8

The "Self-Limiting" Future of Nuclear Power

Benjamin Franklin once wrote that "the great advantage of being a reasonable creature is that you can find a reason for whatever you do." The nuclear power industry possesses no shortage of arguments in favor of a nuclear renaissance, many of them reasonable at first glance. Yet, the central premise of this book is that a global nuclear renaissance would bring immense technical, economic, environmental, political, and social costs. Nuclear power generators cannot be mass-produced. As Table 1 summarizes, they take much longer to build, and are therefore exposed to escalating interest rates, inaccurate demand forecasts, and unforeseen labor conflicts. Their centralization requires costly and expansive transmission and distribution systems. Modern nuclear reactors are prone to a deteriorating energy payback ratio for the nuclear fuel cycle, produce hazardous and extremely long-lived waste, have large water requirements, and possess a larger carbon footprint than energy efficiency and every form of renewable electricity.

All is not lost, however. As this book has also shown, renewable power technologies reduce dependence on foreign sources of uranium, and therefore create a more secure fuel supply chain that minimizes exposure to economic and political changes abroad. Renewable technologies decentralize electricity supply, so that an accidental or intentional outage would

Table 1: Disadvantages of Modern Nuclear Power Plants

Dimension	Category	Explanation
Technical	Safety and accidents	Human error and technological failure have resulted in hundreds of incidents and accidents; the impact of a serious accident, even if the probability is low, would be catastrophic
	Materials and labor	A shortage of key components and skilled labor could result in increased costs for nuclear power plants and/or slow any transition to a nuclear renaissance
	Fuel availability and energy payback	The energy intensity of the nuclear fuel cycle and declining reserves of high-quality uranium result in a low energy payback ratio, whereby plants must operate for decades before they produce any net energy
Economic	Construction and operating costs	Long construction lead times for new plants create substantial risk of cost overruns and create expected high future operating costs
	Reprocessing costs	Reprocessing of nuclear fuel costs billions of dollars and creates its own security risks related to the availability of plutonium
	Waste storage costs	Hundreds of millions of dollars each year must be spent on onsite storage, to say nothing of the gargantuan cost of building permanent geologic repositories for spent fuel
	Decommissioning costs	Decommissioning costs can sometimes be greater than the costs of building a plant in the first place
	Fuel costs	Uranium reserves are consolidated among a small number of countries, and dependence on foreign suppliers runs the risk of disruption and price volatility
	Security costs	Nuclear facilities must be rigorously guarded and protected
	Research costs	The next generation of nuclear reactors will require billions of dollars in research funds and subsidies
Environmental	Land use — uranium mining	Underground mining, open-pit mining, and *in situ* leaching of uranium create serious environmental hazards and can contaminate water supplies

(*Continued*)

Table 1: (*Continued*)

Dimension	Category	Explanation
	Land use — waste storage	More than 10,000 metric tons of waste are created each year by commercial nuclear reactors around the world; the waste they produce is extremely hazardous and difficult to store
	Water use and contamination	Existing nuclear power plants consume and withdraw vast quantities of water needed for operation; risk entrainment, impingement, and thermal discharges; and can contaminate water supplies with tritium and other radioactive pollutants
	Climate change	The carbon footprint for a typical nuclear reactor could be equivalent to that of fossil fuels in the next few decades if high-grade uranium ores continue to be exhausted, as nuclear reactors entail considerable greenhouse gas emissions from their lifecycle (much greater than from renewable energy resources and some other alternatives); the heat discharges from nuclear power plants also indirectly contribute to global warming
	Medical and health risks	Operating nuclear reactors have been shown to create health risks for local communities and workers
Sociopolitical	Transmission and distribution vulnerability	Nuclear power plants rely on a complex distribution system that is subject to cascading failures easily induced by severe weather, human error, sabotage, or even the interference of small animals
	Plant and reactor insecurity	Nuclear power plants and research reactors continue to be attractive targets for terrorists and criminals
	Weapons proliferation	All stages of the nuclear fuel cycle produce fissile material that can be used to manufacture weapons of mass destruction
	Military conflict	Nuclear power plants are often bombed and attacked during military campaigns
	Maritime and transport security	The movement of nuclear fuel and waste is subject to accidents, piracy, and theft
	Community marginalization	Nuclear facilities are often sited and located in peripheral areas that marginalize communities

affect a smaller amount of capacity than an outage at a larger nuclear facility. Renewable energy technologies improve the reliability of power generation by conserving or producing power close to the end-user, and by minimizing the need to produce, transport, and store hazardous and radioactive fuel. Unlike generators relying on uranium and recycled plutonium, renewable generators are not subject to the volatility of global fuel markets. They can also respond more rapidly to supply and demand fluctuations, improving the efficiency of the electricity market. Most significantly, renewable power technologies have enormous environmental benefits, since their use tends to avoid air pollution and the dangers and risks of extracting uranium. They generate electricity without releasing significant quantities of CO_2 and other greenhouse gases that contribute to climate change as well as life-endangering nitrogen oxides, sulfur dioxides, particulate matter, and mercury. They also create power without relying on the extraction of uranium and its associated digging, drilling, mining, leaching, transporting, storing, sequestering, and polluting of land.

In the end, nuclear reactors and renewable power generators do the same thing: they produce electrical energy (kWh). Why rely on a nuclear system that is subject to highly uncertain projections about uranium availability, centrally administered by technocratic elites, and vulnerable to the ebb and flow of international politics (requiring garrison-like security measures at multiple points in the supply chain), when superior alternatives exist?

The simple fact that energy efficiency programs and renewable power technologies are better than nuclear power plants has not been advanced by this book alone. Indeed, consider these following studies, all of which reach a similar conclusion:

- "The limited prospects for nuclear power today are attributable, ultimately, by four unresolved problems: high relative costs; perceived adverse safety, environmental, and health effects; potential security risks stemming from proliferation; and unresolved challenges in long-term management of nuclear wastes"[1];
- "Because of hasty commercialization, safety concerns, and unresolved long-term storage of its wastes, the first nuclear era has been a peculiarly successful failure"[2];

- "The economics are profoundly unfavorable and are getting worse. A significant expansion of nuclear energy worldwide to 2030 faces constraints that … are likely to outweigh the drivers of nuclear energy"[3];
- "The failure of the U.S. nuclear power program ranks as the largest managerial disaster in business history, a disaster on a monumental scale. . . . [O]nly the blind, or the biased, can now think that the money has been well spent. It is a defeat for the U.S. consumer and for the competitiveness of U.S. industry, for the utilities that undertook the program and for the private enterprise system that made it possible"[4];
- "There is no convincing case for building new nuclear power plants anywhere in the world for the sake of business. Nor is there a convincing case for updating or rehabilitating existing plants, especially in light of the limited availability of useful fissile material, considerable risks involved at all stages of production, very high legacy costs, imposed on thousands of future generations, absence of secure long-term waste storage, and additional risks and wastes resulting from reprocessing"[5];
- "No other energy technology spreads do-it-yourself kits and innocent disguises for making weapons of mass destruction, nor creates terrorist targets or potential for mishaps that can devastate a region, nor creates wastes so hazardous, nor is unable to restart for days after an unexpected shutdown"[6];
- "The accumulated experience of the past six decades provides ample evidence of adverse health effects in workers in the nuclear fuel cycle, the potential for disastrous accidents that lead to widespread environmental contamination, the unresolved problems of permanent and secure storage of high-level radioactive wastes, and the extraordinarily high costs of building additional nuclear power generation facilities. . . . Given the availability of alternative carbon-free and low-carbon options and the potential to develop more efficient renewable technologies, it seems evident that public health would be better served in the long term by these alternatives than by increasing the number of nuclear power plants"[7]; and
- "We may not need any [new nuclear power plants,] ever. . . . Renewables like wind, solar, and biomass will provide enough energy to meet baseload capacity and future demands."[8]

Who has made such claims? The sources are, in order, an interdisciplinary team from the Massachusetts Institute of Technology, the historian and energy analyst Vaclav Smil, an independent study from the Centre for International Governance Innovation, *Forbes Magazine*, a recent 2010 dialogue on the future of nuclear energy, the physicist Amory Lovins, a physician writing in *Environmental Health Perspectives*, and Federal Energy Regulatory Commission Chairman David Wellinghoff. The fact that these quotes come from a variety of sources (academic journals, magazines, and reports) across the political spectrum (including business, science, civil society, and medicine) and from different disciplines (physics, economics, epidemiology, and politics) suggests that there is a consensus among a broad base of independent, nonpartisan experts that nuclear power plants are a poor choice for producing electricity.

So why, then, does nuclear power persist? One study supposed that it is the superficially attractive narrative associated with nuclear energy that conflates it with national progress and pride, alongside an immensely powerful and effective lobby, a new generation that has either forgotten or never known why it failed previously, deeply rooted habits that favor giant power stations, and lazy reporting by a credulous press.[9] This chapter argues that three primary culprits exist: the true costs of nuclear energy are not borne by those benefiting from it, resulting in what economists call “market failure”; many of the costs and risks involved with nuclear electricity are passed directly onto ratepayers; and nuclear power has, since its inception, been associated with complex notions of progress and modernity that make it seductive, despite all of its intractable challenges. Taken together, these three culprits — market failure and externalities, the socialization of risk, and hubris and technological fantasy — largely explain why nuclear power plants flourish. When these conditions change (i.e. when the full costs of nuclear energy become apparent or can no longer be socialized, or when the allure of nuclear fission fades), the drive towards nuclear energy stalls. In short, if nuclear energy is to have any future at all, it will be what Joseph Romm has called a “self-limiting” one.[10]

Market Failure and Externalities

As almost any smart undergraduate student of economics knows, free markets for anything — from tomatoes to Tomahawk missiles — need multiple criteria to function properly. One of them is that all costs must be fully internalized in the price of a given good or commodity; if one person is able to shift the costs to someone else while still reaping the benefits, then the market has failed to distribute benefits equally and equitably, creating what is known as market failure. At the heart of the market failure discussion is the concept of an externality.

Defined as costs and benefits resulting from an activity that do not accrue to the parties involved in the activity, externalities have won attention in recent decades as an important (albeit often ignored) aspect of energy production and use.[11] Externalities are part of the "overall social cost of producing energy . . . including the value of any damages to the environment, human health, or infrastructure."[12] Another definition of externalities is "inadvertent and unaccounted for effects of one or more parties on the welfare of another."[13]

Take the classic example of unregulated pollution from a smokestack. A factory produces items that are priced by taking into account the demand for the products as well as labor, capital, and other costs, but the damages from the factory's pollution — health and other effects — are true costs borne by society that are unaccounted for in the price of the factory's product. These latter costs are commonly referred to as "externalities" because people tend to consume them as byproducts of other activities that are external to market transactions and, therefore, unpriced. This means that the factory produces a volume of items that is less than "socially optimal," resulting in a net welfare loss to society in the form of morbidity, mortality, and reduced productivity.

Nuclear power plants have a plethora of these types of externalities that most producers and users of nuclear energy do not have to pay for. A partial list would at least include:

- Catastrophic risks such as nuclear meltdowns and accidents;
- An increased probability of wars due to rapid uranium extraction, the boom and bust cycles of uranium mining communities, or the inability to secure fissile materials associated with the nuclear fuel cycle;
- Public health issues such as chronic exposure to radiation and its consequent advanced morbidity and mortality, as well as worker exposure to toxic substances and occupational accidents and hazards;

- Direct land use by power plants, uranium mines, enrichment stations, and storage facilities;
- The destruction of land by uranium mining and leaching, including acid drainage and resettlement;
- The effects of water pollution on fisheries and freshwater ecosystems, which are sensitive to water chemistry, as well as the release of radionuclides into water sources;
- Consumptive water use, with consequent impacts on agriculture and ecosystems where water is scarce;
- Continual maintenance of caches of spent nuclear fuel;
- Changes to the local and regional economic structure through the loss of labor and jobs, transfer of wealth, and reductions in gross domestic product; and
- Incidence of noise and reduced amenity, lower property values near nuclear plants, and aesthetic objections.

Even though this list is incomplete, one study analyzed 132 externality estimates associated with electricity generation in a variety of countries with an assortment of different energy systems.[14] The study found that net social costs for nuclear power ranged from a low of less than 1 cent per kWh to a high of almost 65 cents per kWh, with a mean of 8.6 cents per kWh. As Table 2 documents, the external costs for nuclear power were twice as high as that of hydroelectric systems, more than 12 times higher than that of solar power, and almost 30 times higher than that of wind power. The amount of 8.6 cents per kWh may not sound like much; but if correct, it means that, since nuclear units produced 2,601 billion kWh of

Table 2: Negative Externalities Associated with Nuclear and Renewable Sources of Electricity (cents/kWh, in 1998 USD)

	Nuclear	Biomass	Hydroelectric	Solar	Wind
Minimum	0.0003	0	0.02	0	0
Maximum	64.45	22.09	26.26	1.69	0.80
Mean	8.63	5.20	3.84	0.69	0.29
Standard deviation	18.62	6.11	8.40	0.57	0.20

energy in 2008, they also generated US$223.7 billion in global social and environmental damages.

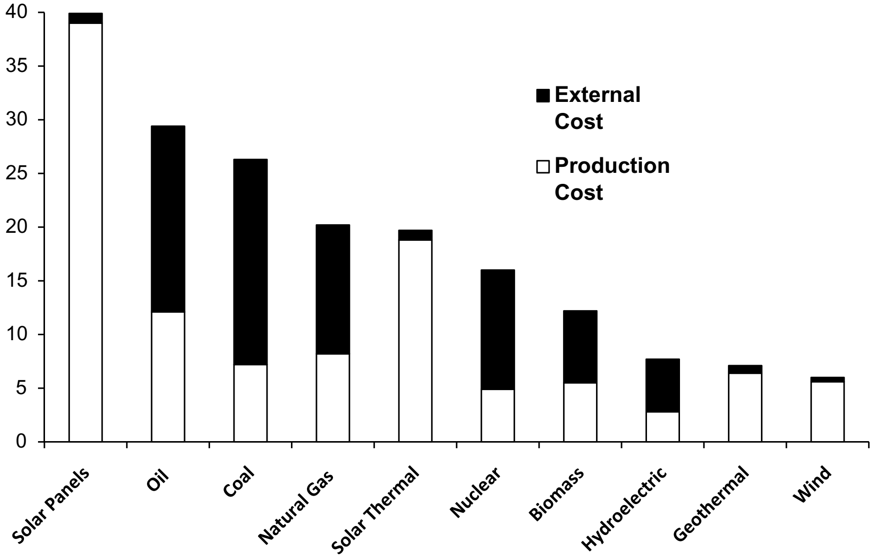
In other words, nuclear power generation created US$223.7 billion of additional costs that are not assumed in traditional estimates of nuclear power's price. Many of these costs are "hidden" because neither nuclear producers nor consumers have to pay for these additional expenses. Instead, the external costs of nuclear energy are shifted to society at large. What is interesting is that — when one takes the negative externalities associated with nuclear power, fossil fuels, and renewable sources of electricity, and adds them on top of existing production costs — Figure 1 shows that wind, geothermal, hydroelectric, and biomass plants are already cheaper than existing nuclear units. Put simply, if the true cost of nuclear energy matched its price, nuclear energy would never be competitive with renewable energy (or energy efficiency) in any free market.

Subsidies and the Socialization of Risk

Because of their capital intensity and financial risk, nuclear power plants are only cost-competitive when they are underwritten with gargantuan public subsidies. Put in other terms, absent an enormous diversion of taxpayer funding, no rational investor would ever finance a nuclear power plant. As one economist put it, investing in nuclear power without the provision of government subsidies is about as useful as "watching a movie with the sound turned off."[15] One 2009 assessment of the global nuclear industry identified no less than ten types of subsidies given to nuclear power plant operators around the world, as presented in Table 3.

Consider the US, where one would think that the electricity market operated freely and with little distortion from subsidies. In fact, the US electricity sector is heavily subsidized, and most subsidies have gone to nuclear power plants. From 1947 to 1999, federal subsidies for nuclear power in the US totaled US$145.4 billion (in 1999 USD). Even in fiscal year 1979, when subsidies for renewable energy peaked in the US at US$1.5 billion, the Department of Energy (DOE) devoted more than 58% of its research budget to nuclear power.

The Energy Policy Act of 1992 promised US$100 million in new funding for reactor designs, set limits on utility payments for decommissioning,



Technology	Market Cost	External Cost
Solar Panels	39	0.9
Oil	12.1	17.3
Coal	7.2	19.1
Natural gas	8.2	12
Solar thermal	18.8	0.9
Nuclear	4.9	11.1
Biomass	5.5	6.7
Hydroelectric	2.8	4.9
Geothermal	6.4	0.7
Wind	5.6	0.4

Figure 1: Production and External Costs for Electricity Generators (in US cents/kWh)

and delegated the authority to set waste disposal standards to the National Academy of Science rather than public participation. However, it failed to incentivize *anyone* to build a new nuclear power plant.[17] The Energy Policy Act of 2005 only worsened the disparity by lavishing the nuclear industry with US$13 billion worth of loan guarantees, US$3 billion in research, US$2 billion in public insurance against delays, US$1.3 billion in tax

Table 3: Subsidies Common to Nuclear Power Plants Around the World[16]

Type	Subsidy	Explanation	Examples
Capital costs	Subsidized access to credit	Policies that dramatically reduce the cost of capital for nuclear plants by enabling them to obtain debt at the government's cost of borrowing, and to use high levels of this inexpensive debt rather than much more expensive equity	Direct government loans Government guaranteed loans Direct government investment in nuclear-related infrastructure
	Rate-basing of in-process plants	Policies that allow recovery of plant investment prior to commencing operations, and that shift performance and investment risks from owners to ratepayers	Work-in-process allowance for funds used during construction
	Subsidized capital goods	Policies that reduce the after-tax cost of capital goods deployed in the nuclear sector; in the case of R&D, the internal cost to develop new product lines or modify old ones is reduced	Accelerated depreciation Research and development Investment tax or production tax credits Capital write-offs transferred to taxpayer
Operating costs	Fuel and enrichment	Policies that socialize the risks of building, operating, and remediating fuel chain facilities, and that reduce the cost of fuel inputs to reactors	Government-owned or government-subsidized enrichment facilities Subsidized access to uranium ore
	Accident and attack risks	Policies that reduce insurance costs for all participants of the nuclear fuel chain, and that shift accident risks from investors to the surrounding population and taxpayers	Caps on mandated liability coverage
	Industry oversight	Subsidies that disadvantage less oversight-intensive competitors, if not fully funded by user fees	Government oversight of domestic industry International oversight through IAEA
	Emissions	Windfall grants of carbon credits that can be immediately resold, and earmarked funds	Privileges under carbon constraints

(*Continued*)

Table 3: (*Continued*)

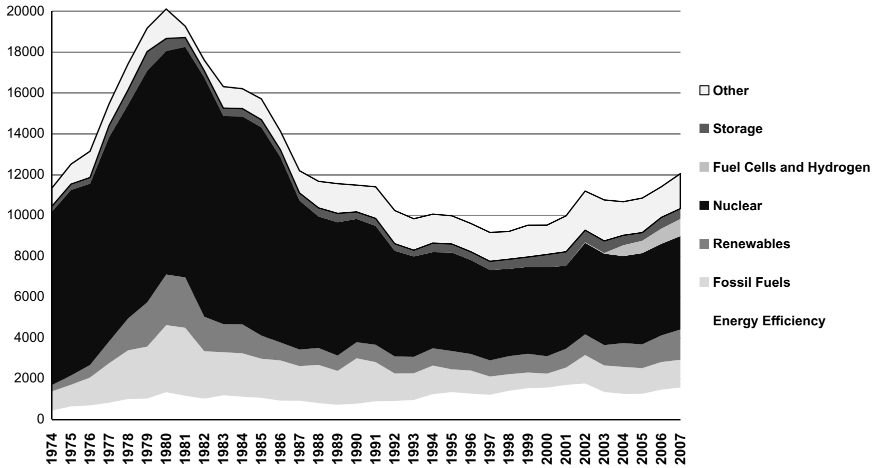
Type	Subsidy	Explanation	Examples
Waste management, plant closure	Nuclear waste management	Policies that convert this very high-risk, capital-intensive, fixed-cost endeavor into something the reactors (and investors) no longer have to worry much about	Government-run long-term management of reactor waste Payments to existing reactors to store waste onsite
	Plant decommissioning, remediation	Policies that reduce the break-even charges needed for nuclear operations; for fuel chain facilities, very large public liabilities result	Tax-advantaged accrual of decommissioning funds Government-provided decommissioning support
Market price support	Market onuses and incentives	Policies that enable nuclear plants to earn higher revenues on power sales than they would be able to in a competitive market	Inclusion of nuclear power in renewable energy portfolios or feed-in tariffs Transfer of capital costs to ratepayers via stranded cost rules, or similar transfer of cost recovery

breaks, an extra 1.8 cents/kWh in operating subsidies, and limited liability for accidents. Yet even this was not enough, despite the fact that these subsidies covered 80% of the costs of a new nuclear plant.[18]

These subsidies are in addition to numerous other benefits the nuclear industry already enjoys: free offsite security, no substantive public participation or judicial review of licensing, and payments to operators to store waste. The subsidy established by the Price–Anderson Act, which ironically charges taxpayers for liability insurance against nuclear accidents that could kill them, alone is possibly estimated to be worth more than twice the entire research budget of the US DOE.[19] According to one estimate, nuclear power operators would be responsible for only 2% of the cost of a worst-case accident, with taxpayers picking up the rest of the tab.[20] Interestingly, this very issue of limited liability for nuclear plants could derail the recent "123 deal" made between the US and India. For the deal to go through, Indian legislation must cap nuclear liability; but when lawmakers put forth a Civil Nuclear Liability Bill that limited damages at US$450 million in the event of a nuclear accident, the Indian Supreme Court argued that it violated Article 21 of the Indian Constitution. The presiding judge in the case stated that the main lesson from the Bhopal disaster was that foreign hazardous industries must be made absolutely liable for any damage caused from their facilities.[21]

One interesting comparison is to look at subsidies for wind, solar, and nuclear power for their respective first 15 years of operation. Nuclear power in the US received subsidies worth US$15.30 per kWh between 1947 and 1961, compared to subsidies worth only US$7.19 per kWh for solar power and 46 cents per kWh for wind power between 1975 and 1989. During the first 15 years, nuclear and wind power produced about the same amount of energy: 2.6 billion kWh for nuclear power, and 1.9 billion kWh for wind power. But, nuclear subsidies outweighed wind subsidies by more than a factor of 40, receiving US$39.4 billion compared to wind's US$900 million over the 15-year period.[22]

The trend of grossly subsidizing nuclear energy holds true globally, as nuclear power has received more public research funding than any other source since the 1970s.[23] This is especially true for many other industrialized countries, including Canada, France, Germany, Japan, Sweden, and the UK (illustrated in Figure 2). As the numbers show, nuclear energy has



Group	1974–2007 Cumulative Total	1974–2007 % Share	1998–2007 Cumulative Total	1998–2007 % Share
Energy efficiency	38,422	8.9	14,893	14.2
Fossil fuels	55,027	12.8	11,114	10.6
Renewable energy	37,333	8.7	10,709	10.2
Nuclear fission and fusion	236,328	54.8	43,667	41.5
Hydrogen and fuel cells	2,824	0.7	2,824	2.7
Transmission and storage	15,717	3.6	5,388	5.1
Other	45,204	10.5	16,599	15.8
Total	**430,855**	**100**	**105,194**	**100**
Nuclear Share of Country Total (%)				
Canada		39.0		28.8
France		81.4		72.5
Germany		67.0		41.0
Japan		72.7		67.2
Sweden		15.2		6.7
United Kingdom		69.0		32.7
United States		38.1		13.2

Figure 2: Government-Funded Subsidies for Nuclear Fission and Fusion Within International Energy Agency Countries, 1974–2007 (in millions of 2007 USD)

received 54.8% of *all* research subsidies among International Energy Agency (IEA) countries, compared to only 8.7% for renewables and 8.9% for energy efficiency.

It may come as no surprise that the only way for utilities to embrace new nuclear units is to receive large subsidies or raise electricity prices for consumers. Some states now allow utilities to increase electricity rates to finance new plants years before construction even begins.[24] In Georgia, these rate increases will amount to a "subsidy" of US$14 billion on top of an additional US$8.3 billion of federal loan guarantees given by the Obama administration.[25] In Levy County, Florida, residential customers will begin paying US$100 per year in higher bills from 2009 to 2016 to help Progress Energy fund a new nuclear unit. South Carolina had to pass a 37% rate hike before it could consider financing a new reactor.[26]

How does the nuclear industry get such sweet subsidies? Part of the explanation may lie in lobbying. In the US, the Investigative Reporting Workshop at American University found that the nuclear industry spent more than US$600 million on lobbying and US$63 million on campaign contributions from 1999 to 2009.[27] In many ways, the nuclear power industry's efforts to win support are a textbook case of how the influence game is played in Washington. Besides the money spent on lobbying and campaign contributions, the industry — led by the Nuclear Energy Institute (NEI) — has created a network of allies who give speeches, quote one another approvingly, and showcase one another on their websites. The effect is an echo chamber of support for nuclear power.

Hubris and Technological Fantasy

One final factor pushing nuclear power is its association with progress, complexity, and modernity. Early advocates promised not only a future of electricity too cheap to meter, but an age of peace and plenty (without high prices or shortages) in which atomic energy would provide the power needed to desalinate water for the thirsty, irrigate deserts for the hungry, and fuel interstellar travel deep into outer space. Other exciting opportunities included atomic golf balls that could always be found and a nuclear-powered airplane, which the US federal government even spent US$1.5 billion researching between 1946 and 1961.[28]

CONTESTING THE FUTURE OF NUCLEAR POWER - A Critical Global Assessment of Atomic Energy

This section suggests that one explanation for the attractiveness of nuclear energy could be its association with national visions of progress. While these visions vary by country and over time, John Byrne and Steven Hoffman propose that the single most consistent predictor of whether a society will embrace nuclear energy is their ability to think in the "future tense." That is, planners and promoters become enthralled by the possible benefits of nuclear energy in the *future*, and are willing to accept the costs in the *present* to realize them. Put another way, they tend to overestimate the advantages of nuclear energy and discount its future costs in the absence of knowledge about current economic or technical compatibility; the reality of present risks and costs is discounted by the unrealized possibilities of future gain.[29] Indeed, the energy historian Martin Melosi has noted that "it's amazing that commercialization of nuclear power occurred at all. . . . The energy market had little to do with this important event, since there was no pressing need for a new source of power in the United States. There was, however, strong interest in enhancing American prestige."[30] Although these psychological benefits are intangible, they are often believed to be real. A cursory look at the genesis of nuclear programs in eight countries — China, France, India, Japan, the former Soviet Union, the US, Spain, and Canada — reveals that, in each case, optimism in the technology and an overarching vision of what nuclear energy could deliver in the future played a role in trumping concerns about present costs.

China, 1953–1992

The prospect of developing nuclear power was first broached in China's first Five-Year Plan in 1953, which emphasized the need for a centralized nuclear development program managed by the government and state enterprises. China's commercial nuclear program formally began in 1972, when the central government approved the first nuclear program — known as the 728 Project — to develop submarine reactors. Nuclear energy quickly became attached to aspirations of Chinese economic power and the legitimatization of China as a superpower.

Throughout the 1970s and 1980s, China experienced massive deficits in electricity supply, with annual demand for electricity surpassing supply by as much as 70 billion kWh. The government had to replace more than 100,000 boilers at conventional power plants between 1972 and 1978, and rolling blackouts hit every major province within China at least twice a year for much of the two decades. Nuclear power was seen as instrumental in overcoming the energy supply deficits, improving Chinese economic competitiveness, "catching up" with Taiwan and other industrialized countries, and enhancing national prestige. Chinese officials even toyed with the idea of exporting both nuclear technology and electricity to the rest of Asia; and built one facility, the Yibin Fuel Component Factory in Sichuan, to manufacture prefabricated components of nuclear power plants for export. They sold one set of components to Pakistan in 1989, and planned to earn billions of dollars of foreign exchange exporting similar packages to Africa and the rest of the developing world.[31]

France, 1945–1970

Left in the devastation caused by the German occupation and fighting of 1944–1945, French technical and scientific experts linked nuclear power to French "radiance" and identity.[32] Nuclear energy was central to this campaign of French economic modernization; and research, development, and construction were dominated by the government. The *Commissariat à l'énergie atomique* (CEA), formed in 1945, had a close association with the bureaucracy in Paris and the military, and was charged with developing indigenous French reactors.[33]

Nuclear energy was seen as a tool to not only provide much-needed electricity to France, but also revitalize the national economy. Nuclear reactors offered the chance for French planners to rebuild infrastructure, promote industry, and augment political influence simultaneously. One key component of this push was the notion of *dirigisme*, or the idea that government-led intervention and planning was the best way to respond to social problems. Another component was the notion of French "national champions," or the idea that key sectors of the economy (such as the state-owned nuclear manufacturer Framatome) deserved special protection and support from the government.[34] After the creation and demonstration of the atomic bomb, "nuclear technology became a quintessential symbol of modernity and national power."[35]

India, 1945–1980

The Indian government began investigating nuclear energy in 1945, when they formed the Tata Institute of Fundamental Research and appointed a prominent physicist, Homi Bhabha, as its director.[36] In 1948, Jawaharlal Nehru, India's first Prime Minister, made an impassioned speech to the General Assembly of India advocating nuclear energy; later that year, an advisory board (the Atomic Energy Commission) was established under the Indian Ministry of Natural Resources and Scientific Research to further study the issue.[37] By August 1956, the first research reactor was operational, despite the accidental death of Bhabha.

The fledgling nuclear energy program was seamlessly connected to a vision of a prosperous and technologically advanced Indian society. Upon attaining independence, the Indian economy was dominated by the agrarian sector while the industrial sector was in a primitive state. From the outset, planners conceived of the national nuclear program as key to confirming the country's standing in the modern era, thus intersecting with the widely held belief that energy abundance underpinned social progress. Nehru argued in 1948 that India had failed to capitalize on the first Industrial Revolution due to lack of technical skill, and believed that success in the ongoing second Industrial Revolution was predicated on engineering prowess, typified by nuclear power. Later in the 1970s, Prime Minister Indira Gandhi reiterated Nehru's position that nuclear power was an essential technology for rescuing developing economies such as India's from "poverty and ignorance." She was convinced that a bold display of scientific and technological might could impress the populace enough to win her re-election.[38]

Japan, 1955–1990

Following defeat in World War II, much like France, Japan was in ruins. More than 30% of the Japanese population was homeless, communication and transport networks were in shambles, and industrial capacity had been bombed into insignificance.[39] With the support of Occupation funding, Japan embarked on a modernization program that would achieve unprecedented economic success. The promise of generating cheap energy through applied nuclear technology meshed perfectly with government aspirations to enhance the international competitiveness of industry. Japan's nuclear power program was officially launched when the government passed the Atomic Energy Basic Law in 1955, which set out the criteria under which peaceful development of nuclear technology was to be undertaken. Government development funding, which commenced that year, led to the inauguration of Japan's first nuclear energy plant, the Tokai Nuclear Power Plant, in 1966.

Japan's nuclear energy program was an offspring of aspirations for enhanced national energy security. National planners came to see nuclear technology as an important export product — a tool to not only free the nation from energy dependence, but also extend its economic reach into the Pacific and the world at large. The sheer lack of indigenous energy resources justified a massive expansion of the nuclear program, including commitment to plutonium-fueled fast breeder reactors. Japanese officials believed that a greater national risk was posed by dependence on imported energy than by a network of nuclear power plants.

Soviet Union, 1954–1986

The former Soviet Union was home to the first nuclear power plant in the world, a 5-MW graphite-moderated reactor at Obninsk that was built in 1954 and similar to the later design which failed at Chernobyl in 1986. Atomic energy was linked to visions of a radiant communist future. The one-party Communist system, its control over the media, and the suppression of doubts about science and technology provided an ideal environment for nuclear expansion.

Nuclear energy was quickly attached to the infallibility of Soviet science and technology, as well as the idea of a progressive communist regime free from energy shortages and wants. As a central slogan of the Soviet nuclear industry put it, "Let the atom be a worker, not a soldier."[40] Atomic energy came to represent not only a source of electricity supply for government planners, but also a pathway towards developing breeder reactors that would meet all of the country's energy needs, a first step towards perfecting nuclear-powered engines for aircraft and automobiles, a system for producing radiation to preserve food, a source of knowledge about nuclear technology that could help the Soviet Union build advanced weapons, and a mechanism of political control whereby planners dispersed nuclear reactors to the republics to strengthen ties and political adherence.[41] It also went hand-in-hand with an agenda to convert an agrarian and peasant society into a "well oiled machine of workers" tirelessly committed to communism.[42]

Early successes in nuclear research were seen as positive proof of the legitimacy of the entire way of Soviet thinking, and the promise of nuclear energy also reassured Soviet leaders about the concentration of the empire's energy reserves in Siberia and the Caspian Sea. Soviet engineers quickly became caught up in the fantasy of a nuclear Soviet Union, and spoke publicly about the applications of gamma ray mineral prospecting and oil surveying, the use of radiation for industrial monitoring and quality control, the creation of atomic fertilizers and viruses, and the irradiation of food and other items to prolong their shelf life. Soviet nuclear energy was "the instruction of nature at its finest"; and it was believed that widespread use would produce the energy needed to fill deserts with water, build canals, excavate waste sites, and accelerate industry. One plan even called for the melting and diversion of Siberian rivers so that the heavily populated Ukraine and Volga Basin regions could be irrigated.[43]

Nuclear power in the Soviet Union therefore fused together faith in Soviet science and technology, secrecy, defense, and gigantism.[44] Russian planners were captivated by science and technology, and became fascinated with the technology on display. Khrushchev encouraged Soviet scientists to "accelerate the construction of communism" by imitating Western methods of scientific experiment and management, culminating in the belief that atomic energy was almost a magical sort of alchemy. Radioisotopes were believed to help grow food quicker and cure diseases. This reaffirmed political control to an inner elite of party members, and created pressure for scientists to avoid delays in nuclear projects that could result in their arrest, dismissal, imprisonment, or even death. Nuclear energy was also pursued on security grounds to ensure parity with Western military might and secure Russian borders from invasion or interference; Soviet military planners spent billions of dollars researching nuclear-powered rockets, jets, ships, and satellites.

United States, 1942–1979

While the Soviet Union exhibited grand visions for nuclear energy, perhaps they paled in comparison to those in the US, where the atomic age began in December 1942 with an experiment at the University of Chicago and culminated in the completion of the Manhattan Project. By the end of World War II, planners were looking for civilian applications of the atom, and its possibilities were seen as endless. Scarcely one year after the War ended, Congress established the Atomic Energy Commission (AEC), which believed that atomic energy should not only enhance defense but also "promote world peace, improve the public welfare, and strengthen free competition in private enterprise."[45] The AEC was established as an executive agency with complete control over nuclear development and exclusive ownership of fissionable materials and all facilities. The creation of the AEC gave the federal government control and authority over all aspects of the technology. Put another way, the AEC was given "monopoly like powers protected by the cover of national security."[46] (This emphasis on peace is a bit ironic, given that, when the US Air Force discovered that the Soviet Union had detonated a nuclear device in September 1949, the civilian reactor program was intertwined with military efforts; generals hoped that civilian reactors could produce a "quantum jump" to develop a thermonuclear weapon.[47])

As one example of the hype surrounding nuclear energy, the same month the atomic bombs were dropped on Hiroshima and Nagasaki, the pocket book *The Atomic Age Opens* was published and widely read. The book depicted a future world in which coal and petroleum would go unused, and existing hydroelectric facilities would be abandoned and as "obsolete as the stagecoach" was in 1945. To give the general public some feeling for the vast amounts of energy soon to be theirs, the authors calculated the atomic power of ordinary things: one pound of water had enough energy to heat 100 million tons of water, a handful of snow could power an entire city, and the energy in a small paper railway ticket was sufficient to power a heavy passenger train several times around the earth.[48] Robert M. Hutchins, President of the University of Chicago, stated in 1946 that nuclear power would make "heat so plentiful that it will even be used to melt snow as it falls." Hutchins went on to suggest that "a very few individuals working a few hours a day at very easy tasks in the central atomic power plant will provide all the heat, light, and power required by the community and these utilities will be so cheap that their cost can hardly be reckoned."[49]

Nuclear energy promotion also reinforced national values and ideas about technology and nature. The anthropologist Gary Downey argues that advanced technology has always been correlated with progress in the US, and was initially used to distinguish the American colonies from their English counterparts. Thus, nuclear energy was seen as politically necessary to avoid the risks of communism, and was key to a postwar identity shaped in defiance to Marxism and Communism. Military planners believed that demonstrating the civilian applications of the atom would also affirm the American system of private enterprise, showcase the expertise of scientists, increase personal living standards, and defend the democratic lifestyle against Communist intrusion.[50]

Less than ten years after Hutchins' statement, the US government fully embraced nuclear power and passed the Atomic Energy Act of 1954 — the same year that President Dwight Eisenhower pledged to "strip the atom's military casing and adapt it to the art of peace."[51] The central theme behind the "Atoms for Peace" project was to show that the power of the atom could be converted from a terrifying military force to a benign commodity. The role of the government was to be a custodian of atoms.[52] Lewis Strauss, Chairperson of the AEC, remarked that atomic power would usher in an age where:

> It is not too much to expect that our children will enjoy in their homes electrical energy too cheap to meter, will know of great periodic regional famines in the world only as matters of history, will travel effortlessly over the seas and under them and through the air with a minimum of danger and at great speeds, and will experience a lifespan far longer than ours as disease yields and man comes to understand what causes him to age.[53]

Partially captivated by such optimism, Eisenhower's "Atoms for Peace" program granted US$475 million in funds to promote nuclear power abroad and Walt Disney even produced a television show entitled "Our Friend, the Atom."

One of the drivers behind atomic energy in the US was competition with the Soviet Union. Developments outside the nuclear industry during the 1940s and 1950s — such as the Alger Hiss case, the pro-Soviet coup in Czechoslovakia, the Soviet blockade of West Germany, the Chinese Revolution, as well as Soviet progress in developing atom bombs, hydrogen bombs, and nuclear reactors — convinced many American planners that they were in a "race to save the world from communism." Nuclear power was one key component of winning this race. It is illustrative that the first nuclear plant built by the AEC in Shippingport, Pennsylvania, started in 1953 directly after the Soviet Union exploded its H-bomb, and that the reason for choosing to go forward was not to produce a "cost-competitive" plant but to show the world that the US could design and operate a reactor.[54]

Spain, 1951–1980

Spain pursued a path of nuclear power partly because of its technocratic government, imperialist ambitions, utopian thinking, and Cold War relationships. Its quest for nuclear energy began in the early 1940s. After the atom bombs were dropped on Japan, Spanish leaders were convinced that military might lay in nuclear weapons, not in soldiers or ships. The country also happened to be sitting on what was believed to be one-seventh of the world's recoverable uranium deposits. Planners there established the *Junta de Energía Nuclear* (Nuclear Energy Board, or JEN) in 1951, and promoted nuclear power on the grounds that Spain had to be involved with important developments in science. As a consequence of its dictatorship and its collaboration with the Third Reich during World War II, Spain was excluded from international forums until 1955 and did not receive economic aid under the Marshall Plan. Impoverished by war, Spanish planners therefore saw nuclear energy as an inexhaustible source of energy necessary to power Spain's national reconstruction, development, and industrialization.[55]

Canada, 1942–1994

Canada's nuclear power industry can be traced back to uranium mining, which was initially under private control during World War II and operated to meet the needs of British and US military research. Under the 1943 Quebec Agreement, Canada funneled high-quality uranium to the Manhattan Project and clandestine British weapons programs; but when the war ended, the government declared all "works, undertakings, and substances relating to atomic energy to be for the general advantage of Canada." One year later, in 1944, construction began on an experimental research reactor. Canada later passed the Atomic Energy Control Act of 1946, which gave the government complete control over nuclear energy, expropriated all private uranium companies, established a Crown corporation (Eldorado Mining and Refining Limited), and prohibited all other actors from selling uranium in Canada to anyone other than this entity until 1959. Also, in 1952, Atomic Energy of Canada Limited was established as a government agency to coordinate research and regulate the export of nuclear materials and equipment.[56] The belief at the time was that Canada would be well positioned to supply the world fleet of reactors with uranium, making the country a de facto power broker in the transition to a global atomic economy.

Conclusion

In each of the above historical cases, planners pursued nuclear power not solely based on its costs and benefits in the present, but with hope about potential future gains, national visions, and technological optimism. As Table 4 shows, these visions differed by country and over time. Yet despite such differences, each of them painted nuclear energy as leading to national "radiance," economic revitalization, progress, and the possibility of a better future of some type. Their prevalence reminds us that energy policymaking is not always guided by coldly rational thinking alone, and that energy systems can play a forceful role in shaping norms and ideals about what the future may hold. However, it also illustrates that nuclear power was never initially designed or intended to be a cost-competitive source of electricity supply.

In the end, the choice between nuclear power and its cleaner alternatives boils down to a simple question: Do we want a nuclear economy, which is centrally administered by technical specialists, completely reliant on government subsidies, dependent on future breakthroughs in research, and sure to promote international proliferation and worsen inequity

Table 4: Visions Associated with Nuclear Power During the Formative Years of Eight National Programs

Country	Period	National Vision
China	1953–1992	"Catching up" with other industrialized countries (including Taiwan), and creating lucrative opportunities for Chinese exports and economic leadership
France	1945–1970	Recovering from World War II and revitalizing the national economy through high-technology "national champions" that would legitimate France as a vital superpower
India	1945–1980	Creating a prosperous and technologically sophisticated Indian society in which social problems (such as hunger and poverty) would be eliminated
Japan	1955–1990	Using technological prowess and nuclear energy to rebuild the national economy, and to offset the risks of energy shortages and dependence on energy imports
Soviet Union	1954–1986	Validating the Communist system and the Soviet approach to science, and achieving a utopian future without scarcities of water, food, heat, or energy
United States	1942–1979	Harnessing the power of the atom for peaceful purposes, legitimizing the Manhattan Project, and creating a future in which electricity would be "too cheap to meter"
Spain	1951–1980	Revitalizing the Spanish economy after World War II and participating in "important" scientific research involving fission
Canada	1942–1994	Cultivating global demand for Canadian uranium and creating a lucrative export market for Canadian reactors

and vulnerability, that requires draconian security measures, wastefully generates and distributes electricity, remains based on highly uncertain projections about theoretical nuclear designs and available fuel, fouls water and the land, and trashes the planet for many future generations? Or, do we want a small-to-medium-scale decentralized electricity system, which is more efficient, independent from government funding, and encompassing commercially available technologies, that operates with minimal harm to the environment, remains resilient to disruptions and terrorist assaults, is equally available to all future generations, and is highly beneficial to all income groups?

When the true costs of nuclear energy are compared to the true benefits of renewable technologies, the answer is almost too obvious. In a carbon-constrained world, continued investment in nuclear technologies still on the drawing board makes little sense, especially as such technologies rely on diminishing stocks of usable uranium that will require more and more energy inputs in order to be enriched to fuel-grade status. Why invest in nuclear energy as a solution to global climate change when, by the time such systems come online, enriching the fuel for them will require emitting as much carbon as today's fossil fuel systems?

Any rational investor, regulator, and citizen would choose instead to invest in the deployment of technologies that require little to no energy inputs so as to harness free and clean fuels widely throughout the world. Policymakers should peek beyond the smoke-and-mirrors Kabuki dance used to obscure the obvious advantages of renewable technologies and the obvious costs of nuclear systems. Any effective response to electricity demand in a world facing climate change involves enormous expansion in our use of renewable technologies and a steady abandonment of nuclear power.

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