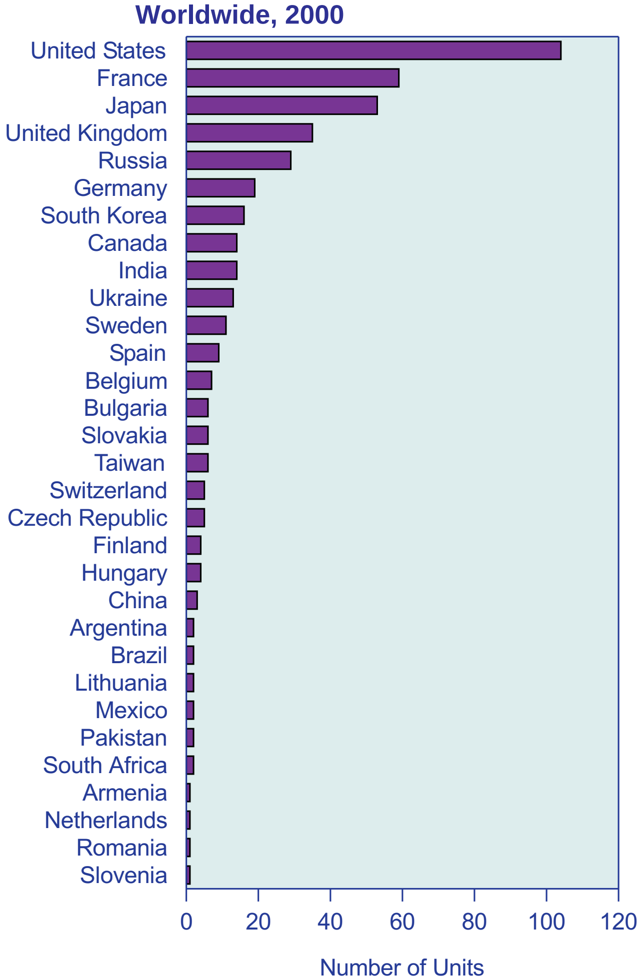
Nuclear Power

Nuclear power is projected to represent a growing share of the developing world's electricity consumption from 1999 through 2020. New plant construction and license extensions for existing plants are expected to produce a net increase in world nuclear capacity.

World nuclear power capacity is projected to increase slightly over the forecast period, from 350 gigawatts in 2000 to 359 gigawatts in 2020. Most of the growth is expected in developing Asia, particularly China, where 17 new power plants are expected to be operational over the forecast period. In the industrialized nations, with few additional nuclear plants being built and a significant number of plant retirements expected, nuclear power capacity is projected to fall considerably, despite the fact that the projections include expected future life extensions for some of the nuclear power plants currently operating in the United States and other industrialized nations.

Figure 62. Operating Nuclear Power Plants Worldwide, 2000



Source: International Atomic Energy Agency, "Power Reactor Information System," web site www.iaea.org/programmes/a2/ (February 12, 2002).

Nuclear power plants generated electricity in 30 countries in 2000. A total of 438 nuclear power plants were in operation around the world, including 104 in the United States, 59 in France, and 53 in Japan (Figure 62). Six new reactors came online in 2000, and two were shut down. The new reactors included Angra 2 (in Brazil), Temelin 1 (Czech Republic), Rajasthan 3 and 4 and Kaiga 1 (India), and Chasnupp 1 (Pakistan) for a total of 3,056 megawatts of capacity [***1***]. The country with the largest share of electricity generated by nuclear power was France, at 76 percent (Figure 63). Belgium, Bulgaria, France, Hungary, Lithuania, Slovakia, South Korea, and Ukraine depended on nuclear power for at least 40 percent of their electricity generation.

Nuclear power accounted for 16 percent of the world's total electricity supply in 1999. That share is projected to fall to 12 percent by 2020, primarily because the industrialized nations are expected to eschew the construction of new units while continuing to retire plants built in the 1970s and 1980s, during nuclear power's heyday. Nuclear power plant operating license extensions or the equivalent, which were first issued in the United States in 2000, are expected to be granted in other industrialized nations. In many countries, extending the operational life of a nuclear plant is a less formal procedure than in the United States, where the U.S. Nuclear Regulatory Commission (NRC) must approve license extensions. In some countries, extending a plant's operating life is a decision that is left primarily to the owner.

In developing Asia, 32 gigawatts of capacity is projected to be added by 2020 to the region's 23 gigawatts of nuclear capacity operating in 2000. China is expected to account for 14 gigawatts of net capacity additions (Table 17). There are currently 33 reactors under construction around the globe (Figure 64), half of which are being built in developing Asia. China accounts for 8 of the new units, South Korea 4, and India and Taiwan 2 each. There are no new plants currently under construction or on order in North America, South America, or Western Europe.

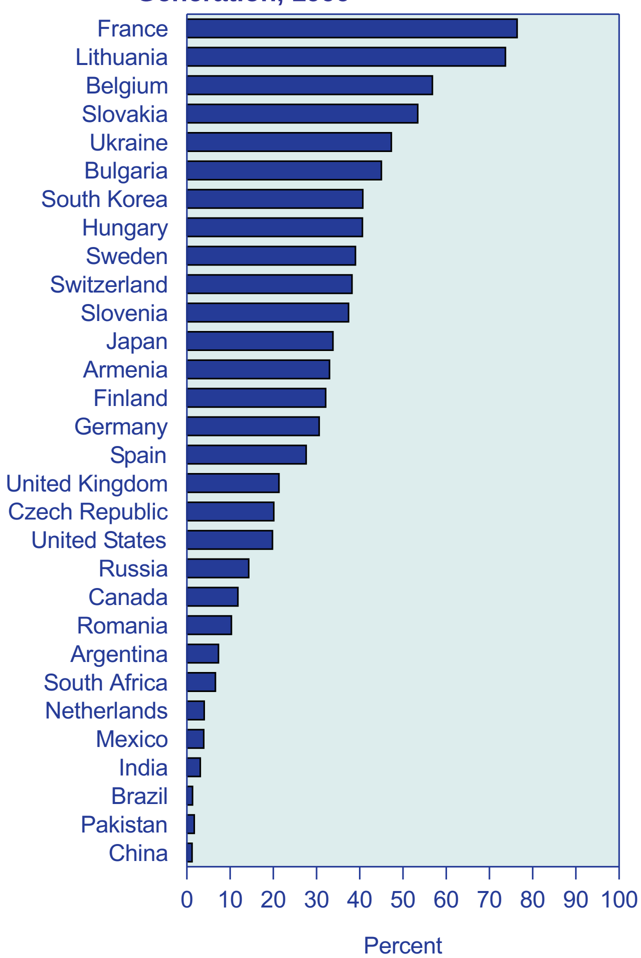
The *International Energy Outlook 2002* (*IEO2002*) reference case forecasts world net capacity at 359 gigawatts in 2020, or 9 gigawatts more than projected in the *International Energy Outlook 2001* (*IEO2001*) reference case. Projected U.S. nuclear capacity in 2020 is 16 gigawatts higher in the *IEO2002* forecast as a result of an expectation that the owners of most of the nuclear power plants now operating in the United States will seek relicensing and will continue operating the plants. The *IEO2002* forecast projects 3 gigawatts fewer retirements in 2020 overseas but also projects fewer new builds overseas than did the *IEO2001* forecast.

In many countries the decision to build a nuclear power plant is fraught with uncertainty. In many cases, nuclear power plants have been announced but their construction has been delayed or abandoned altogether. Some nuclear power plants have taken as little as 4 years to build; others have taken well over a decade. This chapter includes two examples illustrating the difficulties of forecasting nuclear capacity growth and how contemporary events necessitate frequent revisions of earlier forecasts. The box on page 94 discusses the issues (largely political) that are likely to determine the future of nuclear power in the United Kingdom, and the box on page 95 describes financial issues that cast doubt on the future of Ukraine's nuclear option.

The September 11, 2001, terrorist attacks on New York City and Washington, DC, gave rise to new concerns over the safety of the nuclear power plants now operating in the United States. Uncertainties about whether nuclear power plants and nuclear fuel storage facilities were at risk from a similar terrorist attack resulted in heightened security measures at all nuclear facilities around the country. Although a containment tower had in the past survived a head-on test crash of a military jet without major damage [***2***], it remains uncertain whether the same could be said of a head-on crash with a large commercial aircraft loaded with jet fuel. Containment vessels typically have 4 feet of steel-reinforced concrete along with a steel liner. Fuel storage facilities may be more prone to damage in the event of a head-on crash, in that they are not nearly so well protected.

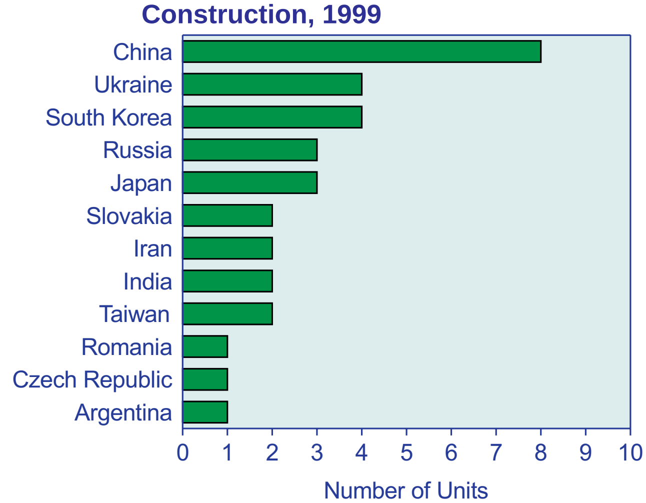
After the September 11 attacks, the Federal Aviation Administration banned commercial airplanes from flying within 10 nautical miles of any nuclear facility. In many States, National Guard troops were deployed to protect power plants from possible terrorist attacks. It is uncertain what lasting impact these recent developments will have on the prospects for nuclear power either in the United States or overseas; the *IEO2002* forecast has not been adjusted to take into account any policy changes resulting from the events of September 11, 2001. One argument that may favor nuclear power is that continued or increased use of nuclear power for electricity generation would lessen U.S. dependence on

Figure 63. Nuclear Shares of National Electricity Generation, 1999



Source: Energy Information Administration, *International Energy Annual 1999*, DOE/EIA-0219(99) (Washington, DC, February 2001).

Figure 64. Nuclear Power Reactors Under Construction, 1999



Source: International Atomic Energy Agency, *Nuclear Power Reactors in the World 1999* (Vienna, Austria, April 2000).

Table 17. Historical and Projected Operable Nuclear Capacities by Region, 2000-2020
(Net Gigawatts)

Region	2000[a]	2005	2010	2015	2020
Reference Case					
Industrialized	**278.1**	**280.3**	**277.3**	**268.4**	**260.4**
United States	97.5	97.7	94.3	88.8	88.0
Other North America	11.4	15.0	15.0	15.0	15.0
Japan	43.5	44.3	47.8	50.8	53.4
France	63.2	62.9	62.9	62.9	64.4
United Kingdom	12.5	11.4	9.8	8.1	4.8
Other Western Europe	50.1	49.1	47.5	42.8	34.9
EE/FSU	**44.5**	**46.2**	**42.6**	**41.5**	**36.7**
Eastern Europe	10.7	11.7	10.1	10.1	10.7
Russia	19.8	21.7	21.3	20.3	14.8
Ukraine	11.2	11.2	11.2	11.2	11.2
Other FSU	2.7	1.6	0.0	0.0	0.0
Developing	**27.4**	**35.9**	**43.3**	**50.6**	**62.3**
China	2.2	6.6	9.6	11.6	16.6
South Korea	13.0	15.9	16.3	19.4	22.1
Other	12.2	13.5	17.5	19.6	23.6
Total World	**349.9**	**362.5**	**363.2**	**360.6**	**359.4**
Low Growth Case					
Industrialized	**278.1**	**273.9**	**264.1**	**239.9**	**217.1**
United States	97.5	97.7	94.3	86.4	85.6
Other North America	11.4	11.4	11.4	10.1	10.1
Japan	43.5	44.0	46.2	42.9	38.7
France	63.2	62.9	62.9	61.1	53.0
United Kingdom	12.5	11.0	8.1	4.2	1.2
Other Western Europe	50.1	46.9	41.2	35.3	28.5
EE/FSU	**44.5**	**43.3**	**36.7**	**27.9**	**17.2**
Eastern Europe	10.7	10.5	10.1	10.1	7.7
Russia	19.8	20.4	15.5	11.2	8.6
Ukraine	11.2	11.2	11.2	6.7	1.0
Other FSU	2.7	1.2	0.0	0.0	0.0
Developing	**27.4**	**33.0**	**38.7**	**42.8**	**44.5**
China	2.2	6.6	8.6	9.6	10.6
South Korea	13.0	14.9	16.3	18.5	20.2
Other	12.2	11.6	13.9	14.7	13.7
Total World	**349.9**	**350.2**	**339.6**	**310.7**	**278.8**
High Growth Case					
Industrialized	**278.1**	**284.8**	**283.1**	**293.1**	**301.5**
United States	97.5	97.7	95.4	89.9	89.1
Other North America	11.4	15.0	15.0	15.0	17.0
Japan	43.5	46.7	48.7	63.8	68.8
France	63.2	63.2	62.9	64.4	64.4
United Kingdom	12.5	12.3	11.0	10.6	12.4
Other Western Europe	50.1	50.1	50.1	49.5	49.9
EE/FSU	**44.5**	**49.2**	**50.5**	**51.7**	**55.8**
Eastern Europe	10.7	12.5	11.9	11.1	13.0
Russia	19.8	22.7	23.9	26.1	26.2
Ukraine	11.2	11.2	13.1	13.1	15.0
Other FSU	2.7	2.7	1.6	1.4	1.6
Developing	**27.4**	**37.9**	**51.6**	**66.6**	**83.0**
China	2.2	7.6	11.6	18.6	20.6
South Korea	13.0	16.8	19.7	21.4	26.2
Other	12.2	13.5	20.3	26.6	36.2
Total World	**349.9**	**371.9**	**385.2**	**411.3**	**440.4**

[a]Status as of December 31, 2000. Data are preliminary and may not match other EIA sources.

Notes: EE/FSU = Eastern Europe/Former Soviet Union. Totals may not equal sum of components due to independent rounding.

Sources: **United States:** Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001). **Foreign:** Based on detailed assessments of country-specific nuclear power programs.

United Kingdom Waxes and Wanes on Nuclear Power

In part because it is the most politicized of all electricity generation technologies, future nuclear power capacity is particularly difficult to forecast. The difficulty arises from a number of issues, such as safety, nuclear proliferation, waste disposal, plant decommissioning, and the cost of future plant construction. In recent years, some government officials and industry leaders have shown renewed interest in building additional nuclear power plants in countries where the movement away from nuclear power appeared inexorable. Nevertheless, the *IEO2002* reference case projects that a number of nuclear power plants currently planned in several nations over the forecast horizon will not be built, and that a fundamental reversal of the trend toward retirement of existing nuclear power plants—a trend that has been evident since the early 1990s—will not take place.

One country where new nuclear construction is now thought to be a possibility is the United Kingdom. In the *IEO2002* reference and low nuclear case forecasts, no new nuclear power plants are expected to come online in the United Kingdom by 2020; however, the high nuclear case projects that three new 1,000-megawatt units will be built and operating by the end of the forecast period. Currently, the UK government has no stated plans to build additional nuclear power plants, although there has been renewed public debate on the efficacy of nuclear power, and the current Labor party government appears to have softened its prior opposition. The *IEO2002* reference and low nuclear case forecasts assume that those factors in themselves are not enough to overcome all the obstacles currently arrayed against the further development of nuclear power in the United Kingdom.

One of the foremost difficulties in forecasting the future role of nuclear power is that different political parties often have opposing views on the subject. In many cases, future election results could alter the course of nuclear power, as they have done in the recent past. Germany's decision to abandon nuclear power, for instance, is clearly the result of the election of the Social Democrats and their anti-nuclear allies, the Green party. When the Conservative party government of Margaret Thatcher was in office in the United Kingdom, nuclear power was viewed as a viable future contributor to new electricity generation. When Labor assumed office, it was felt that Labor's stated opposition to nuclear power would become government policy. For some time, however, the government of Prime Minister Tony Blair has left open the option that nuclear power would continue to play a role in the nation's electricity supply. Britain's support of the Kyoto Protocol was one factor forcing a reevaluation of the nuclear option: if the United Kingdom abandoned its nuclear option, compliance with the Kyoto Protocol would be more difficult. The initial Blair cabinet even included an energy minister, John Battle, who had come out in support of building new reactors.

In February 2002, a UK government review of energy was released. The review called for a national debate on nuclear power and for an examination of "low waste, modular designs of nuclear reactors" and urged the government to "continue to participate in research aimed in this direction."[a] Moreover, the chief executive of the UK nuclear power company, BNFL, has urged the government to promote the building of nuclear power plants.[b]

There are still several reasons why the UK is unlikely to renew its promotion of nuclear power as a source of electricity generation. Two reports completed in the fall of 2001 by the Labor government pointed out that nuclear power was much more costly than wind or biomass, and that increased energy efficiency and combined heat and power were preferable options. Concerns over nuclear proliferation and terrorism in the post-September 11 world may also have inspired a change of heart.

Since the late 1980s, the unexpected large construction cost overruns for Britain's nuclear power plants have led to a reevaluation of the future role of nuclear power in the nation's energy mix. As in the United States, most of the UK electric utility industry's stranded cost problem stemmed from past investments in nuclear energy, largely as a result of cost overruns in the construction of nuclear facilities and unforeseen spent-fuel reprocessing and disposal liabilities, as well as decommissioning costs.

Only one nuclear reactor (Sizewell B) has come online in the United Kingdom since 1988, and it has been controversial. During construction, the capital costs for Sizewell B escalated by 35 percent; and when the plant came online it generated electricity at a cost that was twice what the UK electricity pool was charging. Construction delays have also been a problem for the UK nuclear industry. The Dungeness B reactors, for instance, took 22 years to complete.

(continued on page 95)

[a]"Minister Says UK Energy Review Keeps New Nuclear Option Open," *NucNet: The World's Nuclear News Agency*, Vol. 65, No. 2 (February 14, 2002).

[b]P. Brown and D. Gow, "UK 'Needs Another 20 Nuclear Stations,'" *Guardian Unlimited* (September 7, 2001), web site www.guardian.co.uk / Archive / Article / 0,4273,4252099,00.html.

United Kingdom Waxes and Wanes on Nuclear Power (Continued)

Since the reform of the UK electric power industry was started in 1989, its electricity market has developed into one of the most competitive around the globe. This too does not augur well for nuclear's future in the UK electricity supply industry. For example, a 1995 government white paper concluded that, in a competitive private market, no one would invest in new nuclear capacity and indicated that the government would not provide state subsidies to ensure new construction of nuclear plants.[c]

In the *IEO2002* forecast, natural gas is expected to accommodate much of the growth in UK electricity demand to the year 2020, obviating the need for construction of additional nuclear units. Natural gas remains a viable future source of energy for electricity production in the United Kingdom. Despite increases in consumption over the past 20 years, the country's natural gas reserves have risen by 7 percent. Moreover, wholesale natural gas prices in the United Kingdom generally have tracked below U.S. natural gas prices.

[c]G. MacKerron, "Nuclear Power Under Review," in *The British Electricity Experiment, Privatization: The Record, the Issues, the Lessons* (London, UK: Earthscan PublicationsLimited, 1996), pp. 159-160.

Can Ukraine Finance Nuclear Power?

In most of the industrialized nations, the decision to continue to develop nuclear power as a source of electricity hinges on such factors as the economic viability of a nuclear power plant relative to coal, natural gas, or other sources of electricity. Other considerations include power plant operating safety, decommissioning costs, waste disposal, and concerns about nuclear arms proliferation. In other countries, such as Ukraine, obtaining project funding has been the most critical issue in the development of a domestic nuclear power industry.

Although Ukraine's Khmelnitsky 2 and Rovno 4 (K2 and R4) today are 80 percent complete, it is not clear that either unit will ever be connected to the grid. Construction on both units was aborted in 1991 after the breakup of the former Soviet Union. In 1995, the European Bank for Reconstruction and Development (EBRD) and the Group of Seven (G7) signed a memorandum of understanding with Ukraine's government. An important goal of the EBRD and G7 was to encourage Ukraine to shut down its remaining Chernobyl vintage reactors.[a] As a form of compensation, the EBRD agreed to fund the completion of K2 and R4. An understanding was reached that K2 and R4 would be operated at "western safety levels." Over the course of several years, three outside consulting firms provided analyses of the viability of K2 and R4. Two concluded that completion of the plants represented the least-cost option, and one suggested that economics argued against their completion.[b] Several Western European environmental groups and political parties have also opposed the construction of K2 and R4.

The $1.48 billion in funding for the completion and safety upgrade of K2 and R4 was to have come from a number of sources: $580 million from Euratom, $348 million from export credit agencies, $215 million from the EBRD, $123 million from Russia, $159 million from Energoatom, and $50 million from the Ukranian government.[c] However, as coordinator of the loan package, EBRD's funding became critical to the future survival of the project. Energoatom, the Ukraine nuclear power utility, and the EBRD had a difficult time negotiating a loan agreement. Initially, the EBRD approved a $215 million loan in December 2000 for the completion and safety upgrade of K2 and R4, pending certain conditions involving safety and funding availability. In December 2001, however, loan negotiations between the EBRD and the Ukrainian government foundered over an inability to agree on a future rate structure for sales of electricity from the two plants. Although it remains unclear whether K2 and R4 will be completed, the Ukraine's experience in trying to finance and build the plants is an example of the difficulties some nations face in their efforts to develop a nuclear power industry.

[a]Chernobyl 4 was shut down after the accident in 1986. Unit 2 was shut down after a turbine fire in 1991, and unit 1 was closed in 1997. Unit 3 was shut down in 2000.

[b]The initial study was conducted by a German firm, Lahmeyer, which found completion to be the least-cost option. The second study, conducted by a group of energy experts (the Surrey Panel) argued against completion. The third study was conducted by Stone and Webster, a U.S.-based engineering and construction firm.

[c]European Bank for Reconstruction and Development, "EBRD Approves Ukranian Nuclear Power Project Subject to Strict Conditions" (December 7, 2000), web site www.ebrd.com.

energy imports and thus provide greater national security. The "improved national security" argument can be taken only so far, however, given that the only imported fuel that competes significantly with nuclear power is natural gas, and almost all U.S. natural gas imports come from Canada. In other countries, nuclear power may well be considered a more secure form of electricity production, particularly by those nations heavily dependent on energy imports for electricity production. For instance, Japan relies on imported oil and natural gas for 38 percent of its electricity production, and 79 percent of its oil imports and 20 percent of its natural gas imports come from the Middle East [***3***].

Nuclear power first became a major source of electricity production in the 1970s. Nuclear power consumption worldwide grew from 188 billion kilowatthours in 1973 to 1,843 billion kilowatthours in 1989 [***4***]. By the 1990s, however, the growth of nuclear power consumption had begun to slow, and it is expected to level off by 2010. No lasting orders for new plants have occurred in Austria, Hungary, Italy, Mexico, the Netherlands, Switzerland, or the United States since 1973 [***5***]. Thus far, however, only Germany, Lithuania, Sweden, and Ukraine have committed to the early retirement of some if not all of their nuclear power plants. All other nations seeking to reduce their reliance on nuclear power intend to do so through attrition and by not building any new nuclear power plants. Still, many nations may find that viable alternatives to nuclear power are more difficult to develop than anticipated. Sweden, for instance, after committing to the closure of its Barsebäck nuclear power units by 2001, has delayed the closure of Barsebäck 2 until 2003.

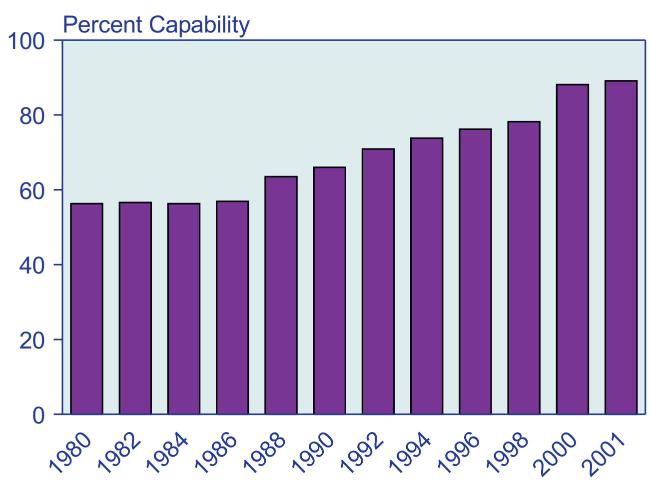
The Economics of Nuclear Power

There has been a significant improvement in the economics of nuclear power over the past several years. Capacity factors in the United States, for instance, which averaged 56.3 percent in 1980, grew to 89.1 percent in 2001 (Figure 65). Since the 1970s and 1980s, the average interval between refuelings for U.S. nuclear units has increased to 18 months from 12 months, resulting in less frequent outages [***6***], and since 1990 the average refueling cycle has fallen from 100 days to 80 days [***7***]. Overseas, capacity factors have also improved measurably. For those developed nations with nuclear power units in operation in both 1980 and 1999 (including the United States), the average capacity factor rose from 59 percent to 77 percent (Figure 66).

One of the ways to increase the capacity factor of a nuclear unit is to have fewer scheduled and unscheduled shutdowns; and improved operational safety has been an important factor in reducing shutdowns. Another means of increasing the output of nuclear power plants is to implement a power uprate, which can be viewed as increasing the absolute capacity of a plant rather than its utilization rate. Since the 1970s, the NRC has approved 62 uprates of U.S. nuclear plants, adding the equivalent of two large nuclear units [***8***]. Power uprates are typically achieved through plant upgrades, including investments in such items as pipes, heat exchangers, pumps, transformers, and generators.

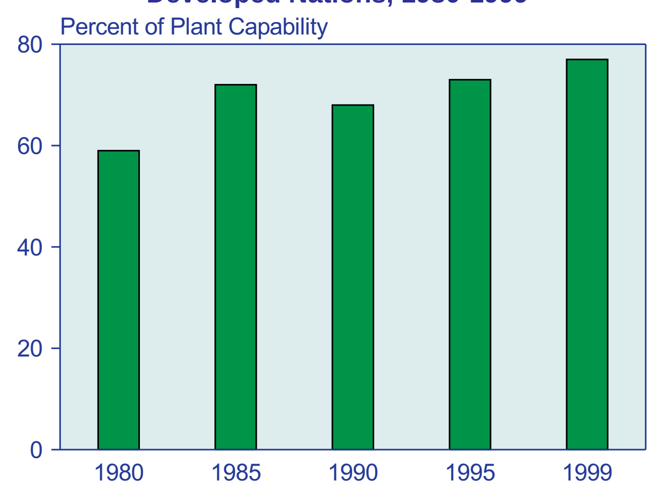
Recently, the U.S. nuclear power industry has witnessed an unprecedented merger and acquisition spree, seeing roughly one-fourth of the industry change ownership and resulting in a much more concentrated industry.

Figure 65. U.S. Nuclear Unit Capacity Factors, 1980-2001



Source: Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(2000/02) (Washington, DC, February 2002), p. 113.

Figure 66. Nuclear Unit Capacity Factors in Developed Nations, 1980-1999



Source: Energy Information Administration, Office of Energy Markets and End Use, International Statistics Database.

One possible motivation for consolidation is the belief on the part of the acquisition companies that a company with several power plants can operate them more efficiently than a company operating only one or a few plants. This also may lead to future efficiency improvements.

Although increased capacity utilization and uprates have improved the economics of nuclear power, for most nations and under most economic assumptions, nuclear power currently is a relatively expensive option for electricity generation when compared with natural gas or coal. A recent study by the International Energy Agency (IEA) on the relative competitiveness of natural gas, nuclear power, and coal among members of the Organization for Economic Cooperation and Development (OECD) [*9*] examined various operating costs, capital costs, plant decommissioning costs, and the costs of waste disposal (see box on page 98). The study compared existing technologies and not future technologies. Expectations are that future nuclear power plants will see significant efficiency gains, although gains are also expected for natural gas, coal, and renewables.

In terms of operating costs, the IEA study concluded that nuclear power plants were competitive against coal and natural-gas-fired generation units. Natural-gas-fired units averaged 2.2 to 4.1 cents per kilowatt hour, coal plants between 1.9 and 3.3 cents per kilowatthour, and nuclear between 0.8 and 3.2 cents per kilowatthour (Table 18).[16] The fuel costs (per kilowatthour of generation) for a nuclear power plant are significantly lower than those for coal or natural gas plants.

Capital costs, however, are another matter. The IEA study looked at different plants operating in various member countries (Table 19). In capital-intensive industries like electricity generation, interest rates play a key role in determining the relative economics of different generation fuel sources. The capital costs of a new nuclear unit are substantially higher than those for new natural gas and coal units. Interest rates vary across countries, as do other factors that affect the relative costs of nuclear power, including labor costs, material and equipment costs, regulation, and infrastructure.

The IEA study assumed three discount rates, 0 percent (i.e., the overnight capital cost), 5 percent, and 10 percent. (As a point of comparison, the U.S. prime rate has averaged 9.30 percent since 1970 [*10*].) Due to their higher construction costs, the relative cost of nuclear power plants is much more sensitive to changes in interest rates than are the costs of coal or natural gas plants. For a French-built pressurized-water reactor, capital costs averaged $1,636 per kilowatt at 0 percent, $1,988 per kilowatt at 5-percent interest, and $2,280 per kilowatt at 10-percent interest. It should be noted that the length of time to build a nuclear plant sometimes far exceeds the average. Although nuclear power plants can theoretically be built (and have been built) in 4 years [*11*], the IEA study notes that in the aftermath of the Three Mile Island accident in Pennsylvania, the average length of time to construct a U.S. power plant was 12 years.

Table 18. Projected Operating Costs of Nuclear, Coal, and Natural Gas Power Plants
(U.S. Cents per Kilowatthour)

Country	Nuclear	Coal	Natural Gas
Canada . . .	0.8	1.9	2.2
Finland	1.5	2.3	3.0
France	1.5	3.3	3.9
Japan	3.2	3.2	4.0
Korea	1.4	2.3	3.7
Spain	1.9	2.9	4.1

Source: International Energy Agency, *Energy Prices & Taxes, Quarterly Statistics, Second Quarter 2000* (Paris, France), p. xiii.

Table 19. Projected Operating Costs of Nuclear Power Plants
(U.S. Cents per Kilowatthour)

Country	Plant Type	Plant Net Capacity (Megawatts)	Total Capital Costs (Dollars per Kilowatthour)		
			Overnight Capital Cost	5% Discount Rate	10% Discount Rate
Canada . . .	Candu	1,330	1,697	2,139	2,384
Canada . . .	Candu	1,762	1,518	1,878	2,053
Finland	BWR	1,000	2,256	2,516	2,672
France	PWR	1,460	1,636	1,988	2,280
Japan	BWR	1,303	2,521	2,848	3,146
Korea	PWR	1,000	1,637	1,924	2,260
Spain	PWR	1,000	2,169	2,540	2,957

Candu = Canada Deuterium Uranium Reactor, which is a Canadian nuclear power plant design. BWR = Boiling Water Reactor. PWR = Pressurized Water Reactor.
Note: Technology to become commercially available by 2005-2010.
Source: International Energy Agency, *Energy Prices & Taxes, Quarterly Statistics, Second Quarter 2000* (Paris, France), p. xiii.

[16] Prices varied for different nations in the study, depending on domestic prices for coal and natural gas.

Nuclear Waste Disposal

Countries approach nuclear waste disposal in various ways (see table below). France, Japan, and the United Kingdom, for instance, rely on reprocessing that separates the spent reactor waste into both a recyclable fuel and a highly concentrated waste—a "closed fuel cycle" that produces both plutonium and uranium. The United States, Canada, and Sweden directly dispose of spent uranium from power reactors in an "open fuel cycle." Several countries have yet to commit to any form of waste disposal, relying instead on interim storage for the foreseeable future. Although a long-term solution to storing nuclear waste is critical, short-term storage is an adequate solution for several years. In 1997, reactor storage facilities stored 87,756 tons of nuclear fuel worldwide, well beneath their storage capacity of 147,868 tons of spent fuel.[a]

Management of Spent Fuel by Country

Country	Deferred Decision	Direct Disposal	Reprocessing
Argentina	x		
Belgium	x		x
Brazil	x		
Bulgaria	x		x
Canada		x	
China			x
Czech Republic	x	x	x
Finland		x	
France			x
Germany		x	x
Hungary	x		x
India			x
Italy	x		x
Japan			x
South Korea	x		
Lithuania		x	
Mexico	x		
Netherlands			x
Pakistan	x		
Romania		x	
Russia			x
Slovakia		x	x
Slovenia	x		
South Africa		x	
Spain		x	
Sweden		x	
Switzerland	x		x
United Kingdom			x
Ukraine	x	x	x
United States		x	

Source: International Atomic Energy Agency, "Rising Needs Management of Spent Fuel at Nuclear Power Plants," web site www.iaea.or.at/worldatom/inforesource/bulletin/bull401/article6.html.

In a closed fuel cycle, waste disposal involves the production of mixed oxide (MOX) fuel, a combination of plutonium and uranium. About 1 percent of the spent fuel coming out of a reactor is plutonium, which can be mixed with uranium to form MOX or used as a fuel for a breeder reactor.[b] France, Belgium, and the United Kingdom account for most MOX recycling. Currently, a multinational consortium is building a MOX plant in Russia with the intention of recycling plutonium derived from destroyed nuclear weapons. An advantage of using MOX as a fuel is that its use should lead to a reduction in plutonium inventories, which could lessen the threat of nuclear weapons proliferation. The disadvantage is that it also results in the production of plutonium, which some fear could be used in the construction of atomic weapons.

France began to reprocess its spent commercial nuclear fuels in 1958, Germany in 1971, the United Kingdom in 1964, Belgium in 1966 (shut down in 1974), Japan in 1981, and the former Soviet Union in 1978. The United States built three commercial reprocessing facilities in the 1970s, but a moratorium was placed on nuclear reprocessing in 1977. Although the moratorium was lifted in 1981, by then the economics of reprocessing had become less viable because uranium prices had fallen.

There is a general consensus that stable, deep, geological formations are the best locations to store high-level nuclear waste. Most nations have identified potential underground storage sites and have conducted geological and geophysical tests as to the suitability of the proposed sites. Currently, however, no underground storage sites have progressed beyond the planning stage. Although in February 2002 President Bush authorized construction of the Yucca Mountain nuclear waste depository in the United States, the U.S. Congress may yet oppose the facility. The greatest concern over the storage of high-level nuclear wastes is that over the tens of thousands of years for which the waste will be stored in containers, it could eventually leak and leach its way into the water table. In addition to the radioactivity it releases, high-level nuclear waste also produces great amounts of heat, necessitating additional efforts at isolation. As a result, the wastes

(continued on page 99)

[a]P. Dyck and M.J. Crijns, "Rising Needs: Management of Spent Fuel at Nuclear Power Plants" (International Atomic Energy Agency, April 1998), web site www.iaea.or.at / worldatom / inforesource / bulletin / bull401 / article6.html.

[b]I. Hore-Lacy, *Nuclear Electricity*, Sixth Edition (Canberra, Australia: Uranium Information Centre and Minerals Council of Australia, August 2000), web site www.uic.com.au / ne.htm.

The IEA study concluded that, depending on the price of various operations and maintenance costs (which are heavily dependent on fuel costs, particularly for coal and natural gas) and the cost of capital (which affects nuclear disproportionately), the economics of natural gas, coal, and nuclear plants differ considerably. Assuming a 5-percent discount rate, nuclear power plants are estimated to be more efficient than coal or natural gas plants in 5 of 9 countries for which data on all three fuels were available. These countries are typically those with high natural gas prices. At a 10-percent discount rate, nuclear power is less efficient in every country. The IEA has also conducted case studies on countries such as China, India, South Korea, Pakistan, and Vietnam and has concluded that nuclear power in those countries was never the cheapest form of electricity production [***12***].

Although currently nuclear power plants are in general not competitive with other sources of electricity, future gains in their efficiency are expected. According to a publication sponsored by the U.S. Department of Energy, *A Roadmap To Deploy New Nuclear Power Plants in the United States by 2010*, which included data from the U.S. nuclear industry on nuclear power plant designs that could be deployed by 2010, "new nuclear power plants can be deployed in the U.S. in this decade, provided that there is sufficient and timely private-sector financial investment." The report also noted that "although conditions are currently more favorable for new nuclear plants than in many years, economic competitiveness in a deregulated electricity supply structure remains a key area of uncertainty with respect to near term deployment potential . . . . [T]here are excellent new nuclear plant candidates that build on the experiences of existing reactors in the U.S. and around the world . . . . [T]hose that are most advanced in terms of design completion and approval status appear to be economically competitive in some scenarios, but not all" [***13***].

Regional Developments

Western Europe

Western Europe relied on nuclear power for 35 percent of its electricity in 1999. Nuclear's share of the Western European electricity market is expected to fall to 24 percent by 2020. Currently, among European countries, only France and Finland have shown any intent to expand their nuclear power industries. Most of the other nations of Western Europe have decided either to curtail

Nuclear Waste Disposal (Continued)

need to be stored for several years in steel-lined cooling pools or aboveground vaults before being transported to long-term waste depository sites.

The physical amount of waste produced thus far by all nations' nuclear power plants is not considered large. For the United States, for instance, it has been estimated that all the wastes from power reactors that have accumulated since the advent of civilian nuclear power production could be stored in a football-field-sized area roughly five yards deep.[c] Nevada's Yucca Mountain, which is scheduled to begin accepting commercial radioactive waste in 2010, is one of the furthest along worldwide, President Bush is the first to officially approve a site.[d] In the meantime, most, if not all, nuclear waste from U.S. power reactors is being stored on site at 70 nuclear power plants and two storage facilities. In addition, three low-level nuclear waste sites are in operation in South Carolina, Utah, and Washington.[e] The U.S. commercial nuclear industry creates about 2,000 metric tons of spent fuel per year, and about 40,000 metric tons of spent fuel are currently in temporary storage.[f]

Other nations with nuclear generating stations face similar storage issues. Underground repository sites are being planned for Belgium (2030), Canada (2025), Finland (2020), France (2020), Germany (2010), Spain (2020), Sweden (2008), and Switzerland (2020). As in the United States, most high-level waste overseas is currently stored on site at nuclear reactors.

Russia appears to be entering the business of storing other nations' high-level nuclear waste. On July 11, 2001, Russian President Vladimir Putin signed into law a measure exploring a plan to import and store other countries' nuclear wastes. Putin authorized a study to determine the long-term environmental impact of such storage. It has been estimated that Russia could earn as much as $20 billion over a decade by storing the nuclear wastes of countries whose own waste disposal efforts have made little progress.[g]

[c]Nuclear Energy Institute, "Nuclear Waste Disposal: Resources: Used Nuclear Fuel Management," web site www.nei.org (January 2002).
[d]E. Pianin, "Nevada Nuclear Waste Site Affirmed," *The Washington Post* (February 16, 2002), p. A1.
[e]M. Holt, "IB92059: Civilian Nuclear Waste Disposal," Congressional Research Service Report, web site cnie.org / NLE / CRSreports (U.S. Library of Congress, July 30, 2001).
[f]M. Holt, "IB92059: Civilian Nuclear Waste Disposal," Congressional Research Service Report, web site cnie.org / NLE / CRSreports (U.S. Library of Congress, July 30, 2001).
[g]Washington Nuclear Corporation, Nuke-Energy.com, web site www.nuke-energy.com / data / other / russian_president.html.

further development of nuclear power or to abandon it entirely. Belgium, Germany, the Netherlands, Spain, Sweden, and Switzerland have made past commitments to gradual phaseouts of their nuclear power programs, although those commitments have been difficult to carry through, as described below.

Sweden and Germany have adopted the most aggressive plans to end their nuclear power programs. In 1980, Sweden committed to a scheduled 40-year phaseout of nuclear power, and in November 1997 the Swedish parliament approved a plan to shut down two of the nation's twelve nuclear reactors, Barsebäck 1 and Barsebäck 2, which accounted for 12 percent of Sweden's nuclear generation capacity. Barsebäck 1, a 615-megawatt reactor that began commercial operation in 1975, was shut down in November 1999, more than a year after the scheduled closing date of July 1998. Barsebäck 2, completed in 1977, was initially scheduled to be closed in July 2001, but in August 2000 the Swedish government announced that the Barsebäck 2 closure would also be delayed until 2003, and then only if secure sources of electricity could be obtained [***14***]. After closing Barsebäck 1, Sweden replaced the lost electricity generation with imported power from a coal-fired plant in Denmark, causing an increase in Western Europe's total carbon dioxide emissions.

In June 2000, Germany's electricity industry agreed to phase out its nuclear power plants ahead of schedule [***15***]. The plan calls for the shutdown of all of Germany's reactors after they have operated for 32 years. Accordingly, the final plant closure would occur in the mid-2020s. Germany's ruling government minority coalition partner, the environmentalist Green party, had favored a 10-year phaseout. The Social Democratic German Chancellor, Gerhard Schroeder, initially favored a 20-year phaseout but reached a compromise with the electric utility industry. The German government also decided eventually to stop the foreign reprocessing of its spent nuclear fuels, but that decision was rescinded in early 2001, ending a 3-year moratorium on spent fuel shipments to foreign reprocessing plants.

There has been some recent apparent backtracking on the move away from dependence on nuclear power as a source of electricity. In Italy, the interim head of the nation's Environmental Protection Agency (Anpa) stated that there was "wide support within the country's scientific community for review of a possible re-emergence of nuclear energy in Italy" [***16***]. Similarly, the European director general for energy, Francois Lamoureux, stated that the use of nuclear is "unavoidable in aiding security of supply and tackling climate change" [***17***]. Martin Villa, the chairman of the Spanish Electricity Company Endesa, called for a reopening of the debate on new plant construction [***18***]. The Tony Blair government in the UK initially stated that it did not want an expansion of nuclear power; however, for some time the Blair government has left open the possibility that it would reverse that stance.

Japan

The Japanese government and electricity industry remain committed to building new commercial nuclear power reactors in the future, despite some public concern over operational safety. The *IEO2002* reference case projects that the nuclear share of Japan's total electricity generation will remain stable at about one-third through 2020.

Developing Asia

Alone among world regions, developing Asia is expected to see rapid growth in nuclear power. Nuclear power plants are currently in operation in China, India, Pakistan, South Korea, and Taiwan, and in the *IEO2002* reference case developing Asia is expected to more than double its nuclear capacity by 2020. Consumption of energy from nuclear power plants in developing Asia is projected to increase from 160 billion kilowatthours in 1999 to 425 billion kilowatthours in 2020. Increases in nuclear generating capacity are expected for all the developing Asian nations that currently have nuclear power plants in operation. By 2020, developing Asia is projected to account for 15 percent of the world's nuclear power capacity, up from 6 percent in 1999.

China and India are expected to show the most rapid growth in nuclear power capacity over the forecast period. China, which had 2,177 megawatts of capacity in 2000, is expected to increase its capacity to 16,607 megawatts by 2020. India is also expected to show a marked increase in nuclear power capacity. India, which currently has 2 nuclear power plants under construction, is expected to increase its capacity from 2,301 megawatts in 2000 to 6,451 megawatts by 2020.

IEO2002 expects substantial additional nuclear capacity to be added to the South Korean nuclear power sector over the forecast period. The additions projected are only slightly less than those forecast by the South Korean government or the state-owned national utility, KEPCO. In 1999, the South Korean nuclear power industry had 12,990 megawatts of capacity. By 2020, South Korea's nuclear power capacity is expected to rise to 22,125 megawatts.

North America

United States

The United States is expected to reduce its reliance on nuclear power significantly over the forecast period, from 20 percent of total electricity generation in 1999 to less than 15 percent in 2020. Only a few years ago it seemed likely that there would be numerous early closures of nuclear power plants in the United States; however, several companies have recently applied to the NRC for extensions of reactor operating licenses, and as many as 90 percent of all operating plants could eventually be relicensed [**19**]. Reductions in operating costs over the past decade have made nuclear plants more competitive, even as electricity markets are increasingly being deregulated.

The Bush Administration's National Energy Policy favors expanding the role of nuclear power by, as stated in the report of the National Energy Policy Development Group, "encouraging the Nuclear Regulatory Commission to facilitate efforts by utilities to expand nuclear energy in the United States by uprating existing power plants safely . . ." and by encouraging "the NRC to relicense existing nuclear plants . . ." by directing the DOE and EPA to "assess the potential of nuclear to improve air quality . . . to increase resources as necessary for the nuclear safety enforcement in light of the potential increase in generation . . . to use the best science to provide a deep geologic repository for nuclear waste . . . to support legislation clarifying that qualified funds set aside by plant owners for eventual decommission will not be taxed as part of the transaction . . . to support legislation to extend the Price Anderson Act" [**20**], which limits a nuclear power plants liability in the case of an accident. In 2001, the Department of Energy's Office of Nuclear Energy, Science and Technology solicited proposals from the civilian nuclear electricity industry to conduct scoping studies "of potential sites for the deployment of new nuclear power plants" [**21**].

In the United States, some utilities have come out in favor of building new units and perhaps resurrecting units already shut down. In March 2001, the Tennessee Valley Authority (TVA) began reconsidering the restarting of Browns Ferry nuclear plant, which was shut down in 1985. In December 2001, the TVA announced that a "preferred option" is to extend the operation of all three Browns Ferry units [**22**]. Exelon Corp, the largest producer of nuclear power in the United States, has been discussing with the NRC the construction of new nuclear plants and announced that it is considering restarting one or both nuclear reactors at its Zion site (in Illinois), which was shut down in 1998. Recently, the NRC has approved three new versions of reactors that are deemed both safer and more economical.[17] To date, however, no firm plans for either constructing a new unit or restarting a mothballed unit have been announced.

Canada

Nuclear power accounted for 14 percent of Canada's electricity generation in 1999, but its share is expected to drop slightly, to 13 percent, by the end of the forecast period. In late 1997 and early 1998, Ontario Power Generation (formerly Ontario Hydro) shut down seven of its older nuclear power plants, or 17 percent (4,300 megawatts) of its operating capacity. Canada still has 14 nuclear power plants currently in operation. In July 2000, Ontario Power Generation announced its planned lease of the operation of eight of its Bruce reactors, four of which were shut down in 1998, to British Energy. In January 2001, Canada's nuclear safety commission scheduled two hearings for licenses to resume operation of three of the closed units. On October 2, 2001, the Canadian Nuclear Power Safety Commission approved an environmental review procedure that is expected to result in the reopening of Ontario's Bruce 3 and 4 nuclear power plants, with a total of 1,500 megawatts of capacity, by 2003 and 2004, respectively [**23**]. In November 2001, the Commission gave provisional approval for the restart of the Pickering A power plant [**24**].

Africa

Among African nations, South Africa is currently the only country with nuclear electricity generation capacity and the only nation expected to produce electricity from nuclear power over the forecast period. South Africa has two 921-megawatt reactors, Koeberg 1 and 2, now in operation, and nuclear power accounted for 7 percent of its electricity generation in 1999. South Africa's state-owned utility, Eskom, has been experimenting with pebble bed modular reactor technology since 1993 and had proposed the construction of a 110-megawatt demonstration reactor beginning in mid-2001, although the most recent phase calls for units in the 120 to 130 megawatt range. In November 2001, the proposed construction start time for the pebble bed modular reactor was delayed for up to 12 months upon completion of a feasibility study [**25**]. The *IEO2002* forecast does not expect the reactor to come online until late in the forecast period.

Eastern European and the Former Soviet Union

Nuclear power capacity in Eastern Europe and the former Soviet Union (EE/FSU) is expected to decline over the forecast period, primarily as a result of the retirement of plants in the FSU that have been the subject of safety concerns. By 2020, the region is expected to have 37,000 megawatts of capacity, compared with 44,000 megawatts in 1999.

The EE/FSU region has 59 reactors operating at 18 nuclear energy sites. Twenty-five are considered to be operating at standards below those acceptable in the West. A major goal of Western efforts has been to shut down the least safe nuclear reactors operating in the EE/FSU countries.

[17]These include the Westinghouse AP600 design, General Electric's Advanced Boiling-Water Reactor, and the Combustion Engineering Systems 80+ model.

In 1992, the International Atomic Energy Agency began a review of safety practices at Soviet-designed RBMK-type reactors. RBMKs are graphite-moderated channel reactors. Six of the 15 RBMK plants currently in operation are "first generation," because they were built in the early to mid-1970s. They are considered less safe than those built later. In total, the Soviets built 17 RBMK units (including the 4 units at Chernobyl), of which 13 are still active. Eleven RBMK reactors are operating in Russia and two in Lithuania, and one is currently under construction.

Lithuania was promised 200 million euros (about $180 million) from the European Commission and twelve other nations in grants to help ease the financial burden of shutting down its RBMK Ignalina 2 nuclear power plant before 2005. Similar efforts are being undertaken to close down Bulgaria's Kozloduy plants and Slovakia's Bohunice plants. Bulgaria intends to close Kozloduy units 1 and 2 in 2002 or 2003. Bulgaria has agreed to close Kozloduy units 1-4 "at the earliest possible date." The European Union (EU) committed 200 million euros to help Bulgaria close Kozloduy units 1 and 2, and in February 2001 Westinghouse announced that it will modernize Kozloduy units 5 and 6 . Both Lithuania's and Slovakia's future entry into the EU has been jeopardized by the concerns associated with their nuclear power industries. In December 1995, the Group of Seven and Ukraine reached an agreement to shut down all units at Chernobyl by 2000. The Chernobyl accident in 1986 destroyed unit 4, and unit 2 was shut down in 1991. Under the agreement, unit 1 was shut down in 1996, and Ukraine shut down the last of the four reactors, Chernobyl 3, in December 2000.

In October 2000, the first of the Czech Republic's two Temelin nuclear power reactors was brought online after a long-running dispute with Austria and Germany. Construction on Temelin, which began in 1987, was delayed for financial and technical reasons [***26***]. Unlike the RBMKs discussed above, Temelin is a pressurized-water reactor. Westinghouse was brought in to upgrade the Temelin plant to Western standards.[18] British Energy has indicated a willingness to purchase both the Temelin plant and the Czech Republic's Dukovany reactors, adding to a portfolio of nuclear assets that includes plants in the United States and Canada.

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