5 Vaunted Hopes

Climate Change and the Unlikely Nuclear Renaissance

Joshua William Busby

After years of stagnation, nuclear power is on the table again. Although the sector suffered a serious blow in the wake of the Fukushima Daiichi nuclear meltdown that occurred in Japan in early 2011, a renewed global interest in nuclear power persists, driven in part by climate concerns and worries about soaring energy demand. As one of the few relatively carbon-free sources of energy, nuclear power is being reconsidered, even by some in the environmental community, as a possible option to combat climate change. As engineers and analysts have projected the potential contribution of nuclear power to limiting global greenhouse gas emissions, they have been confronted by the limits in efficiency that wind, water, and solar power can provide to prevent greenhouse gas emissions from rising above twice pre-industrial levels.

What would constitute a nuclear power renaissance? In 1979, at the peak of the nuclear power sector's growth, 233 power reactors were simultaneously under construction. By 1987, that number had fallen to 120. As of February 2012, 435 nuclear reactors were operable globally, capable of producing roughly 372 gigawatts (GW) of electricity (WNA 2012). Some analysts suggest that, with the average age of current nuclear plants at twenty-four years, more than 170 reactors would need to be built just to maintain the current number in operation (Schneider et al. 2009a).[1] As discussed in the Introduction to this volume, merely besting the current number of reactors would not constitute a renaissance. When analysts refer to a nuclear renaissance, they not only imply that nuclear power will experience a revival of plant construction on the order of thirty new reactors per year, similar to the sector's heyday in the 1960s and early 1970s, but also that the collective growth in nuclear power capacity will be sufficient to offset a significant share of global emissions of greenhouse gases that otherwise would have been emitted from the burning of fossil fuels. Whatever reservations people have about nuclear power—the high cost of reactor construction, the possibility of accidents and nuclear proliferation, issues associated with the disposal of nuclear waste—the potential for nuclear power to partially address the problem of climate change has given the industry a new lease on life after decades of increasing marginalization.

Proponents of nuclear power are often willing to look past the sector's defects and assume that the benefits are large enough and the barriers tractable enough that the imperative for a greenhouse gas solution will ultimately create adequate political will to see through the technological and economic challenges. We can call this line of argument the *nuclear technological optimists* position (examples include IAEA 2000; IEA 2010b). Critics, for their part, seize on negative information—cost overruns on new plant construction, the relative affordability of alternatives (such as natural gas), reports of accidents and stoppages at existing plants, thefts of nuclear material—to pour cold water on the nuclear renaissance. We can refer to this as the *nuclear alarmists* position (some examples include Greenpeace n.d.; Stoett 2003).

Both advocates and opponents have plenty of material to use in bolstering their arguments. A number of countries are again constructing nuclear power plants. Some, such as Finland and France, are experiencing cost overruns and delays. Even before Fukushima, Japan had experienced several worrying accidents around its nuclear facilities. The United States, too, had canceled the waste disposal site at Yucca Mountain. At the same time, after a period in which new construction starts dwindled to a trickle, more than sixty nuclear reactors are being built, with possibly hundreds more on the way. This chapter evaluates the disparate evidence, analyzing the technological possibilities for emissions reductions while recognizing practical challenges facing the sector.

In the wake of Fukushima, it appears that *residual domestic political opposition* in many wealthy Western countries and several middle-income countries elsewhere in the world will complicate strategies for supporting nuclear energy. This relates to countries building new nuclear plants at home, as well as their ability to promote international strategies to support nuclear power through such instruments as the Kyoto Protocol's Clean Development

Mechanism (CDM). At the same time, lingering *technological barriers, capacity issues, and safety concerns* may slow the construction of new nuclear plants even in countries that are otherwise enthusiastic about nuclear power. Other reasons may limit the supply and demand for nuclear power. Indeed, as Christopher Way argues in Chapter 6 of this volume, concerns about proliferation may lead nuclear fuel suppliers to try to regulate access by nuclear aspirants. Concerns about the credibility of commitments of fuel may, in turn, lead would-be nuclear power states to scale back their own demand. The net consequence of countervailing pressure for and against nuclear power will be more nuclear power plant construction but perhaps significantly less than renaissance supporters project. As such, much-vaunted plans for plant construction may never fully materialize.[2]

This chapter unfolds in three parts. The first section reviews the putative potential for nuclear power to offer a significant contribution to reduced greenhouse gas emissions, as well as other reasons for renewed interest in nuclear energy. The second section assesses the likelihood that nuclear power will fulfill the range of aspirations ascribed to it. While the nuclear renaissance ultimately depends on the decisions of states and private investors, the landscape for construction of new nuclear plants may be affected by climate change negotiations and the decisions by international organizations. The third section, therefore, reviews the role of nuclear power in international climate negotiations and assesses the implications of renewed interest in nuclear power for global climate governance.

Climate Change and the Nuclear Renaissance: The Potential

Nuclear power is one of the few nearly carbon-free sources of energy. For example, in the United States, nuclear power was responsible for nearly 70 percent of the country's low-carbon energy in 2008 (Pew Center on Global Climate Change 2009). While the extraction of uranium and the construction process of nuclear power plants release some greenhouse gases, emissions are modest—not quite as advantageous as renewables or hydropower, but far superior to gas and especially coal.

Nuclear power remains an attractive proposition for a number of countries, not least of which is the prospect for an energy source that has an extremely low carbon footprint. For countries reliant on imported fuel sources (particularly those with uranium reserves), diversification through nuclear power potentially provides a source of reassurance for reasons of energy security. This is more the case for countries that import natural gas than it is for oil importers, as oil currently has limited use in the electricity sector where nuclear is deployed. That said, the prospects for increased use of electric vehicles in the transport sector could make low-carbon energy from nuclear power an important way to offset reliance on imported oil. Nuclear power currently provides a significant share of existing power needs in the electricity sector. As of 2012, 435 commercial nuclear reactors, operating in thirty countries, produced 372 GW of electricity, roughly 13.8 percent of the world's total electricity needs (WNA 2012). Of this total, 80 percent is concentrated in just eight countries: the United States, France, Japan, Germany, Russia, South Korea, Ukraine, and Canada (IPFM 2007: 82). Moreover, 63 percent of total world capacity is produced in North America and Western Europe (von Hippel 2010). Some positive trends have buoyed the industry in recent years. In a number of countries, the efficiency of existing nuclear power plants has improved considerably. For example, nuclear plants in the United States have operated at an average fleet capacity of 90 percent since 2003 (MIT 2009). Moreover, though a number of nuclear plants were to be shuttered after twenty years of use, U.S. officials were extending the planned lives of nuclear plants from forty to sixty years (Joskow and Parsons 2009: 49). Prior to the Fukushima disaster, officials in other countries had made similar determinations.

The existing fleet of nuclear power plants is already responsible for significant emissions savings of greenhouse gases. Lester and Rosner estimate that the avoided greenhouse gas emissions from the current nuclear fleet total 650 million tons of carbon, or nearly 9 percent of the current global total (Lester and Rosner 2009: 24).[3] In addition, nuclear power prospectively offers great potential to lower a significant share of future greenhouse gas emissions.

This section reviews three growth trajectories for nuclear power and estimates the emissions savings potential under each scenario. In the "wedge" scenario, nuclear power provides 700 GW of power in 2050. In the MIT scenario, nuclear power provides 1,000 GW of power by midcentury. In the BLUE Map scenario generated by the International Energy Agency (IEA), nuclear provides 1,200 GW of power.

None of these scenarios implies either a continuation of the status quo (nuclear stagnation) or a modest decline in the contribution of nuclear to overall energy needs. The wedge strategy is the closest to what the Introduction describes as a "resurgence" of nuclear power, with a deepening of construction by Korea, Russia, India, and China. Two of the three scenarios—the MIT and BLUE Map— imply a "renaissance" of nuclear power, including substantial construction by the aforementioned states and a revival in nations such as the United States and Japan, as well as significant construction by new nuclear aspirants.

In their 2009 analysis, Socolow and Glaser note that humans currently emit about thirty billion tons of carbon dioxide (CO_2) per year. Some business-as-usual scenarios put 2050 emissions at sixty billion tons per year.[4] In their view, we would be fortunate if 2050 emissions could be stabilized at current levels. This would require a variety of strategies to collectively reduce emissions over projected business-as-usual strategies by thirty billion tons (Socolow and Glaser 2009). In this portfolio of strategies, or what Pacala and Socolow refer to as a "wedge" strategy, each represents about four billion tons of avoided CO_2 emissions (or about 13 percent of total emission savings that are needed) (MIT 2003). Energy efficiency, renewables, reduced deforestation, carbon capture and sequestration, and fuel switching from high-carbon to low-carbon sources are among the possible wedges that could deliver such emissions reductions. No single strategy will be enough to deliver sufficient emissions savings, nor is any particular wedge strategy essential. Of about fifteen different possibilities, we will need to use a combination of at least seven or eight of them (Pacala and Socolow 2004).

Nuclear power was one of the promising wedge strategies. In Socolow's original paper with Pacala, they estimated the emissions savings of substituting 700 GW of nuclear power, roughly twice the size of the current nuclear power sector, for 700 GW of coal-fired power plants. Socolow and Glaser explained further: a nuclear wedge would equal about 700 large baseload nuclear power plants on the scene in 2050, substituting for 700 coal plants that otherwise would have been built. A large baseload nuclear plant would generate 1 GW of electricity and operate roughly 8,000 hours a year. A 1-GW nuclear power plant can provide electricity to a U.S. city of 500,000 people, slightly less than the population of Washington, D.C. (Ferguson 2007). The baseload coal plant that each nuclear power plant would replace would be marginally more efficient than contemporary coal plants, emitting 800 grams of CO_2 per kilowatt-hour of electricity, or 6.4 million tons per year (this assumes a 1-GW power plant operating 8,000 hours per year producing 800 grams of CO_2 per kilowatt-hour). Pacala and Socolow suggested the full lifecycle emissions of nuclear power were 50 grams of CO_2 per kilowatt-hour, sixteen times less than coal plants (Kleiner 2008; Sovacool 2008). Accordingly, they estimated that 700 nuclear plants would emit roughly four billion tons of CO_2 per year *less* than 700 coal plants (without carbon capture and sequestration). If nuclear were to offset natural gas plants instead of coal plants, which are roughly 50 percent less greenhouse gas intensive than coal plants, nuclear plants would generate CO_2 savings of roughly two million tons per year (see Table 5.1) (Pacala and Socolow 2004: 42).

In a 2003 report, scholars from MIT assessed the requirements for increasing nuclear power production globally to 1,000 GW, a more aggressive nuclear growth strategy than the wedge approach. If we again assume that nuclear exclusively replaces coal, then 1,000 1-GW nuclear plants would produce six billion tons of CO_2 less than 1,000 coal-burning power plants. This would be about 20 percent of the thirty-billion-ton reduction needed to maintain emissions at contemporary levels (about a wedge and a half).

An even more aggressive pro-nuclear scenario was developed by the IEA. The BLUE Map scenario for 2050 depicts a world in which emissions in energy-related CO_2 emissions fall by 50 percent below 2005 levels. In this world, nuclear power grows from providing 370 GW to 1,200 GW. The share of global electricity generated by nuclear increases from 14 percent to 24 percent, while total electricity use doubles from 20,000 terawatts-hours (TWh) in 2007 to 41,000 TWh by 2050. China's percentage of global nuclear capacity would rise from 3 percent today to 27 percent in 2050; India's proportion would rise from 2 percent to 11 percent (IEA 2010b). Assuming that 1,200 GW of nuclear power only replaces coal power plants, the emissions savings from nuclear would reduce emissions by 7.2 billion tons a year. This would constitute 24 percent of the cumulative emissions reductions needed to maintain emissions at current levels (almost two wedges) but only about 16.7 percent for a strategy intended to reduce emissions 50 percent below 2005 levels. In all likelihood, the emissions savings predicted in this scenario are optimistic, as some nuclear plants would displace natural-gas-fired plants; the savings would nevertheless be more significant than in the other scenarios, as depicted in Table 5.2.

How many nuclear plants would be needed to deliver significant greenhouse gas emissions savings? If each new plant produced roughly 1 GW, the BLUE Map scenario would imply an additional 830 GW of nuclear plants, more than double the current capacity. However, most of the current nuclear fleet will be decommissioned by 2050. With the extended life of existing

TABLE 5.1 Comparison of emissions from different sources

Fuel source	*Baseload plant capacity*	*Yearly operating*	*CO_2 emissions/kilowatt-hour*	*Number of plants*	*CO_2 emissions tons/year (1,000,000 grams = 1 metric ton)*
	×	×	×	×	÷ 1,000,000
Coal	1 gigawatt (= 1 million kilowatts)	8,000 hours per year	800 grams per kilowatt-hour	700 plants	4,480,000,000 tons
Nuclear	1 gigawatt	8,000 hours per year	50 grams per kilowatt-hour	700 plants	280,000,000 tons
Gas	1 gigawatt	8,000 hours per year	400 grams per kilowatt-hour	700 plants	2,480,000,000 tons
Nuclear – coal difference					–4,200,000,000 tons
Nuclear – gas difference					–2,100,000,000 tons

TABLE 5.2 Comparison of emissions savings between Wedge, MIT, and BLUE Map scenarios

Fuel source	*Gigawatt (GW) nuclear*	*Emissions savings over coal (tons)*	*% of 30 billion tons reduction per year (stabilization strategy)*	*% of 43 billion tons per year reduction (50% below 2005)*
Wedge	700	–4,200,000	14.0	9.8
MIT	1,000	–6,000,000	20.0	14.0
BLUE Map	1,200	–7,200,000	25.0	16.7

nuclear power plants, the IEA estimates that up to 60 GW of existing plant capacity would likely still be on line in 2050, meaning that 1,140 1-GW plants would need to be constructed between 2012 and 2050 to reach 1,200 GW, roughly 28 plants per year. The IEA suggests that new plant size potential is more likely to be in the 1.2 to 1.7 GW range. If plant size averaged 1.2 GW, this would imply an additional 950 new nuclear plants, roughly 24 per year over the next forty years. At the industry's peak in the 1970s and 1980s, construction starts briefly exceeded thirty plants per year. Throughout the 1990s, construction starts were five or fewer in most years. Since 2005, a modest boom in plant construction has been observed, with ten or more plants beginning construction in recent years (IEA 2010c: 20). Even the 1,000 GW strategy of the MIT study would require 940 1-GW plants (or more than 780 plants of 1.2 GW average size). The more modest wedge strategy would imply 700 plants of 1 GW operating in 2050. If we accept the IEA estimate that 60 GW of current capacity will still be around by midcentury, then 640 new plants of 1 GW will have to be built over the next forty years—sixteen a year—for nuclear to provide one wedge of climate mitigation.

While the unit of analysis varies among different studies and the range of emissions differs across energy sources, the core assumptions that truly matter are the projected size of the nuclear sector, total projected energy demand, and the extent to which nuclear replaces coal or natural gas. Ultimately, the ability of nuclear power to displace coal as a fuel source and to generate significant emissions reductions hinges upon a rapid acceleration in nuclear power plant construction. The next section reviews the reasons why such a building spree may ultimately be less than the optimists envision.

The Nuclear Revival: A Reality Check

What is the likelihood that nuclear could contribute emissions savings anywhere near what the wedge strategy, the MIT study, or the BLUE Map scenario suggest might be possible? If technological optimists are correct, then none of the problems previously observed by the nuclear industry—accidents, cost overruns, proliferation concerns, waste disposal issues, public opposition—should matter all that much. New designs should make plants safer, cheaper, faster to construct, harder to proliferate; third- and possibly fourth-generation reactors, as well as the need for low-carbon energy, ought to alleviate public opposition. All the nuclear industry needs is another start, and even if there are early teething problems, construction firms will be able to learn by doing. If these problems persist, however, then the optimists will have engaged in wishful thinking and fewer plants ultimately will be built. If the alarmists are correct, we would expect troubles to befall the nuclear industry, a repeat of the 1970s and 1980s, with serious accidents, soaring costs, and problems with storage that reenergize public opposition, even in states such as China, and ultimately poison investor and political support.

In between these poles is a more realistic scenario, based on some nuclear plants being built but persistent problems dogging the industry, such that instead of a wedge of emissions reductions we will just get a slice. There are a number of reasons to be skeptical that the renewed interest in nuclear energy will deliver the emissions savings that proponents of nuclear power tout. As the 2009 update to the MIT study concluded: "Even if all the announced plans for new nuclear power plant construction are realized, the total will be well behind that needed for reaching a thousand gigawatts of new capacity worldwide by 2050" (MIT 2009: 4).

As of March 2012, sixty nuclear power reactors were under construction according to the World Nuclear Association (WNA) (WNA 2012), with a total of about 60.8 GW capacity. Nearly 50 percent of that added capacity was being constructed in China and Taiwan. In 2009, eleven plants began construction; nine began in China and another two began in Russia. In 2008, of the ten construction starts, six were in China and two were in South Korea and Russia (see Table 5.3 for a list of countries with reactors under construction).

Given that it takes between seven and ten years for plants to be constructed, the net capacity in the nuclear sector by 2020 will likely be around 432 GW (370 GW of current capacity plus 61.6 GW of plants under construction), assuming

TABLE 5.3 Countries with nuclear power reactors under construction as of February 2012

Location	*Number of units*	*Gross capacity (MWe)*[a]
Argentina	1	745
Brazil	1	1,405
Canada	3	2,190
China	26	27,640
Finland	1	1,700
France	1	1,720
India	6	4,600
Japan	2	2,756
Korea (South)	3	3,800
Pakistan	1	340
Russia	10	9,160
Slovakia	2	880
Taiwan	2	2,700
United States	1	1,218
Total	**60**	**60,854**

SOURCE: World Nuclear Association 2012.
[a]MWe = megawatt electrical (as distinct from thermal).

all the current plants are built. This accounts for the reduction of Japan's nuclear sector with the closure of Fukushima's four reactors (which reduced Japan's nuclear capacity by 2.7 GW) and the closure of eight German nuclear reactors after Fukushima (about 8 GW capacity reduction). This estimate does not include plans to close the remaining nine German reactors by 2022 (about 12 GW of capacity) or Switzerland's five reactors (another 3.2 GW), nor does it include projections on Japan's nuclear sector, nearly all of which, as of early 2012, remained in temporary shutdown pending approval by local municipalities. It remains an open question whether Japan's nuclear plants will restart (JEA 2012). Even before Fukushima, the WNA estimated that sixty of the existing nuclear reactors would likely be closed by 2030.

Beyond the plants currently under construction, the WNA has documented the number of planned and proposed reactors worldwide. Forty-five countries (including Taiwan) have plans and proposals to build nuclear reactors, and other countries have expressed interest in nuclear power. If all these reactors were built, the total would be nearly 495 additional reactors with gross capacity of nearly 558 GW.[5] With the 61 GW of plants under construction, this would still be 80 GW (or about 12 percent) short of the additional capacity needed by 2050 to contribute fully to one of the Socolow wedges. If we assume that an additional 60 GW of existing facilities were still on line in 2050, then the world would be about 3 percent short of a wedge. However, this total would be 32 percent below the 1,000 GW MIT target, and about 43 percent below the 1,200 GW BLUE Map scenario (see Table 5.4).

TABLE 5.4 Reactors planned and proposed as of February 2012

Location	*Planned*	*Gross capacity (MWe)*[a]	*Proposed*	*Gross capacity (MWe)*[a]
Argentina	2	773	1	740
Armenia	1	1,060	0	0
Bangladesh	2	2,000	0	0
Belarus	2	2,000	2	2,000
Brazil	0	0	4	4,000
Bulgaria	2	1,900	0	0
Canada	3	3,300	3	3,800
Chile	0	0	4	4,400
China	51	57,480	120	123,000
Czech Republic	2	2,400	1	1,200
Egypt	1	1,000	1	1,000
Finland	0	0	2	3,000
France	1	1,720	1	1,100
Hungary	0	0	2	2,200
India	17	15,000	40	49,000
Indonesia	2	2,000	4	4,000
Iran	2	2,000	1	300
Israel	0	0	1	1,200
Italy	0	0	10	17,000
Japan	10	13,772	5	6,760
Jordan	1	1,000	0	0

(*continued*)

TABLE 5.4 *(Continued)*

Location	*Planned*	*Gross capacity (MWe)*[a]	*Proposed*	*Gross capacity (MWe)*[a]
Kazakhstan	2	600	2	600
Korea (North)	0	0	1	950
Korea (South)	6	8,400	0	0
Lithuania	1	1,350	0	0
Malaysia	0	0	2	2,000
Mexico	0	0	2	2,000
Netherlands	0	0	1	1,000
Pakistan	1	340	2	2,000
Poland	6	6,000	0	0
Romania	2	1,310	1	655
Russia	14	16,000	30	28,000
Saudi Arabia	0	0	16	20,000
Slovakia	0	0	1	1,200
Slovenia	0	0	1	1,000
South Africa	0	0	6	9,600
Switzerland	0	0	3	4,000
Taiwan	0	0	1	1,350
Thailand	0	0	5	5,000
Turkey	4	4,800	4	5,600
Ukraine	2	1,900	11	12,000
United Arab Emirates	4	5,600	10	14,400
United Kingdom	4	6,680	9	12,000
United States	11	13,260	19	25,500
Vietnam	4	4,000	6	6,700
Total	**160**	**177,645**	**335**	**380,255**

SOURCE: World Nuclear Association 2012.

[a]MWe = megawatt electrical (as distinct from thermal).

Attaining the Socolow wedge would require that the countries with the most ambitious plans for nuclear plant construction are able to achieve or exceed their goals, and/or that other countries without plans and proposals to build nuclear plants embrace nuclear power. Yet, the vaunted hopes for a nuclear renaissance may remain unfulfilled, for a number of reasons, including:

1. The pace of construction is currently too slow to realize the gains, particularly in such as like India that are expected to be major locations for new plant construction;
2. Public resistance to nuclear power remains embedded in several Western countries, as well as in some middle-income countries such as Thailand and Indonesia;
3. Cost overruns and delays in Western countries such as Finland and France, where resistance to nuclear power is less strong, have the potential to dampen enthusiasm for nuclear power;
4. The decline of oil prices from historic highs of several years ago, high up-front costs of plant construction, the more favorable costs for natural gas, and the financial crisis have rendered nuclear power less economical or affordable in some places;
5. The current nuclear fleet is aging and likely to be retired in the next twenty years, requiring a significant investment in construction just to maintain the level of nuclear energy provided today;
6. Limits to the number of trained personnel and producers of nuclear equipment make it difficult to implement a large-scale nuclear renaissance, even in countries like China that are prepared to significantly expand plant construction;
7. The unresolved issue of nuclear waste disposal feeds into public and official distrust of nuclear power;
8. Some announced and prospective candidates for nuclear power may be, because of small economies or small power grids, poor candidates for nuclear power;
9. A nuclear accident or act of sabotage anywhere, as Fukushima demonstrated, has major implications for the industry everywhere, making the dispersion of nuclear power technology to inexperienced and unstable countries potentially risky for the nuclear industry across the globe; and, perhaps most important,

10. The proliferation risks associated with nuclear power make nuclear power potentially dangerous for peace and security.

How a number of these issues may affect the actual construction of nuclear plants can be illustrated by country examples.

China

For countries with ambitious plans to build nuclear power plants, the question becomes, Will all the plants planned and proposed actually be built? Will the Chinese build more than 170 reactors over the next fifteen years as their plans suggest? As of March 2012, China has fifteen reactors in operation and, according to the WNA, twenty-six under construction. Will China be able to build on average more than ten a year for fifteen years? Has the enthusiasm for new plant construction dimmed in the aftermath of Japan's nuclear disaster?

In China, the political obstacles to new plant construction are much less daunting than in other places, where local communities have a "not in my backyard" (NIMBY) attitude toward nuclear plant construction and nuclear firms face lengthy permitting processes. The Chinese state possesses more siting capacity for nuclear facilities and is able to provide nuclear companies with land and other amenities at low cost and via an expeditious approval process.[6] Moreover, Chinese communities in general are more supportive of the economic opportunities provided by the nuclear sector. Since the mid-2000s, China has been at a breakneck pace to construct new power plants, adding as much as 70 GW in capacity in successive years, most of it coal-fired power plants (MIT 2007).

However, China's ambitions for the nuclear sector may be more difficult to achieve, or could come at a cost of plant safety and design. Though the country has not experienced a major nuclear power plant accident, the head of China's National Nuclear Safety Administration warned in 2009 that the country might have difficulty with construction and operational safety if it is not careful. In a country that had already experienced scandal for inadequate oversight in drugs, toys, and food, such a warning raised international concern. In August 2009, the president of China National Nuclear Corporation was detained in a US$260 million corruption scandal. In October 2009, China's premier announced that the country would increase the number of nuclear safety inspectors from around 200 to more than 1,000. Although China has demonstrated a willingness to cooperate with international inspectors to ensure nuclear plant safety, there are serious concerns that future safety incidents could upend its aggressive growth plans (Bradsher 2009).

Should China ever experience a serious nuclear incident, the reputational consequences would likely reverberate around the world. Nuclear power safety is what public goods scholars call a "weakest link" type of problem (Sandler 2004). To the extent that a serious accident anywhere will dampen enthusiasm for nuclear power everywhere, the nuclear industry is vulnerable to the negative reputational externalities of international nuclear accidents. The incidents at Three Mile Island in 1979 and Chernobyl in 1986 had such an effect. The nuclear industry likes to tout its subsequent safety record. While newer nuclear power plants are both different from the Chernobyl design and are considered to be safer, it is unclear if the international public will react to a serious accident in China, for example, by differentiating between the kinds of nuclear plants or the practices of a foreign government, particularly since many of the designs employed by China are derived from those developed in Western countries.

The Fukushima disaster did not fundamentally dampen enthusiasm for nuclear power in China. The leadership's immediate response was to introduce a strategic pause in new plant construction, while existing facilities went through rigorous safety inspections. This was projected to impose a modest delay in China's timetable for new plant construction, and was not expected to have a major effect on China's nuclear ambitions (Busby 2011; Kong and Lampton 2011). As discussed below, this contrasted with the developments in other countries, such as Germany, where public opinion turned decisively against nuclear power and the leadership opted to phase out the sector entirely.

Despite China's sustained interest in new nuclear plant construction, its demands for specialized nuclear equipment may face technical bottlenecks, owing to the lack of nuclear parts suppliers and skilled expertise. While nuclear optimists assume that credible demand signals from China will generate the necessary supply of parts and skilled nuclear technicians, any barriers to a nuclear expansion may make it difficult for any of the aggressive nuclear growth strategies—wedge, MIT, and BLUE Map—to meet their aims. The challenges of nuclear construction are twofold: There are only a handful of companies that provide some of the specialized equipment for nuclear reactors, and there is a shortage of people who are skilled nuclear professionals, with many of those who used to work in the industry in the West having retired from the field without being replaced. For example, only one firm, Japan Steel Works, can cast forgings for particular types of reactor vessels (Schneider et al. 2009b). It had a two-year waiting list for forgings, and even with an expansion to be completed in 2010 would only be able to complete eight reactors a year. China's own capacities for casting are unclear (Squassoni 2008a, 2008b). Many of the training staff in countries like the United States and France are on the verge of retirement. The assertion that a large proportion of nuclear power plant workers are five to ten years from retirement has become a common refrain in the industry (Berr 2010). The situation in France was similar. One study noted that in 1980 there were sixty-five nuclear engineering programs in the United States, but by 2008, there were only thirty-one (Schneider et al. 2009b). An IAEA official estimated that there were about 200 nuclear graduates from U.S. universities per year and a similar number from all European universities combined. He noted numerous years in Germany during the 1990s when there were no new nuclear graduates. The situation in China was thought to be less severe but still significant. While China is preparing large numbers of engineers and scientists (360,000), a small proportion of them are nuclear specialists. Therefore, China may need more than 13,000 nuclear engineers by 2020 (Kadak 2006; Kubota 2009).

India

Will India build the nearly sixty reactors it has planned and proposed? As of March 2012, India had twenty reactors in operation and six under construction. Since the United States and India signed a deal sanctioning cooperation on civilian nuclear power in 2005, the Indian parliament has struggled with the contentious issue of whether foreign firms would have limited liability in the event of an accident. This was thought to be a necessary change in India's laws to attract foreign investment, and is a particularly charged issue, given the 1984 chemical accident at the Dow Chemical facility in Bhopal, India. After a long, contentious debate, the Indian parliament finally passed an investor indemnity law in August 2010, but the law did not go as far as foreign investors had hoped, providing only partial legal liability for foreign firms—up to eighty years for suppliers of nuclear equipment, raw materials, and services in the event of an accident. Some suggested that India's supplier liability was unprecedented: Twenty-eight other national laws and three international nuclear treaties all placed liability on operators with limited commercial liability for suppliers. While state-owned firms like France's Areva corporation may be less affected by legal challenges, American nuclear providers, as private firms, could not rely on U.S. government financial backing in the event of an accident (Platts 2010). The Obama administration reportedly had encouraged the Indian government to revise the law, though this was seen as unlikely in the wake of the Fukushima disaster (Devraj 2011). It remains an open question whether this will dampen enthusiasm for investing in India's nuclear sector (Kazmin 2010; *Nuclear Power Daily* 2010).

As in China, the initial impact of the Fukushima accident on India's nuclear power expansion plans was modest. While ordering a safety review, India's Prime Minister Manmohan Singh reaffirmed the country's support for nuclear power (PTI 2011). It remains unclear, however, how long the status quo can hold. Despite assertions of confidence in the sector, the Fukushima accident has emboldened anti-nuclear activists and opposition parties in India (Sasikumar 2011). Of particular concern are siting issues associated with the approved Jaitapur nuclear power plant, located along the coast in Maharashtra state, which with six reactors and a total 9,900 MW capacity is slated to be the largest nuclear facility in the world (Bajaj 2011). In the wake of the government's April 2011 decision not to review the earlier approval of the Jaitapur plant, protests turned violent after 700 demonstrators attacked a police station (*India Today* 2011).

Finland, Bulgaria, and France

Other countries, particularly in Europe, that have decided to build new nuclear plants have experienced considerable cost overruns and delays in the construction of new facilities. Critics also point to the experience of recent power plant construction in Western advanced industrialized countries. The MIT update notes that most plans for construction of nuclear power plants estimate completion in four and a half to five years on paper. Many plants in practice, such as Finland's Olkiluoto plant and France's Flamanville plant, are taking considerably longer. In the Finnish case, the plant, under construction by France's Areva corporation, is likely to take at least seven years to bring to fruition, and the costs have doubled from the initial 3 billion Euros price tag (roughly USD$3.6 billion). The Olkiluoto plant was supposed to herald a European nuclear revival. Placed in 2003, it was the first order in Western Europe and North America since France's Civaux-2 from 1993. Despite the cost overruns, a second plant is slated to begin construction at Olkiluoto in 2012. The Flamanville plant in France, which began construction in December 2007, also was projected to come in between 700 million and 1 billion

Euros (roughly USD$860 million to $1.2 billion) over budget after experiencing problems in the concrete base mat (Schneider et al. 2009a, 2009b). In Bulgaria, two nuclear reactors built with Russian assistance were supposed to cost less than US$4.0 billion but costs have soared to US$11.4 billion (Kanter 2010). If nuclear power providers fail to standardize construction models and costs, with each plant subject to lengthy delays and cost overruns, governments and investors will likely be unable to afford as many reactors, and the reactors will not all be built in a timely fashion to realize the expected emissions savings. Both governments and investors, therefore, may ultimately rethink their commitments to nuclear power.

The Fukushima accident further complicated these governments' nuclear calculations. In June 2011, the Bulgarians reached an agreement with Russia to further delay its decision on constructing a new nuclear project until October, while it continued to review the financial and safety details of the proposed facility (Tsolova 2011). The Finnish coalition government that came into power in June 2011 appointed a Green environment minister and agreed that it would not approve any permits for new nuclear plants (Tanner 2011). In June 2011, France's leader Nicolas Sarkozy pledged more than 1 billion Euros (about USD$1.2 billion) in new investments in fourth-generation nuclear technology (*France 24* 2011). However, he faced difficult reelection prospects in May 2012.

The United States

The 2003 MIT study on nuclear power assessed the emissions saving potential of an increase in nuclear power from 340 to 1,000 GW, implying an expansion in the United States from 100 GW in 2000 to 300 GW at midcentury (MIT 2009: 3). Though the United States has plans to build thirty new nuclear plants over the next fifteen years, progress on actual construction has been slow. Between the 2003 MIT report and a 2009 update, no new nuclear units had begun construction. Only one refurbished unit had been restarted, and one previously ordered reactor that had not been fully constructed was being completed (MIT 2009: 5). Though a cap on carbon would make nuclear more cost-competitive with coal and to a lesser extent with natural gas, the 2009 MIT report also concluded that nuclear power was still not cost-competitive with either. Indeed, nuclear power would become competitive if it could eliminate the risk premium it has to pay on construction. However, as the report noted, the estimated construction costs for large-scale power projects have doubled since 2003, outpacing otherwise rising costs for coal and gas plants (MIT 2009: 6).

The parlous state of the country's economy and financial markets may make it difficult for putative nuclear power producers to secure private financing. Even investments in renewables have been hit hard by the recession, with major projects like T. Boone Pickens' proposed wind farms scaled back or put on hold. Long-time critics of nuclear power like Amory Lovins see investors voting with their feet, shunning nuclear power in favor of natural gas, conservation, distributed power, and renewables, which he argues offer greater emissions reductions at lower cost, given the speed with which such projects can be deployed. In his view, nuclear power will never be able to compete with other energy sources; the up-front capital costs are still so high, the construction periods so long, and the costs and regulatory environment so uncertain that investors will only look to nuclear if there is a vast public subsidy (Lovins and Sheikh 2008; Lovins, Sheikh, and Markevich 2008; Sokolski 2010).

The Obama administration heeded the advice of the MIT study and announced US$54.5 billion in loan guarantees to jolt the U.S. nuclear industry out of its inertia. The animating idea behind the loan guarantees was that the United States needed experience again building nuclear power plants. Only after a few new plants were built could the industry standardize construction costs and drive costs down, thereby minimizing the risk and legitimating the promise of nuclear power for the broader private sector. In February 2010, the Obama administration provided US$8.3 billion in loan guarantees to the Southern Company for construction of two new nuclear plants in Georgia (Shear and Mufson 2010). In May 2010, the Department of Energy offered a second US$2 billion loan guarantee to the French firm Areva to build a nuclear enrichment facility in Idaho (Fehrenbacher 2010).

In the aftermath of the Fukushima disaster, the Obama administration, even as it stepped up efforts to assure the safety of the U.S. nuclear power sector, reaffirmed its support for nuclear power (Hennessey 2011). That said, private sector enthusiasm for nuclear power had already diminished in the face of depressed prices of natural gas and further cooled after Fukushima. Moreover, nearly half of the US$17.5 billion in loan guarantees approved in 2005 had not been claimed (Wald 2011). A project in Maryland was canceled in 2010 (Behr 2010), and after the Fukushima accident, expansion of a nuclear facility in south Texas was canceled (Price and Toohey 2011).

Even as the Obama administration embraced the idea of nuclear power, it rejected the key storage site for nuclear waste, Nevada's Yucca Mountain.

The Obama administration in 2009 effectively mothballed the permanent disposal site of Yucca Mountain by reducing funding of the site to almost negligible levels (Farrell 2010). A presidential commission report from January 2012 recommended that the United States begin pursuing an alternative to Yucca Mountain (Blue Ribbon Commission 2012). While on-site storage in pools and more permanent storage in cement-lined bunkers remain options, the volume of waste in a world of expanded nuclear power has scarcely been thought through. Yucca Mountain, for example, was estimated to be able to hold 140,000 metric tons (MT) of spent fuel equivalent, though its legal limit was restricted to 70,000 MT. The MIT study noted that a nuclear revival on the order of 1,000 GW would require an additional waste disposal site of Yucca Mountain's capacity every three to four years. A threefold increase in nuclear power production in the United States would generate enough waste to require another waste disposal site of Yucca Mountain's legal capacity in twelve years, and of its physical capacity in twenty-five years (MIT 2003: 10, 61).[7]

No country has yet resolved the challenge of permanent nuclear waste disposal storage sites. In advanced democracies, siting issues for storage facilities remain subject to potent NIMBY backlashes. Finland is preparing a storage site at Olkiluoto, which is expected to be operational by 2020. However, if the regulatory uncertainty for waste storage continues for nuclear power producers, it may complicate investor enthusiasm for new nuclear construction, providing yet another reason for plans, particularly in Europe and North America, to be modest and less than what renaissance proponents desire.

Germany

Countries with extensive nuclear power sectors, particularly in Europe, were proposing to build few new reactors even before the Japan nuclear disaster. France had plans to build only two new reactors, with one under construction that was behind schedule and over budget. The country's efforts to export nuclear expertise to the United Arab Emirates were dampened in 2000 when France lost out on the bid for a contract to a South Korea firm that came in with a much less expensive offer. After Japan's nuclear accident, a number of European countries, notably Germany and Switzerland, moved to phase out nuclear power entirely (Sokolski 2011).

Not too long ago, some of those same countries were delicately maneuvering in the other direction. Before Fukushima, several countries with nuclear power plants—including Germany, Spain, Sweden, and Belgium—slowly walked away from plans to shutter their nuclear power sector, and none had plans to build new ones. Fukushima notwithstanding, whether these countries would have been able to extend the lives of the nuclear plants remained deeply contested politically for countries with vibrant Green political constituencies and those possessing parliamentary democracies that allow small parties to become swing coalition partners. In Germany, Chancellor Angela Merkel struggled to reverse the planned closure of the country's seventeen nuclear plants, which provided 20 GW of electricity, about 28 percent of the country's electricity (von Hippel 2010). The four firms that produce Germany's nuclear power vigorously lobbied to reverse the decision, which was made in 2002 by the coalition government comprised of the Social Democratic Party and the Greens. In September 2010, Merkel's government decided to extend the life of Germany's nuclear power sector, with plants built before 1980 having an additional eight years and those built after 1980 receiving an additional fourteen years (Thomas 2010).[8] While Germany embraced an extension of the life of its existing nuclear power sector, the reprieve even before the Fukushima disaster was potentially temporary if the Christian Democrats lost power and the Greens became swing coalition partners again.

In this difficult political environment, the nuclear volte-face in Germany was extraordinary. After Fukushima, Merkel in March 2011 ordered a three-month suspension of operations at the country's seven oldest nuclear reactors (Wiesmann 2011). With German public opinion rallying against nuclear power and her party poised to lose power, Merkel announced in May 2011 that those plants would not be reopened and Germany's entire nuclear power sector would be phased out by 2022 (Buergin and Parkin 2011).

In sum, proponents of nuclear power will not only have to convince investors and the international community to complete the construction of planned nuclear power plants, but also they will have to hope that countries such as China ultimately are overachievers, that countries like Germany reverse course, and that a number of other aspirants prove capable of building new plants.

Nuclear Power and International Climate Negotiations

The ability of some countries to secure adequate financing to build nuclear plants may depend on decisions about nuclear power's eligibility for valuable, tradable emissions credits. Heretofore, nuclear power was excluded from that market. Whether nuclear power will receive significant attention in future international climate negotiations is uncertain. While nuclear power issues have periodically been part of the backdrop of climate negotiations, they have not entered in as a major topic of discussion, consistently overshadowed by more divisive issues concerning national emissions targets and financial support for developing countries. Should those issues be resolved, nuclear power could become a more important agenda item. Of particular importance will be whether the Kyoto Protocol's rules (or those of a successor agreement) are altered to allow nuclear power to be eligible for emissions reductions through the CDM and whether the World Bank prohibition against lending for nuclear power will continue and be extended to new instruments, such as the Green Climate Fund agreed at the 2009 Copenhagen climate negotiations.

Nuclear power was specifically excluded from CDM credits under the Kyoto Protocol. The CDM was one of the flexibility mechanisms established under the Kyoto Protocol that permit companies in advanced industrialized countries (so-called Annex I countries) to pay for emissions reductions in developing countries (so-called Annex B countries). At the follow-on meeting of the Sixth Conference of the Parties held in Bonn, Germany, in July 2001, delegates fleshed out the rules that specified eligibility for certified emissions reductions under the CDM and prohibited Annex I countries from meeting their commitments through nuclear power (UNFCCC 2001).

Most environmental organizations, a number of countries in Europe (including staunch anti-nuclear states such as Austria), and many developing countries (including the low-lying island states) historically have opposed nuclear power's eligibility for emissions credits through the CDM. A few nuclear supplier states such as Japan, France, and Australia have periodically supported a stronger role for nuclear power but have been outflanked by opponents of nuclear power. In the 2000s, diehard opposition by the environmental community to nuclear power fractured as the climate problem became more imminent and dire, with prominent environmentalists including Greenpeace founder Patrick Moore and *Whole Earth Catalog* founder Stewart Brand advocating for nuclear power. With European countries divided and the United States having failed to ratify the Kyoto Protocol, there were few powerful advocates to support revision of Kyoto's rules to include nuclear power. While the Copenhagen climate negotiations in December 2009 were intended to reach an accord on the post-2012 commitment period, higher-order concerns including country commitments; a long-term target;

financing for developing countries; and measurement, reporting, and verification dominated the discussion. The meeting ended with a political accord, with the post-2012 commitment period under the Kyoto Protocol or a successor agreement put off for later discussion. As a consequence, nuclear power's eligibility under the CDM remained as it was in the lead-up to Copenhagen. The draft negotiating text considered in August 2010 in Bonn included the same text of options for nuclear power, including (option 1) maintaining the current rules, (option 2) preventing Annex I countries from meeting their commitments through nuclear power but allowing non–Annex I countries to claim credits, and (option 3) allowing countries to pursue credits from nuclear power for activities beginning January 1, 2008, or later (UNFCCC 2010a). Whether these changes are pursued is bound up with the larger status of the Kyoto Protocol and the CDM. In the interim, climate negotiations in Bonn in June 2011—the Fukushima accident notwithstanding—revived calls to include nuclear power in projects eligible for CDM credits (Climate Action Network 2011).

At the Copenhagen climate negotiations, donor countries agreed to provide up to US$30 billion in fast-start finance to developing countries between 2010 and 2012, and committed to mobilizing up to US$100 billion in public and private sources by 2020. One of the instruments created to transfer these funds was the Green Climate Fund. At Copenhagen, it remained unclear which entity would administer this fund, its likely size, the activities it would finance, and the specific countries that would be the beneficiaries (Busby 2010).[9] At the 2010 climate change conference in Cancun, Mexico, it was agreed after much deliberation that the World Bank would serve as the interim trustee for the fund, though the fund would be governed by its own board of twenty-four members, with developing and developed countries retaining equal representation. Further design details were concluded by the Durban, South Africa, climate negotiations in December 2011, although much remained unsettled even after the conference, including respective financing commitments (UNFCCC 2010b).

The World Bank has long had a policy of not loaning funds for new nuclear power plant construction. The last nuclear project it financed was a reactor in Italy in 1959. The Bank adopted a more official policy proscription against loans for nuclear plants in 1996, though the it has supported modernization of existing nuclear plants and supporting orders to advance the decommissioning of facilities and improve safety. Despite a renewed call in

March 2010 by French president Nicolas Sarkozy to amend the Bank's rules by 2013, a Bank spokesman suggested that it had no plans to support nuclear power in the immediate future (Hollinger and Crooks 2010; Yurman 2010). However, should Bank shareholders make support for nuclear power a priority, the policy could change, though division between pro- and anti-nuclear states makes the maintaining the status quo ban on Bank lending more likely.

In early 2010, the Bank reviewed the rules for energy lending for the next decade with a controversial draft report discussed in April 2011; as of late 2011, a rift over phasing out support for coal in middle-income countries left the strategy in limbo. No change in nuclear's eligibility for Bank lending was ultimately expected (Bretton Woods Project 2011). With lending for coal plants becoming increasingly controversial as part of the Bank's portfolio (particularly after the 2010 decision to support South Africa's Medupi coal plant), it was unclear if nuclear might benefit from the push for low-carbon energy sources. The Bank could conceivably reject funding of future coal-burning power plants, but with a ban on support for nuclear and coal, that would leave it relegated to supporting renewables, potentially marginalizing its influence in middle-income countries. Middle-income countries are especially important to the financial health of the Bank. Even as they have been able to tap private markets for finance, the Bank has been able to retain influence through continued lending to those countries but also through the imprimatur that World Bank support often signals to the private sector. A move to ban support for coal while lifting the prohibition against support for nuclear might be too difficult politically for the Bank's shareholders to reach agreement (Friedman 2010). At the same time, as developing countries seek financing for their power sectors, the World Bank's decision to extend its current moratorium on lending for nuclear power, or a decision to phase out support for coal, could affect not only the direct support countries receive, but also the types of private sector financing that often look to the Bank as a signal of creditworthiness.

Conclusion

Given the grave climate risks worldwide, the environmental community is in the unenviable position of having to put a lot of options on the table, including nuclear power. No single answer is likely to be successful on its own, but there will be room for nuclear in a mix with energy efficiency, renewables, hybrid cars and their successors, combined-cycle gas plants, and even clean coal and carbon sequestration. However, the various scenarios for nuclear power to play a large role in reducing greenhouse gases are conditioned by exceeding ambitious plans for new nuclear power construction. A number of barriers—both political and technical—may undercut the ability for resurgent nuclear power to provide even a wedge of emissions reductions. Lingering doubts about costs, safety, and security make it difficult for advocates of nuclear power to revise international rules to facilitate the sector's renaissance.

For technological optimists, these concerns will yield to the necessity of low-carbon energy. For alarmists, they are enough to stop construction of nuclear power plants. In reality, a considerable number of new nuclear plants will be built. The challenge, however, is to sustain construction of twenty or more plants a year, every year for forty years. Such construction rates were only achieved for a few years at the peak of the nuclear boom before the accidents, cost overruns, and proliferation concerns came to be fully appreciated. For the technological optimists to prevail (and for the far-reaching goals for nuclear power to be met), none of these issues or any other supply constraints can significantly dampen the willingness of governments and investors to support nuclear power. Although the challenges posed by climate change may become so stark as to leaven concerns about nuclear power, political opposition and the technical obstacles attendant to building out the nuclear sector so quickly will likely lead to a partial nuclear resurgence at best.

Notes

1. Schneider et al. note that that the average age of the units that were previously shut down was twenty-two years. They reach their estimates assuming that the existing plants are shut down, on average, after forty years and that new plants under construction have a forty-year operational lifetime (Schneider et al. 2009b).

2. The views presented in this chapter are largely consistent with those of Christopher Way in Chapter 6 of this volume, though he is more pessimistic about the potential resurgence of nuclear power. These differences may be a function of different judgments about China's potential to stay on course with its ambitious nuclear build plans.

3. This assumes that nuclear power would exclusively displace coal-burning power plants, which likely overstates the case, as some nuclear plants may displace natural gas.

4. The IEA's estimate for 2007 was 28.8 gigatons of CO_2 a year, with emissions projected to increase in its baseline scenario to 57.0 gigatons (IEA 2009, 2010a).

5. Planned plants are those that have approval, funding, or a major commitment and are likely to be built in eight to ten years, and proposed plants are those that are likely to be built within fifteen years.

6. For a review of these advantages in the renewables sector, see Bradsher 2010.

7. Yucca Mountain's legal limit was 70,000 MT of nuclear waste.

8. The four nuclear power companies were to pay a new tax from 2011 to 2016 that would go into the country's general budget, expected to bring in 2.3 billion Euros (about USD$2.8 billion) a year. They were also to pay 300 million Euros (USD$370 million) in 2011 and 2012 into a fund to support renewable energy, with payments reduced to 200 million Euros (about USD$250 million) a year for the period 2013–2016.

9. Discussion centered on the poorest countries and China, acknowledging that it would not be an initial beneficiary of climate finance.

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