4

Nuclear Power in Decline

Nuclear power, once lauded as an energy source that would be "too cheap to meter," is becoming too costly to use. For the world as a whole, nuclear power generation peaked in 2006 and dropped by more than 10 percent by 2013. In the United States—the country with the most reactors—nuclear generation peaked in 2010, then dropped by nearly 3 percent by 2014. In second-place France, nuclear output has dropped nearly 7 percent since peaking in 2005. Similar declines can be seen in several other leading countries. These trends are likely to continue and even to accelerate as the world nuclear fleet ages and as solar- and wind-generated electricity comes online at a much lower cost than electricity from new nuclear plants.

The idea of using nuclear technology for peaceful purposes was brought to the fore with U.S. President Dwight D. Eisenhower's "Atoms for Peace" speech to the U.N. General Assembly in 1953. The 1960s and 1970s saw a boom in nuclear plant construction. Then new construction starts dropped sharply, and the worldwide growth in nuclear power generation slowed in the mid-1980s. As a share of global electricity generation, nuclear power reached nearly 18 percent in 1996. But by 2013, it accounted for less than 11 percent.

Industry analysts Mycle Schneider and Antony Froggatt write in their annual *World Nuclear Industry Status Report* that the number of operating reactors worldwide peaked at 438 in 2002. By July 2014, the total had dropped to 388 reactors operating in 31 countries—with most of the decline coming from the massive closure of plants in Japan following the 2011 Fukushima accident. Of the world's remaining reactors, exactly 100 were in the United States. France came next, with 58 nuclear reactors, followed by Russia with 33 and South Korea, China, India, and Canada each with around 20. The other countries rounding out the top 10 were the United Kingdom, Ukraine, and Sweden.

Typically, as more experience is gained with a power generation technology, costs decline. For example, with both wind and solar, costs have been dropping for years from both technological advances and economies of scale. But in one of the ironies of energy economics, the cost of nuclear power plants has increased over time.

A key contributor to rising costs is that plants are taking longer to build. For a number of reasons—including plant design changes, contract disputes, new safety regulations, and shortages of parts or labor—construction schedule delays are the rule, not the exception. For the 37 nuclear reactors that came online between 2004 and mid-2014, the average construction time was 10 years. China and India, which accounted for 20 of these 37 units, averaged 6 and 7 years respectively. But for Russia and Ukraine, construction times averaged 24 and 19 years respectively—nearly a human generation. Iran's first and only reactor took 36 years to build.

As of mid-2014, close to 70 reactors were still under construction worldwide. Mycle Schneider reports that

49 of them were behind schedule, including 20 of the 27 under construction in China. All nine of Russia's reactors were off schedule, as were the five being built in the United States. Even if all of these reactors are eventually completed, the additional generating capacity is unlikely to offset the capacity loss from retirements.

Construction on one of the U.S. reactors, Watts Bar 2 in Tennessee, began in 1972. The project, which was put on hold in the 1980s and revived in 2007, was scheduled to be completed in 2012 for a total of $2.5 billion. Then in early 2012 the utility building the reactor announced that the startup date would be moved to 2015 and the cost would rise to between $4 billion and $4.5 billion. If the plant is completed in 2015, it will have logged 43 years from start to finish—more time than it took to build the Panama Canal.

The other four U.S. nuclear units under construction, two each in Georgia and South Carolina, are the only projects still alive out of the dozens of new reactors planned in the 2000s as part of the "nuclear renaissance" touted by the industry. In June 2014, Georgia officials warned that the first new reactor at Plant Vogtle would be online in early 2018 instead of April 2016 as initially projected. The $14 billion price tag for the two reactors could rise by $2 million for every day of delay. And in August, an even longer delay was announced for the first new South Carolina reactor, tacking on an estimated $1 billion to the project's initial $10 billion cost. In each case, ratepayers are already paying for the projects, regardless of whether the plants are ever completed.

France, which gets more of its electricity from nuclear power than any other country—some 75 percent—has one remaining reactor under construction. Begun in 2007, the third unit at the Flamanville nuclear plant was projected to cost $4.5 billion and be finished in 2012.

Both targets were missed. Now the project may be finished in 2017 and cost at least $11.6 billion. A similar cost escalation has hit the lone reactor under construction in Finland, which broke ground in 2005. It will not go online until late 2018 at the earliest, nearly a decade later than originally planned.

One of the most staggering cases of cost escalation involves a project not yet under construction as of this writing. Beginning in 2005, the British government set its sights on a revival of U.K. nuclear power, promising 10 new reactors. These generators would be built for $3 billion each, need no subsidies, and start producing electricity in 2017. When European Union officials finally approved the plan in October 2014, however, it had been reduced to just two reactors, both heavily subsidized, with a start date of 2023. The U.K government will now cover roughly 70 percent of the estimated $39 billion it will cost French state-owned utility EDF to build the reactors. In addition, the government has agreed to pay EDF twice the current wholesale market rate for the electricity generated by the plant.

As plants age, operation and maintenance become more expensive. For the United States, which has some of the oldest nuclear power plants, this is a growing concern. Credit Suisse reports that the cost of operating aging U.S. reactors is rising 5 percent a year. Meanwhile, fuel costs are climbing 9 percent annually. These rising costs are not only discouraging the construction of new plants, they are leading to the closure of existing ones.

Four U.S. reactors were retired in 2013 because it did not make economic sense to continue operations. Southern California Edison decided to retire two reactors near San Diego rather than pay to repair a leak in a brand-new steam generator. Duke Energy shuttered a Florida nuclear unit because needed repairs were too costly and time-consuming. And Dominion Resources retired a Wisconsin reactor—recently approved by the U.S. Nuclear Regulatory Commission to extend operations until 2033—citing declining profits. A fifth reactor, Vermont Yankee, was shut down for good at the end of 2014, primarily because it was not cost-competitive.

Economist Mark Cooper of the Vermont Law School's Institute for Energy and the Environment has identified 37 more U.S. reactors that may be forced to close for economic reasons. With the operating costs of nuclear reactors escalating while the costs of solar and wind decline, the days for the remaining reactors are numbered.

This is not just a U.S. phenomenon. In 2012, EDF—the world's largest nuclear operator—logged a $2 billion income deficit largely because of rising costs. French data show the generating cost of nuclear there increased by one fifth from 2010 to 2013. In Germany, the giant utility E.ON will close an aging reactor seven months early in 2015 because operating costs exceed projected income. And three Swedish reactors are also having trouble as electricity sales lag costs.

In recent years, the major credit ratings agencies have tended to take a more negative view toward utilities with nuclear investments. One of those agencies, Moody's Investors Service, says companies building new nuclear plants put themselves at greater risk of a credit downgrade due in part to likely cost overruns and schedule delays, as well as vulnerability to being undercut by cheaper power options like wind and solar.

In general, European utilities heavy with nuclear plants have taken a beating in the market. Over the last seven years, EDF's share price has dropped by 70 percent. During the same period, the share price of Areva, the French government-owned company that is the world's largest builder of nuclear plants, dropped by 88 percent.

As the world fleet of nuclear plants—currently averaging more than 28 years in operation—ages, the question is whether to repair older plants or simply close them. It is not always clear exactly when a plant should be closed. As Matthew Wald notes in the *New York Times*, it is sometimes difficult for plant owners to distinguish between "middle-aged aches and pains" and "end-of-life crises."

Closing nuclear plants is costly. For the two California reactors retired in 2013, the 20-year decommissioning process will cost an estimated $4.4 billion. At the extreme end of decommissioning costs is the United Kingdom's Sellafield nuclear facility, site of the world's first commercial nuclear power plant. The U.K. government now estimates that decommissioning the four-reactor site, including cleaning up the legacy of weapons-grade plutonium that was produced in the 1950s, will cost a whopping $130 billion over the next century.

Disposal of nuclear wastes is yet another long-term cost—and an unsolved problem. As a result, nuclear waste is accumulating in every country that has nuclear power plants. As of 2014, the United States had nuclear waste stored at 80 temporary sites in 35 states. Nine states, among them California, Connecticut, and Illinois, have banned construction of new nuclear power plants until an acceptable means is developed to deal with the waste.

For more than 20 years the U.S. government said that the radioactive waste from the country's nuclear plants would be stored in Yucca Mountain, a proposed repository roughly 90 miles northwest of Las Vegas, Nevada. The projected cost to complete this repository, estimated at $58 billion in 2001, climbed to $96 billion by 2008. This comes to almost $1 billion per reactor—a staggering amount.

In addition to becoming more expensive, building the repository fell far behind schedule. Originally slated to start accepting waste in 1998, this was revised to 2017 and then again to 2020. But in 2009 the Department of Energy announced that the Yucca repository was being abandoned and that a search for a new site was under way. Although proponents have pushed to reanimate pursuit of the Yucca Mountain site, there is no guarantee this will happen. The U.S. nuclear industry appears to be caught in a trap it set for itself.

No country has come up with an acceptable long-term solution. South Korea, for example, has also accumulated large amounts of waste, 70 percent of it now in temporary storage pools. Park Jiyoung, a research fellow and nuclear scientist at the Asan Institute for Policy Studies, hit the nail on head when she said: "We cannot keep stacking waste while dragging our feet. If we fail to reach a conclusion [on how to manage spent fuel], it would be time to debate if we should stop nuclear power generation."

Some countries—namely France, India, Japan, Russia, and the United Kingdom—allow used nuclear fuel to be reprocessed, in which plutonium and uranium are separated from the other waste and later used again to fuel reactors. This does not solve the problems of waste storage and disposal because the volume of waste actually increases. Furthermore, isolating plutonium through waste reprocessing increases the risk that terrorists will obtain it for nuclear weapons or that countries with nuclear power facilities will develop their own weapons programs.

The global supply of experienced nuclear engineers and the availability of manufacturers to produce the parts for a nuclear power plant are both tightening. Older nuclear engineers are retiring, and young people are not entering the field—one that is widely perceived as dying—at a rate that will replace retirees. Skills and parts needed by the fading industry are not always readily available, causing costs to rise even more.

Nuclear power's overarching problem is that the economics do not work. But there is also always the risk of an accident—itself an enormous expense—as the world was reminded on March 11, 2011. At 2:46 pm that day, a magnitude 9.0 earthquake struck off Japan's northeast coast. Within one minute, more than 90 miles away, the three operating reactors at the six-unit Fukushima Daiichi nuclear power plant automatically shut down after detecting the tremors. The quake cut off grid power to the plant, prompting emergency diesel generators to start up. Unfortunately, the backup power system was destroyed when the earthquake spawned a massive tsunami, some 40 feet high, and floodwaters infiltrated the reactor buildings. Without electricity to maintain the flow of cooling water to the nuclear fuel rods, the reactor cores began overheating, cooling water evaporated, and the exposed nuclear fuel rods began to produce hydrogen gas.

That evening, the government declared a nuclear emergency and ordered evacuations within a 2-mile radius of the plant. By morning, the evacuation radius was increased to 6 miles. Following a hydrogen explosion at Unit 1 that afternoon, it was 12 miles.

Within four days of the earthquake and tsunami, all three previously operating reactors had melted down, releasing radioactive material and hydrogen. Explosions had rocked two more reactors, including Unit 4, which was off-line when disaster struck but where the spent fuel cooling system had been damaged. The world looked on in shock as 24-hour cable news channels covered this nuclear accident within the broader disaster that claimed some 15,900 lives.

The sheer scale of the recovery operation is difficult for anyone not directly involved with this work to envision. Nuclear industry analysts Schneider and Froggatt describe in detail some of the many dimensions of this effort. As of

May 2014, three years after the accident, 4,200 workers remained on-site. Recruiting workers to manage the site is becoming more difficult, for obvious reasons.

It is taking 360 tons of water a day to continuously cool the molten fuel inside the plant's remains. As of July 2014, more than 500,000 tons of radioactive water were precariously stored on-site at the Fukushima plant. In trying to cope with the continuously growing quantity, plant operator TEPCO plans to expand the tank storage capacity there to hold 800,000 tons. Needless to say, with such a huge operation there have been many problems, including leaks of radioactive water into the soil, groundwater, and nearby Pacific Ocean. It has become a horror story without end.

The social effects of the Fukushima meltdown are extensive, to say the least. Some 130,000 people in Fukushima Prefecture have not been able to return to their homes. Another 137,000 evacuees from the earthquake- and tsunami-affected area are spread out over at least seven prefectures. Some 1,700 deaths, including suicides, are attributed to the disruptions and stresses caused by the meltdown.

It is estimated that decommissioning the Fukushima reactors may take 40 years and $100 billion. And this does not include decontamination of the surrounding area or the compensation that TEPCO is still paying to victims for lost property, mental suffering, and more—which combined may cost another $400 billion. Even more disturbing is the fact that this meltdown took place in one of the world's most technologically advanced societies.

This event altered the future of nuclear power. Prior to the Fukushima disaster, 16 of Japan's 54 reactors were already off-line for inspection or maintenance. When the earthquake and tsunami hit, more than a dozen reactors underwent emergency shutoffs, including the disabled

Fukushima Daiichi units. The rest of Japan's reactors eventually were taken off-line as well, either for inspection or because of earthquake vulnerability. Only two reactors subsequently restarted for any period of time, but these went off-line again in September 2013.

The Fukushima experience has caused widespread public opposition to nuclear power in Japan. Most people do not want to restart any of the country's reactors. As of late 2014, no Japanese reactors were generating electricity. However, two reactors in Kagoshima Prefecture had met new safety requirements and gotten local approval to restart, setting up a possible early 2015 return to operation.

Immediately after the accident, attention in Japan turned to natural gas and oil as a substitute for the lost generating capacity. But with time there has also been rekindled interest in renewable sources of energy, such as solar, wind, and geothermal energy, each of which is widely available there. Although it is too early to tell for sure, Fukushima may have sounded the death knell for nuclear power in Japan.

Within days of the Fukushima accident, Chancellor Angela Merkel announced that Germany's oldest reactors would close. A plan to shut down all 17 of the country's nuclear reactors was agreed to in May 2011. The gap will be filled by harnessing Germany's green energy resources—primarily wind, solar, and geothermal energy.

Germany was not the only country to turn away from nuclear power. Switzerland, which was planning three new reactors, abandoned them. It also announced that its five reactors would close permanently when their operating licenses expired over the next couple of decades. Italy had been planning to restart its nuclear program, which had been halted in the 1980s, but in a June 2011 referendum, 90 percent of Italian voters chose to ban nuclear power. Belgium decided to phase out its seven nuclear reactors, which supply half of the country's electricity. France announced it would reduce its extreme dependence on nuclear power to 50 percent by 2025.

Fukushima alerted the world to the potential dangers of nuclear power—concerns that had been largely set aside following two earlier accidents. On March 28, 1979, the Unit 2 reactor at the U.S. Three Mile Island nuclear generating complex suffered a partial meltdown. It began with either an electrical or a mechanical failure that compromised the plant's water-based cooling system. A series of operator errors followed, leading to overheating and a severe core meltdown. Although this was the most serious U.S. accident in the nuclear era, the radioactive releases were small and had no significant health effects on either workers at the plant or the community at large.

A 13-year cleanup program was devised after this accident, in the end costing close to $1 billion. While the human and environmental impact of the meltdown at the Three Mile Island facility appears to have been minimal, this should have been a wake-up call—a warning that accidents could happen at nuclear power plants, even in an industrial superpower.

Seven years later, in the early morning hours of April 26, 1986, the Unit 4 reactor at the Chernobyl nuclear generating plant in Ukraine, then part of the Soviet Union, exploded. Radioactive isotopes were blasted several miles into the atmosphere. Carried in all directions by the winds over the next 10 days, radioactive fallout contaminated 58,000 square miles of Ukraine, Belarus, and Russia and was detected at lower levels throughout the northern hemisphere. The effect of this explosion on the workers at the plant, the people who were most directly exposed to the radiation, was severe. Of the 134 workers who developed acute radiation sickness from high exposure, 28 died within three months. Thousands of children living in the area developed thyroid cancer.

The severe contamination in the 19-mile exclusion zone surrounding the plant made it uninhabitable. Nearly 200 villages were abandoned. The town of Pripyat, which had 45,000 residents and was within two miles of the Chernobyl plant, was immediately evacuated. It remains a ghost town. Although it has been nearly 30 years since the accident, the costly cleanup is still going on. With limited resources, the Ukrainian government has moved slowly. It may take another 100 years to finish the job.

Numerous studies have been undertaken to try to count the number of deaths from the Chernobyl nuclear fallout, including from the radioactive plumes that drifted over Europe, but the estimates range widely. Even harder to measure is the psychological toll that follows nuclear accidents on top of the physical and financial stresses. There is evidence that the stress of living in contaminated areas may have contributed to higher rates of alcoholism and smoking.

The total cost of dealing with the Chernobyl disaster thus far is difficult to estimate, but it could easily be in the hundreds of billions of dollars. As of the mid-2000s, Ukraine was still spending 5–7 percent of its national budget on Chernobyl-related programs and benefits.

The United States and some 30 other countries are financing a 32,000-ton arch to cover the aging "sarcophagus" that entombs the damaged Chernobyl reactor in order to contain radiation in case the sarcophagus collapses. It has a scheduled completion date of 2017.

It is clear that the risks posed by a catastrophic nuclear power accident are high. In the United States, the public is on the hook for most potential damages. In 1957 the U.S. Congress passed the Price-Anderson Act, which shelters U.S. utilities with nuclear power plants from the cost of an accident. Under the act, utilities are required to maintain private accident insurance of $375 million per reactor site. In the event of a catastrophic accident, every nuclear utility would be required to contribute up to $121 million for each of its licensed reactors to help cover the accident's cost.

The collective cap on nuclear operator liability for personal injury and property damage is $13 billion. So any accident costing more than that would have to be covered by taxpayers. Unfortunately, an estimate by the Sandia National Laboratories indicates that a worst-case accident could cost $700 billion.

Few of the cost calculations for nuclear power that are used by utilities are complete. If the full cost were included upfront, it would be impossible to justify building nuclear plants.

In stark contrast to nuclear power's darkening prospects, wind and solar power are surging ahead, as described in the following chapters. Global wind power generation has grown on average 26 percent a year over the last decade, while electricity from solar photovoltaics (PV) has grown 51 percent annually. During 2013, wind and solar PV together added 72,000 megawatts of generating capacity worldwide. Nuclear power, on the other hand, suffered a net loss of 1,500 megawatts.

In both China and India, wind farms generated more power in 2013 than nuclear plants did. Wind has not only overtaken nuclear power generation in China, it is in a steep upward climb. Nuclear power is continuing to expand there at 10 percent a year, but this is a much slower pace than the growth of wind. From 2008 to 2013, wind generation in China expanded a remarkable 59 percent a year.

And as France—for years the poster child for nuclear power—reduces its nuclear reliance over the next decade, it will boost renewable energy's share in its electricity mix from 16 percent to perhaps 40 percent. A big buildup of wind power, along with gains in energy efficiency and more solar power, will be key components of France's shift away from nuclear.

It simply makes more sense to build new wind farms and solar arrays instead of new nuclear plants. Like nuclear power, wind and solar power generate electricity without climate-disrupting carbon emissions. But they do it more affordably and without the financial, environmental, and health risks associated with nuclear. Wind and solar installations come online in a fraction of the time that it takes to construct a nuclear plant. And once they do, the fuel is free, local, and unlimited.

The overall situation is that as of late 2014 some 31 countries were still operating nuclear power plants, but scarcely half as many were building new ones. Most of the planned build-out is in countries with centrally planned economies. But even in the absence of a free market, the high costs of nuclear power make it a poor energy choice. Nuclear power's best years are now history. The recent worldwide decline in nuclear generation is not a temporary dip but rather the beginning of the end of nuclear power.

Data, endnotes, and additional resources can be found at Earth Policy Institute, www.earth-policy.org.