OR RENEWABLE?

Country	Reactors in Operation		Reactors under Construction		Nuclear Electricity Supplied in 2007		Total Operating Experience through 2007	
	No. of Units	Total MW(e)	No. of Units	Total MW(e)	TW(e)*h	Percent of Total	Years	Months
Mexico	2	1,360			10.42	4.56	31	11
Netherlands	1	482			3.99	4.1	63	0
Pakistan	2	425	1	300	2.31	2.34	43	10
Romania	2	1,300			7.08	13.02	11	11
Russian Federation	31	21,743	7	4,789	147.77	15.97	932	3
Slovakia	5	2,034			14.16	54.3	123	7
Slovenia	1	666			5.43	41.57	26	3
South Africa	2	1,800			12.60	5.45	46	3
Spain	8	7,450			52.33	17.44	253	6
Sweden	10	9,014			64.40	46.12	352	6
Switzerland	5	3,220			26.34	40.03	163	10
Ukraine	15	13,107	2	1,900	87.22	48.09	338	6
United Kingdom	19	10,222			57.52	15.12	1,419	8
United States of America	104	100,356	1	1,165	806.50	19.39	3,330	7
Total ^{b,c}	439	371,895	35	29,343	2,617.92		12,907	2

a. Data is from the Agency's Power Reactor Information System (<http://www.iaea.org/programmes/a2/index.html>).

b. Note: The total includes the following data in Taiwan, China:

- 6 units, 4,921 MW(e) in operation; 2 units, 2,600 MW(e) under construction;
- 38.3 TWh of nuclear electricity generation, representing 19.5% of the total electricity generated in 2006;
- 152 years, 1 month of total operating experience at the end of 2006.

c. The total operating experience also includes shutdown plants in Italy (81 years) and Kazakhstan (25 years, 10 months).

In 1986, world oil prices collapsed as a result of: (i) non-OPEC supplies coming on-stream, stimulated by high market prices (Mexico, North Sea, etc); (ii) the contraction of demand (high price levels, efficiency improvements); (iii) OPEC member attempts to maximize individual market shares; and (iv) the introduction of net-back pricing. Other fossil fuel prices followed suit. The commercialization of the high efficiency, low-capital-cost combined cycle gas turbine (CCGT) – with short construction times and small unit sizes – offered an attractive alternative to the much larger coal and nuclear power plants. Small units and short construction times allowed utilities to minimize market risks,

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especially demand uncertainty, while maximizing shareholder value. Natural gas was no longer viewed as the step-sister of oil and emerged as the fuel of choice for electricity generation—clean, cheap, and quasi-abundant. Energy supply security concerns had all but vanished into thin air and many governments abandoned active involvement in issues related to supply security. Electricity companies shifted into the business of selling commodities (kWh) and commercial services instead of a strategic good.

The Three Mile Island nuclear accident of 1979, even though it led to no deaths or injuries to plant workers or members of the nearby community, had an enormous impact on the nuclear sector worldwide. In response to the accident, a comprehensive program was launched involving education, operator training and radiation protection in many other areas of nuclear power plant operations – including regulatory commissions – in order to tighten their regulatory oversight and improve overall operation safety. Furthermore, regulatory bodies in many countries imposed safety upgrades on existing nuclear power plants or design changes on plants under construction. Retroactive design changes led to delays in plant completion and cost overruns. These cost overruns were further accentuated by the extremely high interest rates during the early 1980s, which adversely affected the economics of capital-intensive investment projects.

Taking the above factors together, by the mid-1980s nuclear power had lost its appeal. Liberalized markets with a focus on short-term returns, demand uncertainty, and the poor economics of new nuclear projects (compared with cheap gas technology) had already curbed the appetite for new nuclear plants when the Chernobyl accident of 1986 – with its dire consequences – put the technology totally out of favor for investors and the public alike. While this was the case for most of the world, it was not so in Asia. Nuclear power has continued to be in demand in populous countries, fast-growing economies and countries with a limited indigenous energy resource endowment. Put simply, rapidly growing energy needs in

India and China, and supply/security concerns in Japan and the Republic of Korea continued to encourage the development of all energy options.

Recent Developments

In 2006, nuclear power supplied about 15.2 percent of the world’s electricity. The world’s fleet of nuclear power reactors maintained a high average availability factor greater than 80 percent (see Figures 3 and 4), which in 2007 allowed a near record production of 2,618 TWh—just 40 TWh below the best ever recorded in 2006.²

Increased competition has generally led to lower generation costs compared to more protected and monopolistic market structures. Liberalization has also prompted consolidation, acquisitions, upratings and license extension applications as selected companies move to define themselves largely by the size and expertise of their nuclear operations. Consistent with liberalized market behavior, existing nuclear plants thrive while new plants wait. New builds of any kind must compete with full costs, including capital against the marginal operating costs of existing plants. In the absence of demand growth sufficient to absorb new generating capacities, new builds – especially large and capital-intensive units – are at a decisive disadvantage.

Figure K.3

Average Availability of the World’s Fleet of Nuclear Power Plants

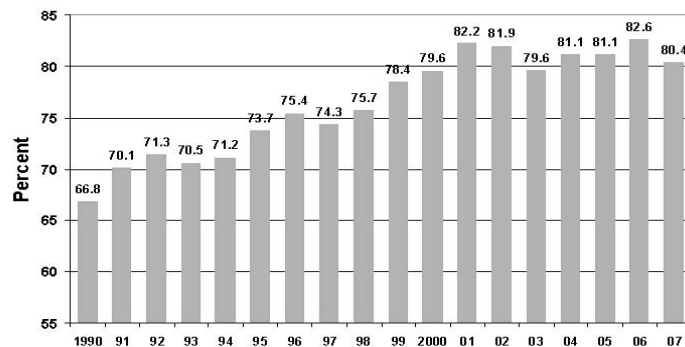
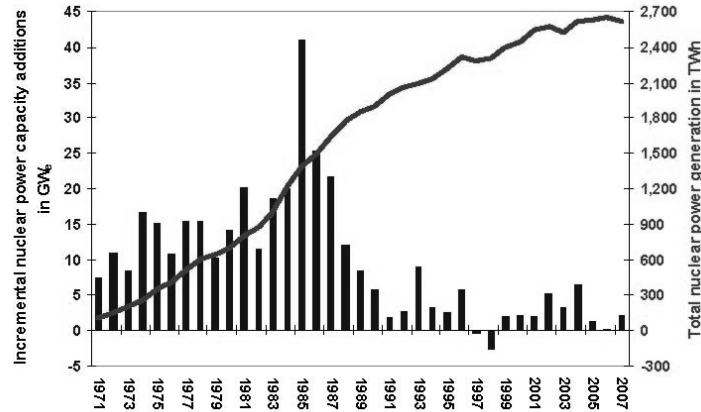


Figure K.4
Incremental Nuclear Generating Capacities
and Nuclear Electricity Generation



The net effect of market pressures has been a substantial increase in availability factors (i.e. the time per year that nuclear plants generate revenues) from the lower 60 percent level in 1990 to more than 80 percent today (see Figure 3). This increase corresponds to the virtual construction of some 34 GW_e of generating capacity at essentially zero cost. It is chiefly responsible for maintaining a relatively stable nuclear share in global electricity supply for the last 15 years despite limited investment in new nuclear builds.

Final data for 2007 is likely to show a decrease in the nuclear share as the small drop in nuclear electricity generation, cited above, contrasts with an estimated growth in total electrical generating capacity (nuclear power plus all other sources) of almost 4 percent per year. Moreover, the increase in availability factors appears now to have leveled out.

Three new reactors were connected to grids in 2007, one each in China, India and Romania, and one laid-up unit was reconnected in the United States. This compares with two new connections in 2006 and four new connections in 2005 (plus one reconnection). There were no reactor retirements in 2007, compared to eight in 2006 and two in 2005. Taking

uprates of existing reactors into account, the net effect was a small increase in global nuclear generating capacity during 2007 of some 2 GW_e.

Using the International Atomic Energy Agency (IAEA) definition that construction begins with the first pouring of concrete, there were seven construction starts in 2007 with a combined future generating capacity of 5,190 MW(e): Qinshan II-4 (610 MW_e) and Hongyanhe 1 (1,000 MW_e) in China; Flamanville 3 in France (1,600 MW_e); Akademik Lomonosov 1 and 2 (2×30 MW_e) in Severodvinsk, Russian Federation; and Shin Kori 2 (960 MW_e) and Shin-Wolsong 1 (960 MW_e) in the Republic of Korea. In addition, active construction resumed at Watts Bar 2 in the United States. This compared to three construction starts plus resumed construction at one reactor in 2006.

Current expansion, as well as near-term and long-term nuclear growth prospects, remains centered in Asia. As shown in Table 1, of the 35 reactors under construction, 20 are in Asia. By the end of 2007, 28 of the last 39 new reactors to have been connected to grids were in Asia.

Increased nuclear capacity in some countries (e.g., the United States, Belgium, Finland, Spain, Sweden, Switzerland and Germany) is the result of uprating existing plants, which can add up to 20 percent of additional capacity. This is a highly cost-effective way of bringing new capacity on-line, particularly where new nuclear builds are otherwise not favored.

Rising Expectations: An Outlook

Fossil Fuel Prices

Higher world market prices for fossil fuels have put nuclear power back on the energy agenda of many countries currently without nuclear power plants and there is revived interest in countries with stagnating nuclear power programs. Because they are driven largely by demand, current high prices for fossil fuels are likely to be more permanent than those of the 1970s. Energy demand growth driven by continuing economic development is expected to persist, hence the pressure on prices is likely

to last. High world market prices for fossil fuels have the greatest impact on countries that are highly dependent on energy imports, particularly developing countries with relatively scarce financial resources. A doubling of international prices translates into generation cost increases of about 35–45 percent for coal-fired electricity and 70–80 percent for natural gas. In contrast, a doubling of uranium prices (which have also increased recently) raises nuclear generating costs by five percent.

Rising fossil fuel and uranium prices not only affect the relative competitiveness of electricity generating options but can also affect supply security. Concerns about energy supply security were important in the nuclear expansion programs of France, Sweden and Japan at the time of the 1970s oil shocks. Supply security concerns form the basis of one of the arguments advanced in Europe today for expanding nuclear power, and may prove an important motivation for some countries currently without nuclear power to consider seriously this option. Developing countries with sizable domestic fuel resources have recently begun looking at the possibility of introducing nuclear power in the 2015–2020 timeframe. These include OPEC members Indonesia and Nigeria as well as the six member countries of the Gulf Cooperation Council (GCC). For them the immediate impact of increased oil prices is not the same as for oil importers, but the logic may lead in the same direction. Nuclear power can be a vehicle to increase export revenues by substituting domestic demand for natural gas (and to a lesser extent oil) with nuclear power. The additional export earnings may well finance the construction of part or all of a country's first nuclear power plants. Also, some oil and gas exporters – e.g. Indonesia – may be interested in nuclear power as a way to reduce currently high rates of oil and gas resource depletion.

Economics

Nuclear power plants have a 'front-loaded' cost structure, i.e. they are relatively expensive to build but relatively inexpensive to operate. The low share of uranium in total generating costs protects plant operators against resource price volatility. Thus existing well-run operating nuclear

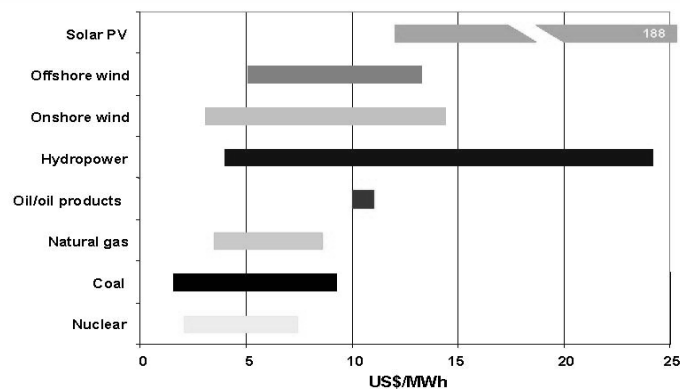
power plants continue to be a generally competitive, profitable source of electricity; but for new construction the economic competitiveness of nuclear power depends on several factors. First, it depends on the alternatives available. Some countries are rich in alternative energy resources, others less so. Second, it depends on the overall electricity demand in a country and how fast it is growing. Third, it depends on the market structure and investment environment.

Other things being equal, nuclear power's frontloaded cost structure is less attractive to a private investor in a liberalized market that values rapid returns, than to a government that can look at the long-term, particularly in a regulated market that assures attractive returns. Private investments in liberalized markets will also depend on the extent to which energy-related external costs and benefits (e.g. pollution, greenhouse gas [GHG] emissions, waste and energy supply security) have been internalized. In contrast, government investors can incorporate such externalities directly into their decisions. Also important are regulatory risks. Political support for nuclear power varies across countries, and within a given country it can change over time. An investor must weigh the risk of political shifts that might require cancellation of the project midstream or introduce delays and costs that would vitiate an originally attractive investment. Different countries also have different approval processes. Some are less predictable than others and create greater risks, from the investor's perspective, of expensive interventions or delays. In Japan and the Republic of Korea, the relatively high cost of alternatives benefits nuclear power's competitiveness. In India and China, rapidly growing energy needs encourage the development of all energy options. In Europe, high electricity and natural gas prices but also the GHG emission limits under the European Union Emission Trading Scheme (EU ETS) have improved the business case for new nuclear power plants. In the United States the 2005 US Energy Act significantly strengthened the business case for new construction. Previously new nuclear power plants had not been an attractive investment given plentiful low-cost coal and natural gas, the absence of GHG emission limits, and investment risks associated with the

lack of recent experience in licensing new nuclear power construction. The provisions of the Energy Act, including loan guarantees, government coverage of costs associated with certain potential licensing delays and a production tax credit for up to 6,000 MW_e of advanced nuclear power capacity, have improved the business case enough to prompt announcements by nuclear firms and consortia of possible Combined License (COL) applications covering approximately 32 possible new reactors in the United States.

Figure 5 summarizes estimates from seven recent studies of electricity costs for new power plants compared with different fuels. Except for oil-fired electricity generation (estimated in only one study) the high end of each cost range is at least 100 percent higher than the low end. This is partly a result of different techno-economic assumptions across the studies, but also of the factors listed above. Moreover, the ranges in Figure 5 incorporate only internalized costs, and if high enough priority is given to improving national energy self-sufficiency, for example, the preferred choice in a specific situation might not be the least expensive.

Figure K.5
The Ranges of Levelized Generating Costs Associated with New Construction



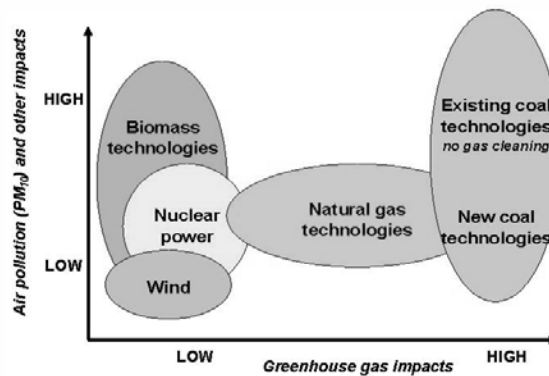
Note: As estimated in seven recent studies for electricity-generating technologies in different countries (PV: photovoltaic).

External Costs

External costs, also known as externalities, arise when the social or economic activities of one group of persons have an impact on another group, and when that impact is not fully accounted, or compensated for, by the first group. Thus, a power station that releases emissions as a result of its operation causing damage to human health or the ecosphere imposes an external cost. This is because the impact on those who suffer damage to their health or a degraded environment is neither taken into account by the generator nor the user of the electricity. Matters are complicated because the use of electricity provides an enormous benefit to society which must be balanced against the losses incurred by its production and use. External costs have typically not been included in the market price of electricity, which has consequently sent the wrong price signal to producers and consumers alike. Neglect of these costs is not only owing to the lack of a systematic and common methodology for attributing and monetizing damages, but also to different priorities regarding economic development and protection of the environment. Still, several studies have attempted to quantify the external costs associated with electricity generation. A general ranking of all electricity-generating options in terms of both greenhouse gas emissions and traditional air pollutants (such as particulates, sulfur dioxide and nitrogen oxides) is shown in Figure 6, and is taken from the European Commission report “External Costs: Research results on socio-environmental damages due to electricity and transport.”

Nuclear power generates minimal air pollution, making it an attractive alternative to mitigate the adverse health and environmental impacts of particulates, acid rain precursors or GHG emissions. In contrast to non-nuclear power generation, most nuclear externalities (waste disposal, protection of the public, decommissioning) are already internalized. Taking into account full life-cycle emissions, nuclear power, wind power and biomass technologies are the lowest GHG emitters. For traditional air pollutants, only wind power emits less than nuclear power.

Figure K.6
External Costs of Different Electricity Generating Options



Source: EC, 2003.

Energy Security

The best way to strengthen a country's energy-supply security is by increasing the number and resiliency of energy-supply options, and for many developing countries, expanding nuclear power would increase the diversity of energy and electricity supplies. Moreover, nuclear power has two features that generally further increase resiliency. The first was noted above: that nuclear electricity generating costs are much less sensitive to changes in resource prices than are fossil-fired electricity generating costs. Second, the basic fuel, uranium, is available from diverse producer countries and small volumes are required, making it easier to establish strategic inventories. In practice, the trend over the years has been away from strategic stocks toward supply/security based on a diverse, well functioning market for uranium and fuel-supply services. However, the option of relatively low-cost strategic inventories remains available for countries that find it important.

Environment

Environmental considerations may weigh increasingly in favor of the nuclear option. Nuclear power at the point of electricity generation does

not produce any emissions that damage local air quality, cause regional acidification or contribute to climate change. There are some emissions associated with plant construction and the nuclear fuel cycle (i.e. mining, enrichment, transportation, waste management, etc.), but the impacts on a per kWh basis over the lifetime of the plant from these emissions are far below those of fossil-fired power plants and at least comparable to those of wind power and biomass conversion (see Figure 6).

Figure 7 summarizes the life-cycle GHG emissions found in a comprehensive search of the peer-reviewed literature. While the spread of emissions for specific technologies is substantial – reflecting different vintages, efficiencies and lack of homogeneity of fuels – the ranking of the GHG-intensity of electricity-generation options corresponds to the impact ranking in the EC study. The Kyoto Protocol, which entered into force in February 2005, requires most developed countries to limit their GHG emissions in the “first commitment period” of 2008–2012. Before the Protocol’s entry into force, nuclear power’s advantage of very low GHG emissions was largely invisible to investors, as the lack of restrictions or taxes on such emissions meant there was no economic value to their avoidance.

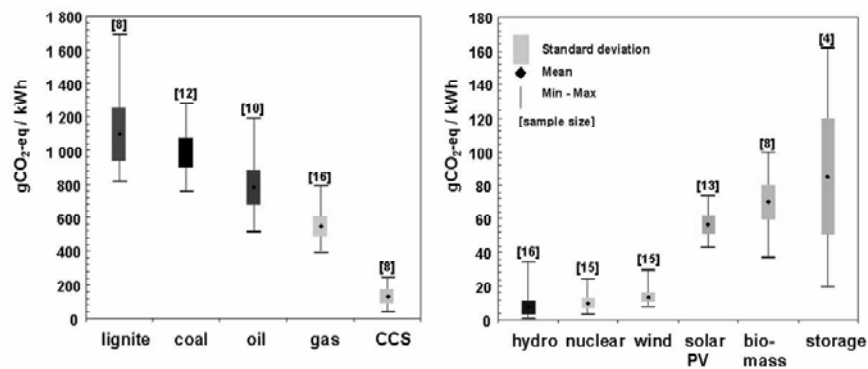
Different countries have adopted different policies to meet their Kyoto Protocol limits. Not all benefit nuclear power despite its low GHG emissions, but in the longer term the limits on GHG emissions should make nuclear power increasingly attractive. For example, a charge on carbon dioxide emissions of €20 per metric ton of carbon dioxide (tCO₂), would improve a nuclear plant’s generating costs relative to a modern coal-fired plant by 10–20 percent. During the early months of 2008, CO₂ traded in Europe between €19 and €24 per tCO₂.

Waste and Decommissioning

The spent fuel from a nuclear power plant is highly radioactive. Although its volume is small – the approximately 10,500 metric tons of heavy metal (tHM) produced annually by the world’s 439 nuclear power plants would

cover a space the size of a soccer field to a depth of 1.5 meters – it must be securely contained for tens of thousands of years. Today’s spent fuel is stored mainly on-site at the power plant where it was produced.

Figure K.7
Life-Cycle GHG Emissions from Different Electricity Generating Chains³



Source: Weisser, 2007.

Two different management strategies are being implemented for spent nuclear fuel. In the first strategy, spent fuel is reprocessed (or stored for future reprocessing) to extract usable material (uranium and plutonium) for new mixed oxide (MOX) fuel. Approximately one third of the world’s discharged spent fuel has been reprocessed. In the second strategy, spent fuel is considered as waste and is stored pending disposal. Based on more than 50 years of experience with storing spent fuel safely and effectively, there is a high level of technical confidence in both wet and dry storage technologies and in the ability to cope with rising volumes pending implementation of final repositories for all high-level waste.

As of today, China, France, India, Japan and the Russian Federation reprocess most of their spent fuel or store it for future reprocessing. Reprocessing plants are in operation in France, India, the Russian Federation and the United Kingdom (UK), although in 2007 the UK plant

at Sellafield was out of operation due to an internal leak. In Japan, active testing began at the new Rokkasho vitrification plant, with separated high-level wastes being combined with borosilicate glass. However, because of limited fabrication of MOX fuel, less than 50 percent of the world's existing reprocessing capacity is currently used. Canada, Finland, Sweden and the United States have opted for direct disposal, although in 2006 the United States announced a Global Nuclear Energy Partnership (GNEP), which includes the development of advanced recycling technologies for use in the United States. Most countries have not yet decided which strategy to adopt, and are currently storing spent fuel whilst keeping abreast of developments associated with both alternatives.

With regard to permanent high-level radioactive waste (HLW) repositories, the Finnish, Swedish and US repository programs continue to be the most developed, but none is likely to have a repository in operation much before 2020. The world's one operating geological repository is the Waste Isolation Pilot Plant (WIPP) in the United States. Since 1999, it has accepted long-lived transuranic waste generated by research and the production of nuclear weapons, but no waste from civilian nuclear power plants. In 2006 the US Environmental Protection Agency approved the WIPP's first recertification application, submitted in 2004. Recertification is required every five years.

France's new legislation on spent fuel management and waste disposal, which established spent fuel reprocessing and recycling of usable materials as French policy, also established deep-geologic disposal as the reference solution for high level, long-lived radioactive waste. The legislation sets goals to apply for a license for a reversible deep geological repository by 2015 and to open the facility by 2025. It also calls for operation of a fourth generation prototype fast reactor by 2020 in order to, among other tasks, test transmutation of long-lived radioisotopes.

The UK's Committee on Radioactive Waste Management concluded that the best disposal option for the UK is deep geological disposal, with 'robust interim storage' until a repository site is selected.

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The Swedish nuclear fuel and waste management company SKB applied in 2006 to the Swedish nuclear power inspectorate for a permit for an encapsulation plant in Oskarshamn. The encapsulation plant is the first step towards final disposal using the KBS-3 method, in which fuel is encapsulated in copper canisters and deposited in bedrock at a depth of approximately 500 meters. A final ruling on the application is not expected until after 2009, when the application for a final deep geological repository is scheduled to be submitted. Site investigations for a final repository are being carried out near Forsmark in Osthrammar and in the Laxemar area of Oskarshamn.

Following a three year, nation-wide consultative process, Canada's Nuclear Waste Management Organization recommended an "adaptive phased" approach to managing Canadian spent fuel. During the next 30 years spent fuel would continue to be stored at reactor sites, a suitable site for a deep geological repository would be selected, and a decision would be made whether to also construct a centralized interim shallow underground storage facility to start receiving spent fuel in about 30 years. With or without a centralized interim facility, the deep repository would begin accepting spent fuel in about 60 years' time.

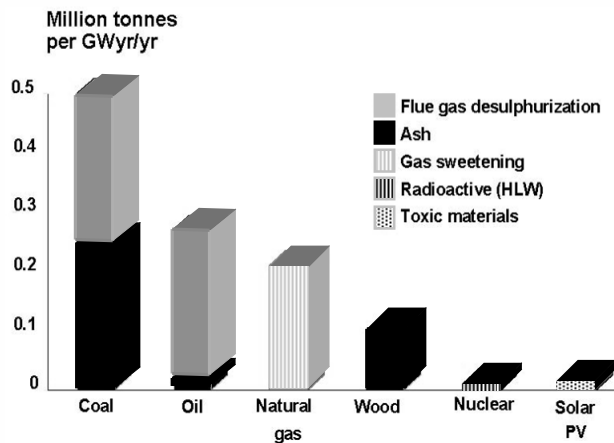
There is also renewed interest in the possibility of international repositories, both because of limited domestic options for waste disposal and because of new proposals to strengthen the global non-proliferation regime through international control of important parts of the nuclear fuel cycle, like uranium enrichment and spent fuel management. The International Atomic Energy Agency (IAEA) is actively pursuing this issue in connection with a study of possible multilateral oversight of the nuclear fuel cycle. In 2007 the UN Nuclear Regulatory Commission (NRC) approved the release of most of the Big Rock Point nuclear power plant site and most of the Yankee Rowe nuclear power plant site for unrestricted public use. Thus, ten power plants around the world have been completely decommissioned, with their sites released for unconditional use. Seventeen plants have been partially dismantled and

safely enclosed, 32 are being dismantled prior to eventual site release, and 34 are undergoing minimum dismantling prior to long-term enclosure.

As with GHG emissions, all electricity-producing technologies generate waste of sorts—some with a high level of radiation and toxicity. Radiation is relevant for nuclear, coal, oil, gas and geothermal power plants. All bring radioactive material in the Earth’s crust to the surface. The US Environmental Protection Agency (EPA) estimates that someone living within 50 miles of a coal-fired power plant receives an average dose of 0.3 microsieverts (μSv), while someone living within 50 miles of a nuclear power plant receives 0.09 μSv . Both are more than one thousand times less than the average dose received by people in the United States from X rays and other medical procedures, and more than ten thousand times less than their average dose of natural background radiation.

Figure 8 shows the level of waste generated by different technologies. On the basis of delivered electricity the volumes of toxic materials associated with the manufacture of solar photovoltaic cells are similar to the HLW from nuclear power.

Figure K.8
Solid Wastes from Different Electricity Generating Options



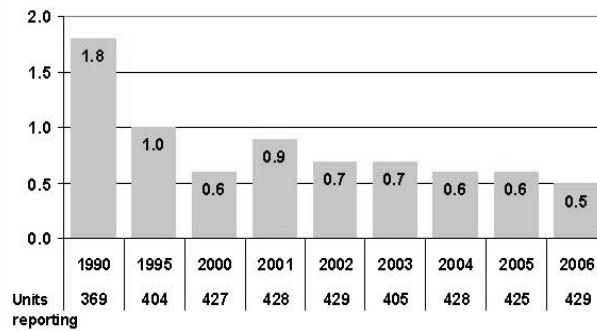
Safety

Significant health impacts from nuclear power plants thus arise only from major accidents that release radiation, of which there has been only one—the 1986 Chernobyl accident. The accident at Chernobyl was caused by severe design flaws coupled with serious operator mistakes. It was a catastrophic accident that cost lives and caused widespread suffering, but it also brought about major changes, including the founding of a “safety culture” of constant improvement, thorough analysis of experience and sharing of best practices. International mechanisms to facilitate exchange include the World Association of Nuclear Operators (WANO) – created in the wake of Chernobyl – and the International Nuclear Safety Advisory Group (INSAG), both of which help to spread best practices, tighten safety standards and infuse nuclear power plants around the world with a safety culture. Regular meetings of the IAEA/NEA Joint Incident Reporting System are an additional element of this global exchange process, where recent incidents can be discussed and analyzed in detail. Safety indicators, such as those published by WANO and reproduced in Figures 9 and 10, improved dramatically in the 1990s.

The Convention on Nuclear Safety brings countries together to report on how they are living up to their safety obligations and to critique each other’s reports. The international exchange of nuclear power plant operating experiences and, in particular, the broad dissemination of “lessons learned” are essential parts of maintaining and strengthening the safe operation of nuclear power plants. The collecting, sharing and analyzing of operating experiences are all vital safety management elements, and there is clear empirical evidence that learning from nuclear power plant operating experience has led to continuing improvements in plant safety.

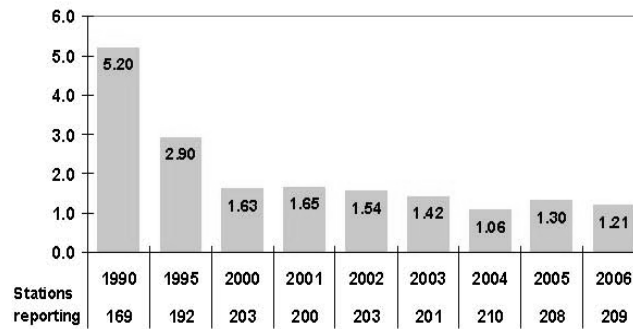
However, in some areas improvement has stalled in recent years. Also, the gap between the best and worst performers is still large, providing substantial room for continuing improvement. Since the 1986 accident at Chernobyl, enormous efforts have been made to upgrade reactor safety features, but facilities still exist at which nuclear safety assistance should be made a priority.

Figure K.9
Unplanned Scrams (Emergency Shutdowns) per 7,000 Hours Critical



Source: WANO 2006 Performance Indicators.

Figure K.10
Industrial Accidents at Nuclear Power Plants per 1,000,000 Person-Hours Worked



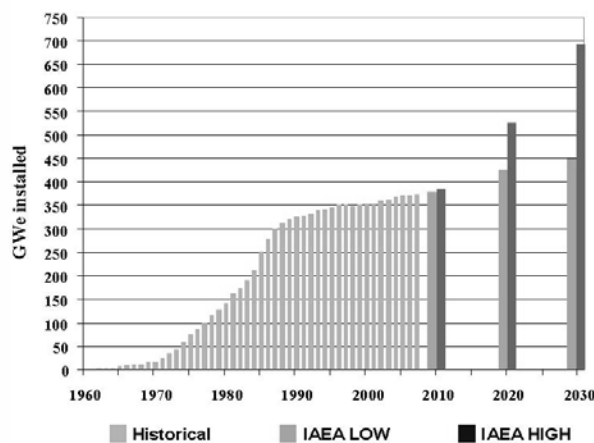
Source: WANO 2006 Performance Indicators.

Projected Growth for Nuclear Power

IAEA Projections

Each year the IAEA updates its low and high projections for global growth in nuclear power (see Figure 11). In 2007 both the low and high projections were revised upwards. The IAEA low projection assumes that no new nuclear power plants are built beyond what is under construction or firmly planned today, and old nuclear power plants are retired on schedule. In the updated low projection, global nuclear power capacity and generation reach 425 GW_e and 3,120 TWh respectively in 2020, compared to 372 GW_e and 2,618 TWh at the end of 2007. Between 2020 and 2030 capacity and generation remain essentially unchanged (3,325 TWh generated by 447 GW_e). The corresponding annual growth rate of nuclear power over the 2007–2030 period is 1.1 percent, i.e., considerably lower than the expected annual 1.6 to 2.8 percent per year expansion of total electricity demand over that period. As a consequence, the future market share of nuclear power may well slip below 10 percent by 2030.

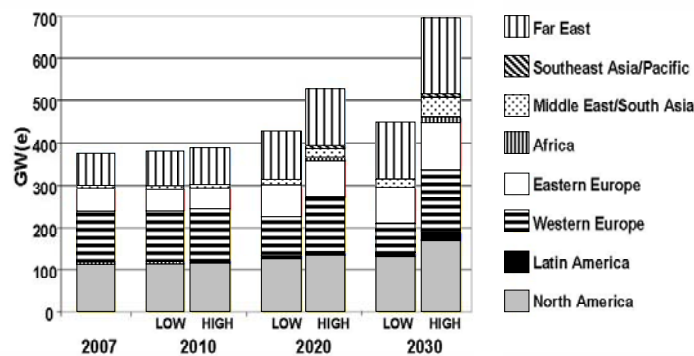
Figure K.11
Global Nuclear Power Capacity Projections of the
IAEA Low and High Scenarios



The updated IAEA high projection incorporates additional reasonable planned and proposed nuclear projects beyond those already firmly in the pipeline. At the global level, it shows steady growth to 692 GW_e, generating 5,141 TWh in 2030 (2.9 percent growth per year). Depending on the expected development of total electricity demand, the projected nuclear market share ranges from 13–16 percent by 2030.

However, the global aggregates in Figure 11 mask regional differences, particularly in the low projection. Nuclear electricity generation in Western Europe in the low projection drops by almost 40 percent between 2006 and 2030, as projected retirements consistently outpace new construction, but nuclear power generation in the Far East grows by 80 percent and in Eastern Europe by 75 percent. By 2030, 145 of today’s reactors, or 104 GW_e of generating capacity, will have been retired and 178 new reactors representing 181 GW_e will have been built. On average, the unit capacity of new nuclear builds is some 40 percent larger than the plants taken out of operation, and 85 percent of the retirements will be in Eastern and Western Europe. While there will be new reactors built in all regions, most will be in the Far East and Eastern Europe, with substantial but more limited new construction also in the Middle East and South Asia (see Figure 12).

Figure K.12
Regional Nuclear Capacity Projections of the
IAEA Low and High Scenarios



In the high projection, there are only 82 retirements (51 GW_e), and there is more than twice as much new construction—357 new reactors or 373 GW_e by 2030. Most of the retirements would still be in Europe. New construction would be spread more broadly, growing in all regions, although the Far East, Eastern Europe, the Middle East and South Asia are projected to experience above average growth.

Other Nuclear Power Projections

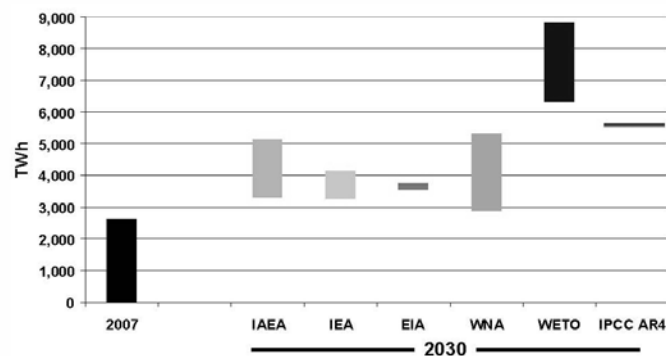
The IAEA's nuclear projections were not the only ones to have been revised upwards in 2007. Updated projections were also published by the US Energy Information Administration (EIA), the OECD International Energy Agency (IEA) and the World Nuclear Association (WNA). The IEA *World Energy Outlook 2007* includes a reference scenario plus an alternative scenario that assumes additional measures to enhance energy security and mitigate CO₂ emissions. The EIA International Energy Outlook presents a reference economic growth case enveloped by (a) a higher and lower economic growth outlook and (b) high and low world oil price variants of the reference case. The WNA based its projection on market expectations and nuclear industry expert opinions.

Each organization raised its nuclear projections except for the WNA, which reduced the high end of its range slightly. Figure 13 compares the ranges of the 2007 nuclear projections of the EIA, IEA, IAEA and WNA. The bars in Figure 13 show the spread between the “low” (IAEA), “reference” scenario (IEA), “low growth” (EIA) and “low nuclear expectation” (WNA) – the bottom of the respective bars – and the “high” (IAEA), “accelerated policy” (IEA), “high growth” (EIA) and “high expectations” (WNA)—the top of the respective bars.

The *World Energy Outlook* reference scenario is a “business-as-usual” scenario that assumes the continuation of current policies and trends. Projected nuclear electricity generation in this scenario is almost identical to that in the IAEA low projection. The measures in the alternative policy scenario to enhance energy security and mitigate CO₂ emissions are

expected to boost nuclear electricity generation but, as shown in Figure 13, not enough to match the IAEA high projection.

Figure K.13
Global Nuclear Electricity Generation in 2007 and the
Ranges of Projections for 2030 (from six studies)



Notes: Except for 2007 and the IPCC AR4 projection, the bottom part of each bar corresponds to the respective “low” or “reference projections”; the top of each bar to the “high,” “accelerated policy” or “carbon constraint/hydrogen scenarios.”

Figure 13 also shows the nuclear power ranges of two further studies: the *World Energy Technology Outlook 2050 – WETO H2* (EC, 2006), published by the European Commission (EC) in early 2007 – and the 4th Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), completed in 2007. Built on a business-as-usual or reference case, WETO H2 analyzes two specific scenarios that reflect political objectives of mitigating climate change and promoting new clean energy technologies. The reference case foresees a much faster expansion of nuclear-generated electricity—the 6,300 TWh by 2030 are approximately twice the amount projected by both the IEA and IAEA. While in the IAEA and IEA scenarios the nuclear share declines to 12–13 percent (IAEA) and 10 percent (IEA), the WETO cases project, after some decline by 2020, a return to the 16–17 percent market share

observed between the early 1990s and 2005. Although the reference case is essentially a continuation of existing economic and technological trends, the short-term constraints on the development of oil and gas production, receding public reservations against nuclear power and the implementation of moderate climate policies lead, after 2020, to a strong expansion of nuclear power for its climate-friendly characteristics and for reasons of energy security.

A “carbon constraint case” explores the consequences of more ambitious carbon emissions policies aimed at the long-term stabilization of atmospheric CO₂ concentrations. It involves only marginally higher nuclear electricity generation than the reference case, but the nuclear share approaches 19 percent due to the lower global demand for electricity in an inherently more energy efficient world economy.

The “hydrogen case” builds on the “carbon constraint case” and explores a series of technological breakthroughs that significantly increase the cost effectiveness of hydrogen technologies. A world that develops, commercializes and adopts hydrogen end-use technologies as well as supply infrastructures would boost demand for nuclear electricity to more than 8,800 TWh (top of the WETO bar for 2030 in Figure 13) or 1,200 GW_e installed capacity by 2030. In its AR4, Working Group III of the IPCC reviewed the literature on GHG mitigation potentials and costs and concluded that in a carbon emission constrained world, nuclear power could generate 18 percent of global electricity by 2030.⁴ Given that global electricity will have doubled by 2030, the 18 percent translates to a little more than the IAEA High projection for that year.

Several of the organizations whose projections are shown in Figure 13 are engaged in energy demand and supply analyses that extend to 2050 and beyond. The analyses and scenarios account for a changed overall energy resource situation including depletion of low-cost fossil occurrences or the likely fact that the most convenient sites for renewables will have already been utilized. Fossil fuels extracted in 2050 therefore come from higher cost categories than the cheaper fossil fuels against

which nuclear energy is competing in the short-term. Furthermore, such scenarios have become increasingly “climate interventionist” and include often stringent GHG emission constraints. In short, longer-term energy outlooks tend to break with short-term trends and associated projections. For example, the non-climate intervention scenarios of the IPCC project nuclear electricity to reach 15–26 percent for the year 2050.⁵ The analysis horizon of these scenarios extends to 2100. Having to supply energy services for another 50 years exerts enormous pressure on fossil resources and depletion considerations. Depletion of cheap fossil reserves as well as the lead-time requirements for building up alternative supply infrastructures stimulate an earlier market penetration of nuclear power (and renewables) than in scenarios which end in 2050.

The WETO cases in 2050 use between 14,800 TWh (reference case— 25 percent share) and 21,400 TWh (the climate motivated hydrogen case— 37 percent share) of nuclear electricity. The WETO cases assume the implementation of drastic climate change policies (carbon taxes, etc.) consistent with a definition of a 2°C increase in mean global temperature (or a maximum CO₂ concentration of 450 parts per million by volume [ppmv]) as the normative limit for the avoidance of dangerous anthropogenic interference with the climate system. Other critical assumptions are accelerated innovation and technology learning, technology diffusion and adoption of Generation IV nuclear technologies and fuel cycles. Nuclear power would thus become a major supplier of both electricity and hydrogen. The IEA developed a “Sustainable Development Vision Scenario”⁶ which for 2050 foresees almost 32,000 TWh of nuclear electricity production – a 12-fold increase over current production levels – and is certainly an outlook that breaks with its usual cautious projections.

Concluding Remarks

Taken together, these new projections and scenarios present a picture with opportunities for significant nuclear expansion, but still with substantial uncertainty. A number of developments since 2006 suggest that the

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renewal of interest in nuclear power may soon lead to increases in construction. These include expansion plans recently announced by Japan and the Russian Federation, as well as the previously announced expansion plans of China, India, the Republic of Korea and Pakistan. They include a large number of intended Combined License applications that companies and consortia have announced in the United States, which together cited approximately 32 new reactors. They include two site preparation applications in Canada and the UK energy review's conclusion that new nuclear power stations would make a significant contribution to meeting the UK's energy policy goals. They also include a joint feasibility study launched by utilities from Estonia, Lithuania and Latvia of a new nuclear power plant to serve all three countries; the Belarus government's approval of a working plan for construction of the country's first nuclear power plant to follow the expiration of a 10-year moratorium on nuclear construction; announcements made by Egypt, Indonesia, Nigeria, Poland, Turkey and Vietnam on steps they are taking toward their first nuclear power plants; and the explicit interest in nuclear power expressed by more than two dozen countries that currently do not operate nuclear power plants. Whether and how quickly this interest ripens into a broader commitment to nuclear power will in large part depend on economics: on the affordability of nuclear power relative to alternatives, on the ability of next generation nuclear technologies to cut capital costs, on the ability of nuclear power to deliver its services and benefits at reasonable costs, and on creative fuel cycle arrangements that allow countries to enjoy the benefits of nuclear power plants without the need to incur the costs of nuclear infrastructure (take-back and leasing of nuclear fuel or nuclear batteries). It will also depend on government policies: environmental considerations driving or driven by the Kyoto Protocol, and supply/security considerations driving or driven by the need to strengthen the NPT. Most importantly, however, it will depend on the continued safe and economic operation of the current fleet of nuclear power plants around the world.