Nuclear Power – Global Status and Trends

a report by

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Status and Trends

As of June 2006, there were 441 nuclear power reactors in operation around the world. They total 369GW(e) of generating capacity and supply about 16% of the world's electricity. This percentage has been roughly stable since 1986, indicating that nuclear power has grown at the same rate as total global electricity for 20 years. There are also 27 new reactors under construction. *Table 1* shows the distribution across countries of both operating reactors and those under construction.

As shown in the table, nuclear power is mainly used in industrialized countries. In terms of new construction, however, the pattern is partly reversed. Sixteen of the 27 new reactors under construction (59%), and half of the 22GW(e) under construction are in developing countries.

Current expansion, as well as near-term and long-term growth prospects, are centred in Asia. Of the 27 reactors under construction worldwide, 16 are in Asia. In addition, twenty-five of the last 35 reactors to have been connected to the grid are in Asia.

Figure 1 shows historical growth in worldwide nuclear generating capacity since 1960 plus high and low projections through 2030 by the International Atomic Energy Agency (IAEA).[1] The low projection assumes that no new nuclear power reactors will be built beyond those already under construction or currently planned. Nuclear power capacity grows only slightly in this projection, to 416GW(e) in 2020, before leveling off. The high projection incorporates nuclear projects proposed beyond those already firmly committed. Global nuclear power capacity in this projection grows steadily to 640GW(e) in 2030, an average growth rate of slightly over 2% per year. While both projections show significant differences in different parts of the world, both project greatest growth in the Far East. There is also significant expansion in Eastern Europe in both projections, and for North America in the high projection. In Western Europe, there is a contraction in the low projection as retirements outpace new construction, but substantial growth in the high projection. Growth rates are high in the Middle East and South Asia in both projections, although these regions start from a small 2005 base.

In recent years expectations for nuclear power have been rising: i.e. more people are expecting future growth closer to the high projection in *Figure 1* than to the low projection. There are five reasons.

First is strong performance. Nuclear power's good and lengthening track record is reflected in the 11,991 reactor-years of experience shown in *Table 1*, improved capacity factors (from 73% in 1990 to 83% in 2004), lower generating costs and an excellent safety record.

There has been one accident with major off-site consequences — at Chernobyl in 1986. That accident cost lives and caused widespread misery. 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. This safety culture has been demonstrating its effectiveness for two decades, and this safety record provides the basis for countries considering constructing nuclear power plants.

Second, energy forecasts keep showing persistent long-term growth, which increases interest in all energy sources.

Third is energy supply security. In the 1970s concerns about supply security, triggered by the oil shocks, were a major cause of nuclear expansion in both Japan and France. Similar concerns may also prove important today.

Fourth are new environmental constraints, particularly the entry-into-force of both the Kyoto Protocol and the EU Emissions Trading Scheme in 2005. The

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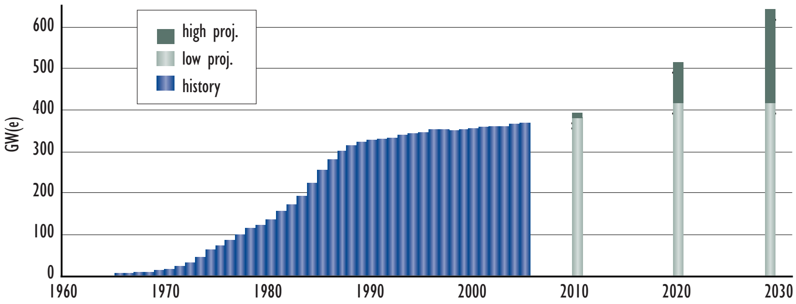
1. *IAEA (International Atomic Energy Agency), Energy, Electricity and Nuclear Power Estimates, Reference Data Series No. 1, July 2005 Edition, IAEA, Vienna.*

Figure 1: Installed Nuclear Power Generating Capacity Worldwide



The blue bars to the left show historical growth from 1960 through 2005. The bars on the right show the IAEA's latest low and high projections.

complete nuclear power chain, from resource extraction to waste disposal, including reactor and facility construction, emits only 1–6 grams of carbon equivalent per kilowatt-hour. This is about the same as wind and hydropower and well below coal, oil and natural gas. In the past, nuclear power's advantage of very low greenhouse gas (GHG) emissions has been invisible to investors, as the lack of restrictions or taxes on such emissions meant there was no economic value to their avoidance. Now, in countries with emission restrictions, there is a tangible financial benefit to avoiding GHG emissions.

Fifth are policy developments favourable to nuclear power in key countries around the world. These include specific nuclear power expansion plans in countries such as India, China, Japan, the Republic of Korea, the Russian Federation and France. They include new energy legislation in the US and statements by the British prime minister in anticipation of a new review of UK energy policy that was due out in June 2006. They also include the broad support expressed by high-level representatives of 74 governments, including 25 representatives at the ministerial level, at a conference organised by the IAEA and French government in Paris in 2005. The vast majority of participants affirmed that nuclear power can make a valuable contribution to meeting energy needs and sustaining the world's development in the 21st century, for a large number of both developed and developing countries. Among them were a number of countries currently without nuclear power programmes, such as Egypt, Indonesia, Morocco, Poland, Turkey and Vietnam.

India currently leads the world in nuclear power construction, with eight of the world's 27 reactors under construction. It plans a 10-fold nuclear power increase between 2002 and 2022 to 10% of the electricity supply, and a 100-fold increase to 2052 to 26% of the electricity supply. A 100-fold increase is equivalent to average growth of 9.2%/yr, identical to average global growth in nuclear power from 1970 through 2004.

China is experiencing tremendous energy growth and is developing all energy sources, including nuclear power. It has three reactors under construction and plans a five- to six-fold expansion in just the next 15 years.

Japan has 55 reactors in operation, one under construction, and plans to add 10 reactors by 2014, increasing nuclear power's share of electricity to more than 40%. South Korea connected its 20th reactor in 2005 and started site preparations for two more. Russia has 31 nuclear power plants in operation and four under construction, second only to India. In 2005 construction started at Olkiluoto-3 in Finland, the first new construction in Western Europe since 1991. France will start construction of a new 1,600MW(e) reactor in 2007.

Some believe that nuclear power's future in the US will be a critical determinant of its future worldwide. For several decades, US nuclear expansion has taken the form of power uprates and licence renewals at existing nuclear power plants. Forty-two reactors have received 20-year license renewals, for a total licenced lifetime of 60 years each. New energy legislation in 2005, which provides government coverage of costs associated with certain potential licensing delays and a production tax credit for up to 6,000MW(e) of advanced nuclear power capacity, has, however, prompted broad industry interest in new construction. The US Nuclear Regulatory Commission is reviewing three applications for early site permits, and it expects to receive four applications for combined construction and operating licences by the end of 2007, with several more possible in 2008.

The new interest shown in developing countries faces challenges associated with high capital costs, infrastructure requirements, waste management and the fuel cycle. Possible responses to these challenges include regional co-operation, interconnected grids, shared facilities, shared education and training programmes, shared expertise in safety and operation, and shared skilled labour pools.[2] They also include small and medium-size reactor (SMR) designs that allow a more incremental investment than is required for a big reactor, and provide a better match to grid capacity in countries with smaller grids. In addition, new international fuel cycle arrangements, such as the US Global Nuclear Energy Partnership and the Russian proposal for a system of international centres providing fuel cycle services, could reduce burdens associated

2. *Sokolov Y A, McDonald A, "The Nuclear Power Options for Africa",* ATDF Journal*, Vol 2, Issue 2, pp 12–18, 2005 (http://www.atdforum.org/IMG/pdf/nuclearpower_options_Africa.pdf).*

Table 1: Nuclear Power Reactors in Operation and Under Construction in the World (as of June 2006)[a]

Country	Reactors in operation		Reactors under construction		Nuclear electricity supplied in 2005		Total operating experience through 2005	
	No of units	Total MW(e)	No of units	Total MW(e)	TW·h	% of Total	Years	Months
Argentina	2	935	1	692	6.4	6.9	54	7
Armenia	1	376			2.5	42.7	38	3
Belgium	7	5,824			45.3	55.6	205	7
Brazil	2	1,901			9.9	2.4	29	3
Bulgaria	4	2,722	2	1,906	17.3	44.1	137	3
Canada	18	12,599			86.8	14.6	442	8
China	10	7,572	3	2,610	50.3	2.0	56	11
Czech Republic	6	3,368			23.3	30.5	86	10
Finland	4	2,676	1	1,600	22.3	32.9	107	4
France	59	63,363			430.9	78.5	1,464	2
Germany	17	20,339			154.6	31.0	683	5
Hungary	4	1,755			13.0	37.2	82	2
India	15	3,040	8	3,602	15.7	2.8	252	0
Iran, Islamic Republic of			1	915				
Japan	55	47,593	1	866	280.7	29.3	1,221	3
Korea, Republic of	20	16,810			139.3	44.7	259	8
Lithuania	1	1,185			10.3	69.6	39	6
Mexico	2	1,310			10.8	5.0	27	11
Netherlands	1	449			3.8	3.9	61	0
Pakistan	2	425	1	300	2.4	2.8	39	10
Romania	1	655	1	655	5.1	8.6	9	6
Russian Federation	31	21,743	4	3,775	137.3	15.8	870	4
Slovakia	6	2,442			16.3	56.1	112	6
Slovenia	1	656			5.6	42.4	24	3
South Africa	2	1,800			12.2	5.5	42	3
Spain	8	7,446			54.7	19.6	237	2
Sweden	10	8,910			69.5	44.9	332	6
Switzerland	5	3,220			22.1	32.1	153	10
Ukraine	15	13,107	2	1,900	83.3	48.5	308	6
United Kingdom	23	11,852			75.2	19.9	1,377	8
United States	103	98,145			780.5	19.3	3,087	6
Total[b]	441	369,122	27	21,421	2,625.9	16%	11,991	8

a. Data are from the IAEA'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, 4,904MW(e) in operation; 2 units, 2,600MW(e) under construction; — 38.4TW·h of nuclear electricity generation, representing 20.3% of the total electricity generated in 2005; — 146 years, 1 month of total operating experience.

with fuel cycle and waste management issues, thus lowering the threshold for introducing nuclear power.

Economics

The most important determinant of nuclear power's future is cost-competitiveness compared with alternatives. Nuclear power plants have a 'front-loaded' cost structure, i.e. they are relatively expensive to build but relatively inexpensive to operate. Thus, existing well-run operating reactors 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 front-loaded cost structure is less attractive to a private investor in a liberalised market that values rapid returns, than to a government that can look longer-term, particularly in a regulated market that assures attractive returns. Private investments in liberalised markets will also depend on the extent to which energy-related external costs and benefits (e.g. pollution, GHG emissions, waste and energy supply security) have been internalised. In contrast, government investors can incorporate such externalities directly into their decisions. Also important are regulatory risks. Different countries have different approval processes, and political support

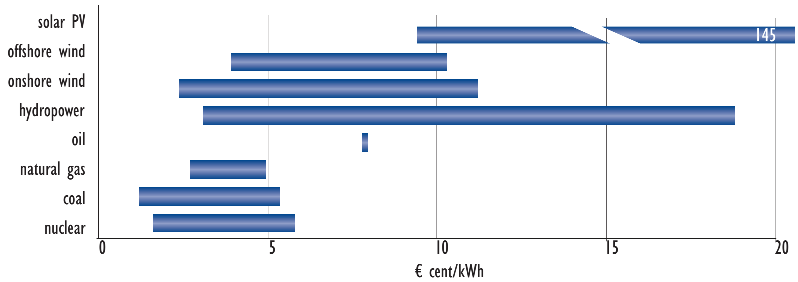
Table 2: Years of Resource Availability for Various Nuclear Technologies[4]

Reactor/Fuel cycle	Years of 2004 world nuclear electricity generation with identified conventional resources	Years of 2004 world nuclear electricity generation with total conventional resources	Years of 2004 world nuclear electricity generation with total conventional resources and phosphates
Current fuel cycle (LWR, once-through)	85	270	675
Pure fast reactor fuel cycle with recycling	5,000–6,000	16,000–19,000	40,000–47,000

varies. Some processes are less predictable than others and create greater investment risks.

Figure 2 summarizes new construction cost estimates from seven recent studies.[3] It shows fairly broad cost ranges, with much overlap among different technologies. Except for oil-fired electricity generation (estimated in only one study) the high end of each cost range is at least 100% higher than the low end. This is due partly to different technological assumptions across the studies, but also to the factors listed above. Moreover, the ranges in *Figure 2* incorporate only internalised costs. 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 2: The Ranges of Levelized Costs Associated with New Construction as Estimated in Seven Recent Studies for Electricity Generating Technologies in Different Countries (PV = photovoltaic)



Resources and Waste

Spot prices on the uranium market have risen more than five-fold since 2000, to US$117/kgU. However, the latest compilation of global uranium resources by the IAEA and the OECD/NEA expects total conventional resources of uranium available at less than US$130/kgU to last several hundred years using current technology and current consumption rates (second column from the right in *Table 2*, top row of numbers). If unconventional uranium resources associated with phosphate deposits are included, the figure more than doubles (right column), and if recycling technologies are used, resource longevity in measured in thousands of years (bottom row). Since all the numbers in *Table 2* are based on current uranium consumption rates, they will all decrease in proportion to any expansion of nuclear power.

For high-level waste, the most progress on disposal facilities has been made in Finland, Sweden and the USA although none is expected to be in operation much before 2020. In Finland construction work began in 2004 on the underground laboratory at Olkiluoto that will be used to characterize the local geology and may later be incorporated into the final repository. Sweden has begun detailed geological investigations at two candidate sites. The Swedish Nuclear Fuel and Waste Management Company (SKB) hopes to make a final site proposal by about 2008. In the US the Waste Isolation Pilot Plant in New Mexico began accepting military transuranic waste in 1999 for permanent disposal, and in 2002 the US government decided to proceed with the Yucca Mountain disposal site. A licence application for the repository at Yucca Mountain, US, was scheduled for submittal to NRC in 2004, but has been delayed.

Conclusion

Nuclear power is not a one-size-does-fit solution. Each country's situation is different, and each must make its own energy choices. But nuclear power will certainly be part of the mix of solutions. The current outlook is that it will be a growing part of the mix, driven by expanding energy needs, energy security concerns, limits on greenhouse gas emissions and the sustained strong performance of nuclear plants.

3. *The Massachusetts Institute of Technology, The Future of Nuclear Power, Cambridge, Massachusetts, USA (2003); The University of Chicago, The Economic Future of Nuclear Power, Chicago, Illinois, USA (2004); The Royal Academy of Engineering, The Cost of Generating Electricity, London, UK (2004); General Directorate for Energy and Raw Materials (DGEMP), French Ministry of the Economy, Finance and Industry, Paris, France (2003); Ministry of Economy, Trade and Industry, Tokyo, Japan (2004); Matt Ayres, Morgan MacRae and Melanie Stogran, Levelised Unit Electricity Cost Comparison of Alternate Technologies for Baseload Generation in Ontario, Canadian Energy Research Institute (CERI), Calgary, Alberta, Canada, 2004; Nuclear Energy Agency and International Energy Agency, Projected Costs of Generating Electricity: 2005 Update, Organisation for Economic Co-operation and Development, Paris, 2005.*
4. *NEA/IAEA (2006), Uranium 2005: Resources, Production and Demand, OECD Nuclear Energy Agency, NEA No. 6098, Paris.*