Nuclear power: status and outlook

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Nuclear power is important. Worldwide there are 441 nuclear power plants (NPPs) operating at the end of 2002, supplying 16% of global electricity generation.[1] In 2001, 20% of the US's electricity was nuclear, 27% of Spain's, 31% of Germany's, 34% of Japan's, 39% of the Republic of Korea's, 44% of Sweden's and 77% of France's. Cumulative operating experience stands at over 10,000 reactor-years.

Six new NPPs were connected to the grid in 2000, three in 2001 and six in 2002. Figure 1 summarises world nuclear experience as of December 2002.

Looking ahead to nuclear power's prospects in the new century, four features stand out:

1. New nuclear power plants are not being built fast enough to maintain nuclear power's 16% share of global electricity generation.
2. Current expansion, as well as near-term and long-term growth prospects, are centred in Asia.
3. But 2002 also saw some signs of revitalised growth in Western Europe and North America, where growth has stagnated because of economics, market liberalisation, and excess capacity.
4. Long-term projections for nuclear power, particularly in the event of international agreement to significantly limit greenhouse gas (GHG) emissions, are more bullish than near-term trends. The key determining factor will be economics.

Near-term outlook

The most significant recent trend has been that of steady increases in NPP availability factors. Their cumulative impact since 1990 is equivalent to building 33 new NPPs of 1000 MWe each. Without such improvements in availability factors, nuclear power could not have maintained its 16% share of global electricity.

Growth is centred in Asia. Of 33 reactors currently under construction worldwide, 20 are located either in China; Taiwan, China; the Republic of Korea; the Democratic People's Republic of Korea; Japan; or India. Seventeen of the last 26 reactors to be connected to the grid are in the Far East and South Asia. And the greatest growth in nuclear electricity production in 2001 was in Japan.

Within Asia, capacity and production are greatest in Japan (54 NPPs) and the Republic of Korea (18 NPPs). Both countries lack indigenous energy resources, and consequent concerns about supply diversity and security make the construction of new NPPs more economically competitive. Seven NPPs are in operation in China; four more are under construction. Taiwan, China has six NPPs with two more under construction. India has 14 small NPPs (up to 220 MWe) operating, and eight under construction.

In the United States there is no construction. The key development is market liberalisation, which has prompted consolidation, acquisitions, upratings and licence extensions. The average availability factor rose from 72% in 1990 to 89.7% in 2001, and nuclear generation costs dropped to record lows. The US Nuclear Regulatory Commission (NRC) has granted licence extensions to 60 years to 10 US reactors, with 20 more under review. In Canada, near-term nuclear expansion will probably take the form of restarting some or all of eight nuclear units that are currently laid up. More novel uses of nuclear energy are also under discussion, including dedicated nuclear generated heat and hydrogen for mining the Alberta tar sands.

Western Europe has 146 reactors. Overall capacity is likely to remain near existing levels, even with nuclear phase-outs in Belgium, Germany and Sweden. The most significant possibility for new nuclear capacity is in Finland. In May 2002 the Finnish Parliament ratified the Government's favourable "decision in principle" on Teollisuuden Voima Oy's (TVO's) application to build a fifth Finnish NPP. In September 2002 TVO invited bids from reactor vendors. Eastern Europe and the economies in transition have 68 operating NPPs. Ten more are under construction.

In Latin America there are six operating NPPs and one under construction. Two NPPs are operating in South Africa.

Economics

New NPPs are most attractive where energy demand growth is rapid, alternative resources are

Figure 1: Nuclear power reactors in operation and under construction in the world (as of December 2002)

Country	Reactors in operation		Reactors under construction		Nuclear electricity supplied in 2001		Total operating experience	
	No of units	Total MW(e)	No of units	Total MW(e)	TW·h	% of total	Years	Months
Argentina	2	935	1	692	6.54	8.19	48	7
Armenia	1	376			1.99	34.82	35	3
Belgium	7	5,760			44.1	58.03	184	7
Brazil	2	1,901			14.35	4.34	23	3
Bulgaria	4	2,722			18.24	41.55	125	2
Canada	14	10,018			72.35	12.85	461	2
China	7	5,318	4	3,275	16.68	1.14	31	6
Czech Republic	6	3,468			14.75	19.76	68	10
Finland	4	2,656			21.88	30.54	95	4
France	59	63,073			401.30	77.07	1,287	2
Germany	19	21,283			162.30	30.52	629	1
Hungary	4	1,755			14.13	39.09	70	2
India	14	2,503	8	3,610	17.32	3.72	209	5
Iran, Islamic Republic of			2	2,111			0	0
Japan	54	44,287	3	3,696	321.94	34.26	1,070	4
Korea, Dem. Peoples Rep. of			1	1,040			0	0
Korea, Republic of	18	14,890	2	1,920	112.13	39.32	202	7
Lithuania	2	2,370			11.36	77.58	34	6
Mexico	2	1,360			8.11	3.66	21	11
Netherlands	1	450			3.75	4.16	58	0
Pakistan	2	425			1.98	2.86	33	10
Romania	1	655	1	655	5.05	10.46	6	6
Russian Federation	30	20,793	3	2,825	125.36	15.40	731	4
Slovakia	6	2,408	2	776	17.10	53.44	97	0
Slovenia	1	676			5.03	38.98	21	3
South Africa	2	1,800			13.34	6.65	36	3
Spain	9	7,574			61.07	26.88	210	2
Sweden	11	9,432			69.20	43.85	300	1
Switzerland	5	3,200			25.29	35.96	138	10
Ukraine	13	11,207	4	3,800	71.67	46.36	266	10
United Kingdom	31	12,252			82.34	22.44	1,301	8
United States of America	104	98,230			768.83	20.35	2,767	8
Total	**441**	**358,661**	**33**	**27,100**	**2,543.57**		**10,696**	**4**

Note: The total includes the following data in Taiwan, China:
- 6 units, 4884 MW(e) in operation; 2 units, 2700 MW(e) under construction;
- 34.09 TW·h of nuclear electricity generation, representing 21.57% of the total electricity generated there;
- 128 years 1 month of total operating experience.

scarce, energy supply security is a priority or nuclear power is important for reducing air pollution and GHG emissions. Most current construction and planned expansion is therefore in Asia.

But prospects have begun to improve in Western Europe and North America. What will be needed to make the business case in these markets, where liberalisation has progressed furthest? We illustrate the issues with three examples - from the US, Finland and the UK.

There are three challenges:

1. Achieving continuing cost reductions so that new nuclear power plants are economically competitive with constantly improving alternatives.
2. Overcoming the "front-loaded" nuclear cost structure, with its current high capital and low operating costs, which is a disadvantage in liberalised markets that value rapid returns.
3. Eliminating non-market barriers[2].

The US strategy has concentrated first on eliminating non-market barriers, i.e. streamlining the regulatory process (e.g. bankable early site permits and joint construction-operation licences), approval of the Yucca Mountain disposal site, certification of three new designs, and extension of the Price-

Anderson Act. Regarding Point 2, the US is reviewing options for better aligning short-term market incentives with long-term interests in nuclear expansion in the new National Energy Policy. Point 1, cost reduction, is left largely to the private sector.

In Finland, a new NPP is more economical for TVO than the best alternative – likely additional natural gas imports from Russia. Three features of TVO's situation, however, may be less pertinent elsewhere in Europe. First, TVO is owned by Finnish industry and power companies and supplies electricity to its shareholders at cost. Nuclear power's front loaded cost structure is thus less of a concern. Second, Russia supplies 100% of Finland's natural gas. Further increasing dependence on Russian gas increases financial and energy security risks. Third, Finland has been a leader in taxing carbon emissions, but will have to further limit emissions under the Kyoto Protocol. This creates an additional financial risk for fossil alternatives to a new NPP.

The importance of "situational economics" is vividly illustrated at the other end of the spectrum by the financial crisis at British Energy (BE). In September 2002, BE sought government support to stave off bankruptcy. As of this writing BE is still afloat, supported by emergency government loans that run through March 9, 2003. But bankruptcy looms absent changes in BE's economic setting. The crisis was triggered by BE's failure to negotiate lower costs for waste management services from British Nuclear Fuels plc (BNFL). BNFL, whose only shareholder is the UK government, reprocesses spent fuel rather than stores it, although storage is cheaper. The impact is substantial as BE's former Chairman Robin Jeffrey noted in 2001: "Had direct disposal been the UK policy on terms analogous to the US, then BE would have been in profit in the UK. Conversely, had reprocessing been adopted in the US, then our North American profit would have been wiped out." Other economic burdens are the UK's climate tax levy, which the government applies to nuclear power although it emits virtually no GHGs; property taxes that are higher than those applied to competitors; and the huge drop in British wholesale electricity prices due to a combination of liberalisation and excess UK capacity. Most of these economic burdens arise from UK government policies.

The other two economic challenges – high capital costs and a front-loaded cost structure – are more within the control of utilities and nuclear vendors. Continuing improvements to reduce costs will always be necessary because competitors also continuously improve. However, the fact that improvements often entail substantial "learning-by-doing" creates particular challenges for the nuclear industry. Much of the industry's innovative expertise is in established nuclear countries where growth prospects are limited. Where growth prospects are best, including developing countries in Asia, there may be an understandable preference for proven - rather than innovative - designs. To speed up the rate at which the market in developing countries, where demand is growing fastest, can provide the learning-by-doing for innovations from outside (as well as inside), vendors and buyers will need creative risk sharing arrangements that strike the right balance between the reassurance needed in the expanding market country, and the profit incentive for innovation needed in the supplier country. Similarly, making nuclear power's currently front-loaded cost structure more attractive to myopic liberalised markets will depend partly on industry and customer innovations in trading arrangements, risk-sharing, and partnerships.

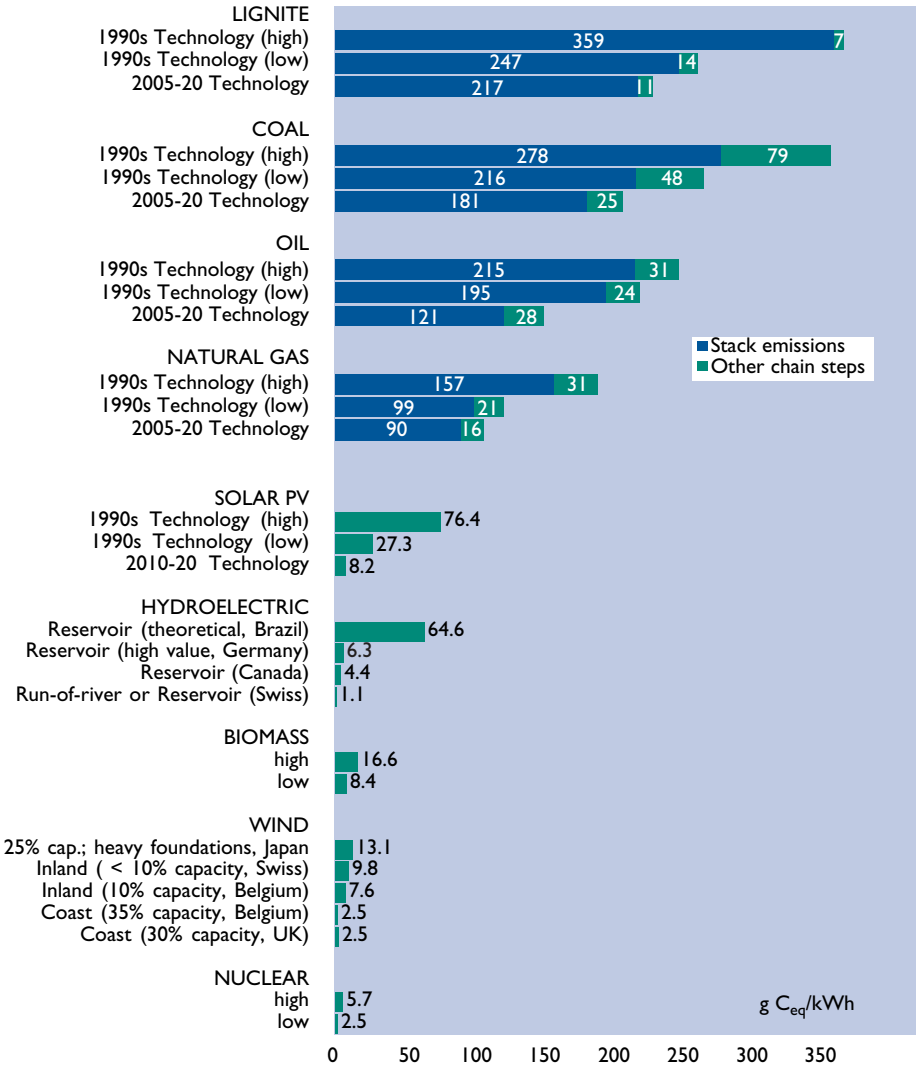
Environmental developments

The biggest event in 2002 concerning nuclear power and the environment was the World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa. In preparation for WSSD, nuclear power had been exhaustively debated at the Ninth Session of the Commission on Sustainable Development (CSD-9) in 2001. The first outcome was that parties "agreed to disagree," approving text stating that some countries view nuclear as an important contributor to sustainable development and others do not. Second, there was unanimous agreement that "the choice of nuclear energy rests with countries."

The expectation prior to Johannesburg was that most parties had little interest in repeating the CSD-9 nuclear debate. However, several delegations attempted to remove the phrase "advanced energy technologies" from "positive technology lists" (i.e. lists of technologies that parties agree to encourage) in the Johannesburg Implementation Plan. They (and others) understood the phrase as code for nuclear power. The efforts were unsuccessful, so nuclear power's code phrase is included in the Implementation Plan's relevant "positive technology lists," something of an improvement for nuclear power over the CSD-9 outcome.

A more visible debate at the WSSD concerned targets and timetables for renewable energies' share of future energy supplies. Nuclear power and renewable energy are not intrinsically in conflict, but targets and timetables create conflict. A minimum mandatory percentage for renewables creates a

Figure 2: Full energy chain GHG emissions from electricity generation



Source: **Spadaro *et al.*, 2000**

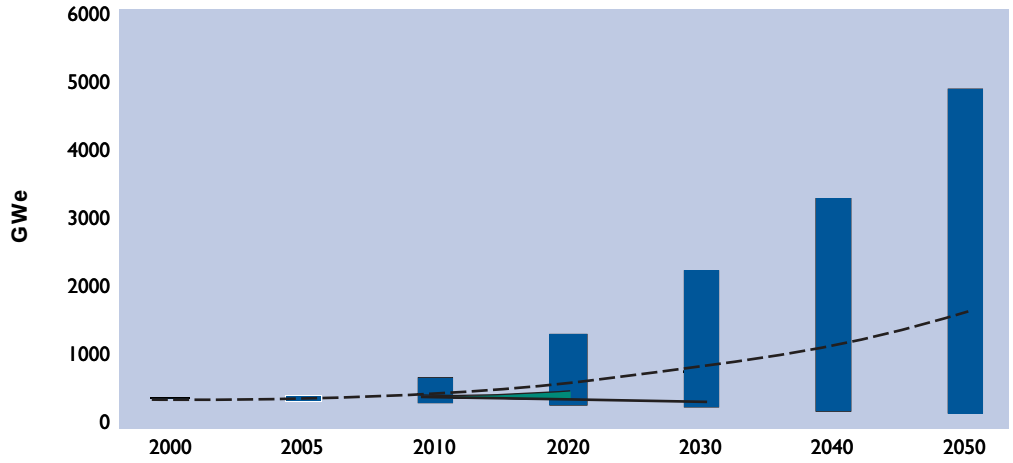
mandatory cap for everything else – another non-market barrier. Through the WSSD's rejection of targets and timetables for renewables, nuclear power effectively avoided the EU's non-market barrier being extended to the rest of the world.

With the ratifications of Canada and Poland in December 2002, the Kyoto Protocol needs only ratification from Russia (or the US, but that is extremely unlikely) to trigger entry-into-force. At the WSSD Russia spoke encouragingly about ratification and currently plans to submit the issue to the Duma after the Moscow World Climate Conference scheduled for September and October 2003. The Protocol's entry-into-force would be an important step towards attaching a tangible economic value to nuclear power's avoidance of GHG emissions. Although nuclear power produces virtually no greenhouse gases (Figure 2), and the Intergovernmental Panel on Climate Change (IPCC) estimates that it has the greatest GHG mitigation potential of all electricity supply options (IPCC, 2001), these advantages are invisible to investors. With very few exceptions, there are no restrictions or taxes on GHG emissions and thus no economic value to their avoidance. Currently, the Kyoto Protocol is the only operative route toward widespread, coordinated restrictions.

Efforts to attract key additional countries to accept GHG emission limits after 2008-2012, the period covered by the Kyoto Protocol, are likely to reopen negotiations on the exclusion of nuclear projects from the clean development mechanism (CDM) and joint implementation (JI). The exclusions were the result of political horse-trading, not compelling logic, and can be reversed by political horse-trading. Key countries for expanding the effectiveness of the Kyoto Protocol are the US and large developing countries (e.g. China, India, Brazil).

Figure 3: Nuclear capacity projections from three sets of scenarios

The vertical bars show the range projected by the IPCC, with the dotted line indicating the IPCC medians.
The green triangle shows the range between the IAEA high and low projections through 2020.
The heavy black line is the latest IEA Reference Scenario.



All have an interest in nuclear power, and thus in reopening the Protocol's current nuclear exclusions.

Political developments

There have been a few changes in Europe's political map with respect to nuclear energy. The new French government is expected to be more supportive of nuclear energy than its predecessor and is accelerating a nationwide nuclear debate to among other things increase the strength of Framatome ANP's likely bid to build the new Finnish reactor. In Germany, however, voters returned to power the Red-Green coalition that engineered Germany's nuclear phase-out law. In Sweden they did the same for the Social Democrat led government that supports Sweden's nuclear phase-out. And in January 2003, Belgium became the third country to pass nuclear phase-out legislation, completing passage of a law requiring nuclear power plants to shut down after 40 years of operation.

Looking to the East, in 1999 the EU targeted eight reactors in accession candidate countries for closure based on expert opinion that it was not possible, at reasonable cost, to modernise them sufficiently to reach a satisfactory safety level. In June 2002 Lithuania, which had agreed to close Ignalina-1 in 2005, also agreed to shut Ignalina-2 in 2009 in exchange for "adequate and additional financing", while keeping open the option of building a state-of-the-art nuclear power plant. Bulgaria shut down Kozloduy-1 and -2 on December 31, 2002 to meet a prior commitment to the EU to close them "by 2003". The EU continues to press for the additional closure of Kozloduy-3 and -4 by 2006. In September Bulgaria called for a binding review of safety improvements at Kozloduy-3 and -4, citing an IAEA conclusion that the plants have essentially reached a level of safety comparable to that of similar-vintage plants elsewhere. Opinion polls show a majority of Bulgarians believe the EU's insistence on closure will better protect EU electricity producers from low-cost Bulgarian competition, than it will those near Kozloduy from safety risks.

The projection gap

Given marginal economics of new NPPs in liberalising markets, remaining non-market barriers, and no investor benefit from GHG avoidance, intermediate-term global projections for nuclear power are not auspicious. The OECD International Energy Agency's (IEA) reference case projects nuclear's share of global electricity generation dropping to 9% by 2030. The IAEA projects a drop to between 12% and 14% in 2020.

The view beyond 2030 looks different. The vertical bars in Figure 3 show nuclear capacity projections corresponding to 40 reference scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). None of the scenarios includes policies to mitigate climate change, so nuclear projections that do could be even higher. The IAEA and IEA intermediate-term projections are shown in the lower left by the green triangle (IAEA) and heavy black line (IEA). Even the IAEA high projection remains below the IPCC median.

The "projection gap" between the intermediate-term scenarios and long-term scenarios is due to differing assumptions. The absence of new North American or Western European NPPs (other than Finland's) in the IEA and low IAEA projections

assumes hostile or indifferent political environments, no innovation and little progress on new NPP costs. In contrast, the long-term scenarios assume that nuclear costs improve and investments are based largely on economics in a politically neutral market. Scenarios with the largest nuclear growth also assume that nuclear energy breaks out of the "electricity ghetto" and into markets for heat and, via hydrogen, transportable chemical fuels. But even in the near term, closing the projection gap will require continuing progress on costs, smoothing nuclear power's front-loaded cost structure, and eliminating non-market barriers.

The IAEA is active in all these areas. Our International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) includes both developed and developing countries and both supplier and user countries (current and potential). INPRO complements the focus on concrete research and development in the US-led Generation IV International Forum (GIF), which selected six specific concepts in 2002 for future development - the gas cooled fast reactor, lead cooled fast reactor, sodium cooled fast reactor, supercritical water cooled reactor, very high temperature reactor, and molten salt reactor. INPRO provides a longer-term perspective on nuclear power's global setting and the potential needs of developing countries as well as established nuclear countries. It incorporates IAEA expertise on global concerns about proliferation, international safety and the environment.

With respect to non-market barriers, the Agency's contributions to worldwide safety improvements, to safeguards and security, and to progress on the long-term disposition of spent fuel and radioactive waste are designed not just for substantive improvement, but to provide the transparency, double-checks and assurances that politicians and publics need.

Summary

Increasing market liberalisation means that nuclear power's future will rise or fall on the technology's economic competitiveness. In part, competitiveness depends on non-market barriers that are removed, adjusted, or reinforced by governments. In part it depends on cost improvements and innovations in the nuclear industry. The challenge for the industry is to match impressive continuing improvements in NPP operations with equally (or more) impressive innovation in design and in managing capital costs and financial risks. Many are working on this challenge. Their success will determine how quickly the "projection gap" is closed.

Reference:

- IPCC (Intergovernmental Panel on Climate Change), 2001: "Climate Change 2001 – Mitigation," Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.
- Spadaro, Joseph V., Lucille Langlois, and Bruce Hamilton, 2000: "Assessing the Difference: Greenhouse Gas Emissions of Electricity Generating Chains," *IAEA Bulletin*, Vol. 42, No. 2, Vienna, Austria).

Notes:

[1] International Atomic Energy Agency, Power Reactors Information System (PRIS) Database, (http://www.iaea.org/programmes/a2/). International Atomic Energy Agency, *Reference Data Series No. 1*, Vienna, July 2002.

[2] An alternative formulation views non-market barriers as "regulatory risk" factors that require a higher return on investment. Both formulations lead to identical conclusions.

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