Nuclear power is important. Worldwide there are 439 operating nuclear power plants (NPPs) supplying 16% of global electricity generation, primarily in industrialised countries (86%). Six new NPPs were connected to the grid in 2000. Construction started on five more, bringing the total under construction to 33 by the end of 2001.

However, the six new NPPs in 2000 accounted for just 3% of total incremental generating capacity, well below figures for the 1970s and 1980s when nuclear power was the fastest growing source of electricity.

Figure 1 summarises world nuclear experience as of January 2001. Since then one additional reactor in Russia has been connected to the grid.

Two reasons for the decline are excess generating capacity in key nuclear countries and electricity market reform. Liberalisation and privatisation have shifted investment decisions and financing from the public sector to smaller and private sector entities.

In addition, several countries have policies restricting nuclear power based on concerns about safety, radioactive waste, and proliferation, and Green parties elsewhere advocate similar policies.

The resulting political and regulatory risks, coupled with low prices and enhanced performance for fossil-fired generation (especially natural gas), have caused utilities to prefer fossil plants that are smaller, cheaper and quicker to build than the large, capital-intensive units now offered by the nuclear industry.

Many key developing countries confronted with a galloping demand for electricity desperately need all supply options, but cannot generate internally sufficient capital for an accelerated expansion of nuclear power.

Are nuclear power's days numbered? The answer is "no," although uncertainties remain. First, we must distinguish between the short and long term.

For existing NPPs, the most significant recent trend is a steady increase in availability factors through improvements in operational practices, engineering support, strategic management, fuel supply, and spent fuel disposition.

These have reduced generating costs and improved safety. Their cumulative impact is substantial - during the 1990s, availability increased by an amount equivalent to building 28 new NPPs of 1,000 MWe each.

In the US the average availability factor rose from 72% in 1990 to 88% in 2000. Nuclear generation costs dropped to record lows, now beating out even coal (the next cheapest option) for the first time since the mid-1980s. Liberalisation has prompted consolidation, acquisitions, upratings, and license extensions as selected companies move to define themselves largely by the size and expertise of their nuclear operations.

Recent sales of existing plants have brought record high prices, and the US Nuclear Regulatory Commission (NRC) granted license extensions to 60 years to six reactors in 2000 and 2001. An additional 40% of US plants intend to seek license extensions. The NRC expects the figure eventually to reach 85% or higher.

Although no new NPPs has been ordered in the US since 1978, seven units that were out of service for extended periods have been restarted since 1998, and the investment climate is more promising now than it has been for decades.

Exelon, a US partner in developing South Africa's Pebble Bed Modular Reactor (PBMR), has stated its intention to start building PBMRs in the US before 2010. The new US energy policy recommends government support for "the expansion of nuclear energy in the US as a major component of our national energy policy." And the NRC is currently conducting pre-application reviews for both the PBMR and Westinghouse's AP 1000 reactor design. It has already certified three new standard designs.

Privatisation in Europe's electricity sector has led to cost reductions and productivity improvements. It has also led to significant excess capacity, and with...
### Figure 1: Nuclear power reactors in operation and under construction in the world (as of January 2001)

<table>
<thead>
<tr>
<th>Country</th>
<th>Reactors in operation</th>
<th>Reactors under Nuclear electricity</th>
<th>Nuclear electricity supplied in 2000</th>
<th>Total operating experience to December 31, 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of units</td>
<td>Total MWe</td>
<td>No of units</td>
<td>Total MWe</td>
</tr>
<tr>
<td>Argentina</td>
<td>2</td>
<td>935</td>
<td>1</td>
<td>692</td>
</tr>
<tr>
<td>Armenia</td>
<td>1</td>
<td>376</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>7</td>
<td>5,712</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>2</td>
<td>1,855</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>6</td>
<td>3,538</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>14</td>
<td>9,998</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>3</td>
<td>2,167</td>
<td>8</td>
<td>6,420</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>5</td>
<td>2,569</td>
<td>1</td>
<td>912</td>
</tr>
<tr>
<td>Finland</td>
<td>4</td>
<td>2,656</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>59</td>
<td>63,073</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>19</td>
<td>21,122</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>4</td>
<td>1,755</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>14</td>
<td>2,503</td>
<td>2</td>
<td>900</td>
</tr>
<tr>
<td>Iran</td>
<td>2</td>
<td>2,111</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>53</td>
<td>43,491</td>
<td>3</td>
<td>3,190</td>
</tr>
<tr>
<td>Korea Republic of</td>
<td>16</td>
<td>12,990</td>
<td>4</td>
<td>3,820</td>
</tr>
<tr>
<td>Lithuania</td>
<td>2</td>
<td>2,370</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>2</td>
<td>1,360</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>1</td>
<td>449</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pakistan</td>
<td>2</td>
<td>425</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Romania</td>
<td>1</td>
<td>650</td>
<td>1</td>
<td>650</td>
</tr>
<tr>
<td>Russia</td>
<td>29</td>
<td>19,843</td>
<td>3</td>
<td>2,825</td>
</tr>
<tr>
<td>South Africa</td>
<td>2</td>
<td>1,800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slovak Republic</td>
<td>6</td>
<td>2,408</td>
<td>2</td>
<td>776</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1</td>
<td>676</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>9</td>
<td>7,512</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>11</td>
<td>9,432</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>5</td>
<td>3,192</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>35</td>
<td>12,968</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ukraine</td>
<td>13</td>
<td>11,207</td>
<td>4</td>
<td>3,800</td>
</tr>
<tr>
<td>US</td>
<td>104</td>
<td>97,411</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>438</strong></td>
<td><strong>351,327</strong></td>
<td><strong>33</strong></td>
<td><strong>28,656</strong></td>
</tr>
</tbody>
</table>

**Note:** The total includes the following data in Taiwan, China:
- six units, 4,884 MWe in operation; two units, 2,560 MWe under construction;
- 37 TWh of nuclear electricity generation, representing 23.6% of the total electricity generated there;
- 116 years one month of total operating experience.

EU enlargement the situation will continue.

Where new capacity is required, private investors prefer smaller, cheaper and simpler fossil-fired alternatives. With the possible exception of Finland and France, no new reactor construction is under consideration in Western Europe. In Finland the utility Teollisuuden Voima Oy (TVO) applied in November 2000 for a government decision “in principle” to build a fifth Finnish NPP.

On the political front, Belgium, Germany, the Netherlands, and Sweden all have policies to gradually phase out nuclear power. In Austria, Denmark, Greece, Ireland, Italy, and Norway it is banned. For all these reasons, the number of NPPs in Western Europe is likely to decrease from today’s 150. Lifetime extensions may slow the trend in some countries.

Eastern Europe and the economies in transition have 69 operating NPPs. Ten more are under construction. The European Union continues to seek the closure of first generation Soviet designed water-cooled WWER and graphite moderated...
RBMK reactors. At the same time, the European Commission, several EU countries and the European Bank for Reconstruction and Development are helping to finance safety upgrades at other Eastern European NPPs.

In Asia there are 94 operating NPPs, 19 are under construction, and at least 20 more planned. Capacity and production are greatest in Japan, with 53 NPPs. Three new plants are currently under construction, with plans to start construction on 10 more between 2002 and 2005.

A relative lack of indigenous energy resources and consequent concerns about supply diversity and security make new NPPs attractive in Japan, as in the Republic of Korea (with 16 NPPs and four under construction).

Nuclear power also plays an important role in Japan’s plans for meeting its Kyoto Protocol commitment to reduce greenhouse gas (GHG) emissions in 2008-2012 by 6% relative to 1990.

Three NPPs are in operation in China; eight more are under construction. Taiwan has six NPPs with two more under construction. India has 14 small NPPs (up to 220 MWe) operating, and two larger reactors under construction. The country’s target is 20 GW of (gross) capacity by 2020, and it is developing fast breeder reactors to make use of its extensive indigenous thorium reserves.

There are six operating NPPs in Latin America, two each in Argentina, Brazil and Mexico. One more is under construction (in Argentina).

The only African country with operating NPPs is South Africa. Eskom, the South African operator, also leads an international consortium developing the PBMR, with plans to begin construction of a demonstration plant in South Africa in 2003.

The PBMR concept envisages a number of small (~100 MWe) modularly designed reactors that can be built relatively quickly at different scales as needed. Projected capital and generating costs for the PBMR compare favourably with competitive market conditions.

Thus, for the immediate future, new construction is concentrated in Asia, and global NPP additions are below the level needed to maintain nuclear power’s share of worldwide capacity. In North America and Western Europe, squeezing additional profits out of existing NPPs is currently more promising and less risky than embarking on new construction.

**Economics of new plants: Current generation of reactor designs**

New NPPs can cost two to four times more to build than fossil fuel plants (see Figure 2), excluding the cost of commercial risks due to non-completion, cost overruns, and regulatory uncertainty. Return of investment may take 20 years.

Levelised generating costs for nuclear plants are roughly comparable to alternatives, but are amortised over much longer periods. Can nuclear power afford to pay higher returns to compensate long-term risks and still be profitable?

Key factors that might change this situation include: higher fossil fuel prices, higher priority for energy supply security, restrictions on GHG emissions, the eventual disappearance of excess capacity in Europe, growing energy demand in developing countries, and NPP designs with shorter construction times and lower capital costs.

Such economic improvements in new NPP designs will be most effective if they also continue nuclear power’s steady progress in three important areas: cost-effective safety, spent fuel and waste management, and proliferation resistance.

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**Figure 2: Capital costs, generating costs and construction time for different electricity generating options**

<table>
<thead>
<tr>
<th></th>
<th>Cost per kWe installed US$</th>
<th>Total cost for 1,000 MW capacity US$b</th>
<th>Construction period years</th>
<th>Typical plant size MW</th>
<th>Typical plant turn key costs US$b</th>
<th>Indicative generating costs US c/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear LWR</td>
<td>2,100–3,100</td>
<td>2,1–3,1</td>
<td>6–8</td>
<td>600–1,750</td>
<td>1.5–4.2</td>
<td>4.9–6.8</td>
</tr>
<tr>
<td>Nuclear, best practice</td>
<td>1,700–2,100</td>
<td>1.7–2.1</td>
<td>4–6</td>
<td>800–1,000</td>
<td>1.3–2.1</td>
<td>4.0–4.7</td>
</tr>
<tr>
<td>Coal, pulverised, ESP</td>
<td>1,000–1,300</td>
<td>1.0–1.3</td>
<td>3–5</td>
<td>400–1,000</td>
<td>0.5–1.3</td>
<td>3.2–4.5</td>
</tr>
<tr>
<td>Coal, FGD, ESP, SCR</td>
<td>1,300–2,500</td>
<td>1.3–2.5</td>
<td>4–5</td>
<td>400–1,000</td>
<td>0.6–2.5</td>
<td>3.6–6.3</td>
</tr>
<tr>
<td>Natural gas CCGT</td>
<td>450–900</td>
<td>0.45–0.9</td>
<td>1.5–3</td>
<td>250–750</td>
<td>0.2–0.6</td>
<td>2.6–4.8</td>
</tr>
<tr>
<td>Wind farm</td>
<td>900–1,900</td>
<td>0.9–1.9</td>
<td>0.4</td>
<td>20–100</td>
<td>0.03–0.12</td>
<td>3.5–9.2</td>
</tr>
</tbody>
</table>

ESP = Electrostatic precipitator; FGD = Flue gas desulphurisation; SCR = Selective catalytic reduction; CCGT = Combined Cycle Gas Turbine.

a) Including interest during construction

b) Based on 10% discount rate, 20 year planning horizon and fuel costs ranging from 1$/GJ to 2$/GJ for coal and 1$/GJ to 5$/GJ for natural gas. Wind generating costs depend on mean wind speeds and availability factors.
Nuclear safety

The nuclear industry's safety philosophy is one of continual improvement and rapid sharing of new knowledge. The industry has over 10,000 reactor-years of experience and an overall safety record second to none.

In particular, substantial technical and institutional improvements in response to the industry's two major accidents, Three Mile Island in 1979 and Chernobyl in 1986, have now been thoroughly diffused throughout the industry.

The general lesson under liberalisation has been that safety both enhances profits and protects assets.

The broad acceptability of current reactor safety levels is attested to by the approval they receive in practice - in the US about 100 NPPs have been generating approximately 20% of the electricity supply since the 1980s; in Western Europe about 150 NPPs provide approximately 30%; in France 59 NPPs provide 76%.

As with other technologies (e.g. airplanes, automobiles, and buildings in earthquake zones), new ideas and engineering advances mean there is always room for improvement. Continuing safety progress is thus an essential objective of all new reactor and fuel cycle designs.

Spent fuel and waste management

The solid waste produced by NPPs is small in volume, well confined and highly monitored. Final repositories for low level radioactive waste from NPPs, medical, research, and other applications are already in operation in many countries.

High level waste is more controversial. Although the scientific community generally agrees this can be disposed of safely in stable geologic formations, most high level NPPs waste is still stored on-site or at interim storage sites. The process of siting a high level waste facility is most advanced in Sweden, Finland, and the US.

In the meantime, existing on-site and interim storage capacity is, with moderate modifications, sufficient for many more decades. Nonetheless, continued demonstrable progress toward an operating geological repository will be an important determinant of nuclear power's future.

Proliferation

Effective safeguards against nuclear weapons proliferation are required as long as nuclear technologies generate, or can be used to generate, weapons-grade fissile material irrespective of whether the material is used for NPPs, medical, agricultural or other peaceful applications.

At the centre of the international non-proliferation regime is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), signed in 1970 and extended indefinitely in 1995. Other components of the international non-proliferation regime include verification and development of proliferation-resistant technology, export controls on nuclear and nuclear-related material and equipment, the creation of nuclear weapon free zones, controls against nuclear material illicit trafficking, and the physical protection of nuclear material.

In the future, resources devoted to such safeguards will need to keep pace with the expansion of nuclear power.

The future

Reflecting these concerns, near-term global projections for nuclear power are not terribly auspicious. The OECD International Energy Agency's (IEA) reference case projects a 3% decrease in nuclear electricity generation from 2000 to 2020. This combines a 14% decrease in developed countries and a 162% increase in developing countries, especially in Asia.

Global projections by the IAEA range from a 9% drop in nuclear electricity generation by 2020 (similar to the IEA's reference case) to a 53% increase where nuclear generation expands in all regions, but with absolute and relative growth still greatest in Asia.

The view beyond 2020 looks different. New reference scenarios published in 2000 by the Intergovernmental Panel on Climate Change (IPCC) generally project growing - not shrinking - nuclear contributions.

For 2050 the range is from 350 GW(e (essentially the same as today) to more than 5,000 GW(e, with a median of more than 1,500 GW(e. These levels would require 50-150 GW(e of new nuclear capacity to be added each year between 2020 and 2050. This recognises that nuclear power is better suited for baseload generation than intermittent renewables.

It also reflects the fact that nuclear technologies, like other technologies, are not static, with improvements resulting in shorter construction times, lower capital costs, solutions to waste disposal, and enhanced safety and proliferation resistance, all of which would reduce the commercial risk of NPPs and the costs associated with such risk.

In practice, of course, such progress requires continuing innovative R&D on the part of industry and governments. Both currently have active programmes underway promoting both evolutionary improvements of current designs and truly innovative new concepts.

Quite a few of the IPCC scenarios have high shares of both new renewables and nuclear power. The two need not be in conflict. For example, most
of the growth in global energy demand will be in developing countries. In many cases, the best promise for rural areas may be that offered by off-grid renewables.

For growing mega-cities, however, the energy mix will need to include large centralised power generation to match large centralised power demand.

For nuclear power the “Bonn Agreement” negotiated at Part 2 of the Sixth Session of the UNFCCC conference of the Parties is an important step forward.

Nuclear power produces virtually no greenhouse gases (see Figure 3). Globally, nuclear power reduces

**Figure 3: Full energy chain GHG emissions from electricity generation**

<table>
<thead>
<tr>
<th>Source</th>
<th>1990s Technology (high)</th>
<th>1990s Technology (low)</th>
<th>2005-20 Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>355</td>
<td>247</td>
<td>217</td>
</tr>
<tr>
<td>Coal</td>
<td>278</td>
<td>316</td>
<td>181</td>
</tr>
<tr>
<td>Oil</td>
<td>315</td>
<td>95</td>
<td>171</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>157</td>
<td>29</td>
<td>90</td>
</tr>
<tr>
<td>Solar PV</td>
<td>76.4</td>
<td>27.3</td>
<td>8.2</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>64.6</td>
<td>6.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Run-of-river or Reservoir (Swiss)</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Biomass</td>
<td>high 16.6</td>
<td>low 8.4</td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>25% cap.: heavy foundations, Japan 13.1</td>
<td>9.8</td>
<td>7.6</td>
</tr>
<tr>
<td>Inland (10% capacity, Belgium) 2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Nuclear</td>
<td>high 5.7</td>
<td>low 2.5</td>
<td></td>
</tr>
</tbody>
</table>

The Kyoto Protocol and the Bonn Agreement

The Kyoto Protocol and the Bonn Agreement

For nuclear power the “Bonn Agreement” negotiated at Part 2 of the Sixth Session of the UNFCCC conference of the Parties is an important step forward.

Nuclear power produces virtually no greenhouse gases (see Figure 3). Globally, nuclear power reduces
annual carbon emissions by about 600 million tonnes compared to where they would be otherwise.

However, this advantage has been invisible to investors. Except for a very few instances, there have been no restrictions or taxes on greenhouse gas emissions and thus no economic value to their avoidance.

At the moment, the Kyoto Protocol is the world’s only operative route toward widespread, coordinated restrictions on GHG emissions. The Bonn Agreement is thus an important step toward attaching a tangible economic value to nuclear power’s avoidance of GHG emissions.

Much of the press focused on the Bonn Agreement’s exclusion of nuclear projects from two of the three flexible mechanisms in the Kyoto Protocol, Joint Implementation and the Clean Development Mechanism. This is likely to have little practical impact during the first 2008-2012 commitment period.

More important, the absence of the US from the Bonn Agreement and the greater credit it gives for carbon sinks cut the projected market price for GHG reduction credits by more than two-thirds.

Nuclear power today supplies one-sixth of the world’s electricity. Well managed existing NPPs in liberalised electricity markets are a profitable business. Thus the current emphasis on productivity improvements, licence extensions, upgrades and restarts.

The economics of new NPPs, however, with their front-loaded cost structure, longer construction times and regulatory risks - are less attractive in liberalised markets. Rules that discourage new base-load capacity of any sort - restrictions on long-term electricity contracts for example – compound the problem.

New NPPs are more attractive in countries with rapid energy demand growth, or countries where alternative resources are scarce, energy supply security is a priority and/or nuclear power is seen as an important way to reduce air pollution and GHG emissions. Most current construction and planned expansion is therefore in Asia.

With a longer planning horizon, interest in nuclear expansion becomes more universal. Most of the IPCC scenarios project substantial global growth. A recent report by the European Commission points out that the absence of new NPPs in current Western European plans - either to replace retiring NPPs or to increase total capacity – is inconsistent with ambitions to reduce GHG emissions and increase energy supply security. Policy reviews underway in the UK and the European Commission may prove more open to nuclear power than would have been likely even in 2000.

The exploration of possible new NPPs in the US certainly intensified with the encouragement provided by the new US Energy Policy. Prospects for nuclear power in Russia have been reinforced by President Putin’s focus at the Millennium Summit on new fuel cycles that would “open fundamentally new horizons for secure life on the planet”.

At present, existing nuclear plants are successful, but new nuclear plants in North America and Western Europe for the most part remain in limbo. The intermediate future depends partly on factors over which the nuclear industry has control, but partly on factors outside its control.

Among the latter are fossil fuel prices, the priority given to energy supply security, restrictions on GHG emissions, growth in energy demand, regulatory uncertainty and innovation, and the political will to move ahead on waste disposal.

The key factors over which the nuclear industry has substantial control are innovation, cost control and commercial risk reduction, which usually translate into shorter construction times, lower capital costs, and enhanced safety and proliferation resistance. All three are crucial to any future investment in nuclear power. They can determine whether the costs and the commercial risks associated with nuclear power can be reduced or sufficiently secured for nuclear power to compete for financing in capital markets.

As for technology innovation, the challenge is to match the industry’s impressive continuing improvements in NPP operations with equally (or more) impressive improvements in new designs. Serious innovations to reduce capital costs and financial risks for new NPPs will be needed to prevent nuclear power being priced out of the market, even where it offers other significant advantages. Many are working on this challenge. Their success will determine how quickly the “projection gap” is closed.

Notes:
1 UNFCCC: United Nations Framework Convention on Climate Change