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Nuclear Nonsense: Why Nuclear Power is No Answer to Climate Change and the World's Post-Kyoto Energy Challenges

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NUCLEAR NONSENSE: WHY NUCLEAR POWER IS NO ANSWER TO CLIMATE CHANGE AND THE WORLD'S POST-KYOTO ENERGY CHALLENGES

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ABSTRACT

Nuclear power plants are a poor choice for addressing energy challenges in a carbon-constrained, post-Kyoto world. Nuclear generators are prone to insolvable infrastructural, economic, social, and environmental problems. They face immense capital costs, rising uranium fuel prices, significant lifecycle greenhouse gas emissions, and irresolvable problems with reactor safety, waste storage, weapons proliferation, and vulnerability to attack. Renewable power generators, in contrast, reduce dependence on foreign sources of uranium and decentralize electricity

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supply so that an accidental or intentional outage would have a more limited impact than the outage of larger nuclear facilities. Most significantly, renewable power technologies have environmental benefits because they create power without relying on the extraction of uranium and its associated digging, drilling, mining, transporting, enrichment, and storage. As a result, renewable energy technologies provide a much greater potential for substantial carbon emissions reductions than significant investments in new nuclear power generation.

> *I think that nuclear power should be in the mix when it comes to energy.*
>
> –Senator Barack Obama, June 2008[1]

> *It is time we recommit to advancing our use of nuclear power.*
>
> –Senator John McCain, June 2008[2]

INTRODUCTION

Almost everywhere one looks today, politicians, pundits and prognosticators all declare nuclear power as a safe and carbon-free source of electricity, a viable response to global climate change in a carbon-constrained world. Jacques Foos, Director of the Nuclear Science Laboratory and a professor at the Conservatoire des Arts et Metier in France, writes "No More Nuclear Energy? A Lost Fight Before It Even Starts!"[3] "Daniel Gross states in *Newsweek* that 'nuclear power plants are the obvious fix for global warming and U.S. oil dependence.'"[4] Echoing such faith, the

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[1] Robert Schroeder, *Nuclear Power Wins Support on the Campaign Trail*, MARKETWATCH, July 24, 2008, http://www.marketwatch.com/news/story/nuclear-power-wins-support-campaign/story.aspx?guid={4C4C7CA5-E406-4E17-AA8C-55E59DBD68CE}&dist=msr_1 (last visited Oct. 15, 2008).
[2] *Id.*
[3] Jacques Foos, *No More Nuclear Energy? A Lost Fight before It Even Starts*, SCITIZEN, JUL. 12, 2007, http://www.scitizen.com/screens/blogPage/viewBlog/sw_viewBlog.php?idTheme=14&idContribution=846 (last visited Oct. 15, 2008), *quoted in* Benjamin K. Sovacool, *What's Really Wrong With Nuclear Power?*, SCITIZEN, Nov. 30, 2007, http://scitizen.com/stories/Future-Energies/2007/11/What-s-Really-Wrong-With-Nuclear-Power/ (last visited Oct. 15, 2008).
[4] Sovacool, *supra* note 3.

Economist proclaimed in 2005 that if oil and gas prices continue to rise, nuclear power plants are "[t]he shape of things to come."[5] Pulitzer Prize winning historian Richard Rhodes has recently written that "[n]uclear power is environmentally safe, practical, and affordable. It is not the problem—it is one of the best solutions."[6]

Opponents of nuclear power have responded in kind. Physicist and efficiency guru Amory Lovins declared nuclear power was not the climate change panacea for a laundry list of reasons: electricity generation is only responsible for forty percent of global greenhouse gas emissions; nuclear plants must run steadily rather than with widely varying loads as other power plants do; nuclear units are too big for many small countries or rural users; and nuclear power has higher costs than competitors per unit of net carbon dioxide ("CO_2") displaced, meaning that every dollar invested in nuclear expansion buys less carbon reduction than if the dollar were spent on other readily-available solutions.[7] One study, for example, found that each dollar invested in energy efficiency displaces nearly seven times as much CO_2 as a dollar invested in nuclear power.[8] The Oxford Research Group projects that because higher grades of uranium fuel will soon be depleted, assuming the current level of world nuclear output, by 2050 nuclear power will generate as much carbon dioxide per kWh as comparable gas-fired power stations.[9]

Which side is right? What if the emerging nuclear renaissance is, in fact, just a clever ruse to subsidize an industry with insurmountable

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[5] *The Shape of Things to Come?—Nuclear Power*, ECONOMIST, Jul. 9, 2005, at 58-60, *quoted in* Sovacool, *supra* note 3.

[6] Richard Rhodes & Denis Beller, *The Need for Nuclear Power*, 79 FOREIGN AFF. 30, 44 (2000).

[7] Amory B. Lovins, *Nuclear Power: Economics and Climate-Protection Potential* ii (Rocky Mountain Inst., E05-08, 2005), *available at* http://www.rmi.org/images/other/Energy/E05-08_NukePwrEcon.pdf. Specifically, Lovins calculates that every ten cents spent to buy a single kWh of nuclear electricity, assuming subsidies and regulation in the U.S., could have purchased 1.2 to 1.7 kWh of wind power, 0.9 to 1.7 kWh of gas, 2.2 to 6.5 kWh of building scale cogeneration, or 10 kWh or more of energy efficiency. Put another way, nuclear power saves as little as half as much carbon per dollar as wind power and cogeneration, and from several fold to at least tenfold less carbon per dollar than end-use energy efficiency. *Id.*

[8] Bill Keepin & Gregory Kats, *Greenhouse Warming: Comparative Analysis of Nuclear and Efficiency Abatement Strategies*, 16 ENERGY POLICY 538, 552 (1988).

[9] *See* Jan Willem Storm van Leeuwen, *Nuclear Power and Global Warming: CO_2 Emissions from Nuclear Power*, *in* SECURE ENERGY? CIVIL NUCLEAR POWER, SECURITY AND GLOBAL WARMING 40 (Frank Barnaby & James Kemp eds., 2007), *available at* http://www.stormsmith.nl/publications/secureenergy.pdf.

logistical problems and little hope of addressing global climate change? What if the industry's strategy of relying on the next generation of nuclear reactor designs depends on improbable technical breakthroughs and billions of dollars of additional research?

Drawing from examples mostly in the United States, this article argues that nuclear power plants are a poor choice for addressing energy challenges in a carbon-constrained, post-Kyoto world. Nuclear generators are prone to insolvable infrastructural, economic, social, and environmental problems. They face immense capital costs, rising uranium fuel prices, significant amounts of lifecycle greenhouse gas emissions, and irresolvable problems with reactor safety, waste storage, weapons proliferation, and vulnerability to attack. Renewable power generators, in contrast, reduce dependence on foreign sources of uranium and decentralize electricity supply so that an accidental or intentional outage would have a more limited impact than the outage of larger nuclear facilities. Most significantly, renewable power technologies have environmental benefits because they create power without relying on the extraction of uranium and its associated digging, drilling, mining, transporting, enrichment, and storage. As a result, renewable energy technologies provide a much greater potential for substantial carbon emissions reductions than significant investments in new nuclear power generation.

To make the case against nuclear power and for renewable energy, Part I of the article begins by explaining the resurgence of interest in nuclear power plants. It briefly describes the nuclear fuel cycle and outlines current approaches to nuclear research and development ("R&D"), with a special emphasis on Generation IV nuclear reactors. It notes that rapidly rising demand for electricity, dire warnings about climate change, and a desire to keep electricity prices low have motivated growth in the nuclear industry, and the section outlines the contours of a possible global expansion of nuclear power plants.

Part II lays out the financial, social, political, and environmental challenges facing nuclear power. It notes that the costs for plant construction, fuel, reprocessing, storage, decommissioning, and further research are, and will continue to be, immense. It documents that even modern nuclear reactors are prone to catastrophic accidents and failures, that shortages of high quality uranium ore are imminent, and that the thermoelectric fuel cycle of nuclear plants consumes and degrades vast quantities of water. It argues that the greenhouse gas emissions associated with the nuclear lifecycle are notable, that reactors and waste storage sites invariably degrade land and the natural environment, and that nuclear plants are at the ever-present risk of attack and sabotage and contribute to the proliferation of weapons of mass destruction.

Part III describes a much better alternative: renewable power sources such as wind, solar, hydroelectric, geothermal, and biomass that have immense advantages over nuclear plants. These smaller and more environmentally friendly generators cost less to construct, produce power in smaller increments, and need not rely on continuous government subsidies. They generate little to no waste, have less greenhouse gas emissions per unit of electricity produced, and do not substantially contribute to the risk of accidents and weapons proliferation.

I. A BIG BANG—THE RAPID RENAISSANCE OF NUCLEAR POWER

Ever since the first experimental nuclear reactor produced electricity in 1951 in Idaho,[10] the first commercial nuclear facility went online in 1956 at Calder Hall in the United Kingdom,[11] the first demonstration plant in the U.S. was completed at Shippingport in 1957,[12] and the first American commercial nuclear plant was built in 1963,[13] nuclear energy has been touted as the modern solution to the world's growing demand for energy. See Figure 1.

As of 2008, thirty-one countries[14] operated 441 nuclear power plants[15] representing about 372 gigawatts ("GW") of total installed capacity.[16] Together, the world's fleet of nuclear power plants represents roughly 12,600 reactor years of experience.[17] Moreover, "[fifty-six] countries operate . . . 284 research reactors and a further 220 reactors are used to power ships and submarines," bringing the world total to 943 nuclear reactors.[18] In 2005, nuclear plants supplied 15 percent of the world's power,

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[10] A.P. Jayaraman, Nuclear Energy in Asia, Seminar on Sustainable Development and Energy Security 13 (Apr. 22-23, 2008) (on file with author).
[11] *Id.*
[12] Richard Hirsh & Benjamin Sovacool, The Role of Nuclear Power in the Past and Future, Presentation to the Choices & Challenges Forum 10 (Nov. 8, 2007) (on file with author).
[13] *Id.*
[14] T.S. Gopi Rethinaraj, Nuclear Breeders in Japan and India: Policy Options, Faculty Seminar at the Lee Kuan Yew School of Public Policy 7 (Apr. 25, 2008) (on file with author).
[15] Gert Claassen, PBMR Multi-Energy Systems, Seminar on Sustainable Development and Energy Security 3 (Apr. 22-23, 2008) (on file with author).
[16] Jayaraman, *supra* note 10, at 12.
[17] *Id.* at 13.
[18] *Id.*

generating a total of 2768 terawatt-hours ("TWh") of electricity.[19] In the U.S. alone, which has 29.2 percent of the world's reactors, nuclear facilities accounted for just 19 percent of the national electricity generation.[20] In France, however, 79 percent of electricity comes from nuclear sources, and nuclear energy contributes to more than 20 percent of national power production in Germany, Japan, South Korea, Sweden, Ukraine, and the United Kingdom.[21]

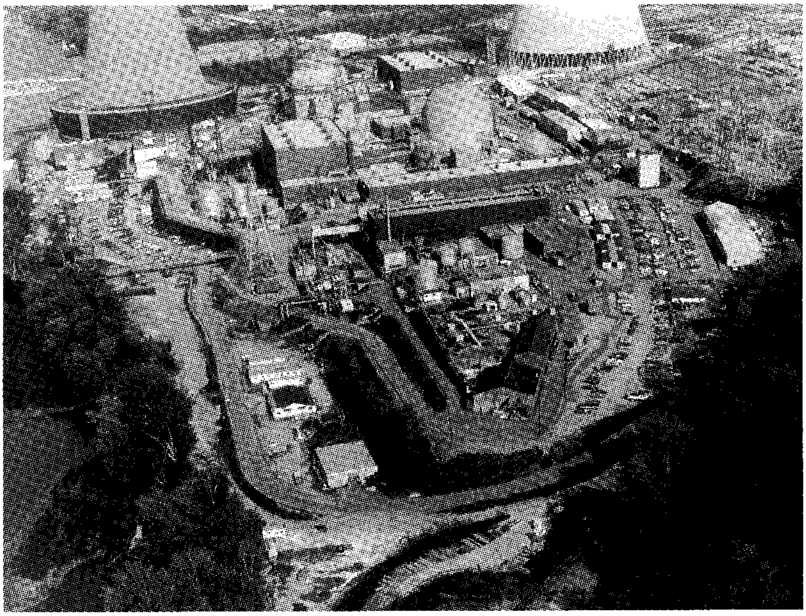

Figure 1: The 60 MW Nuclear Power Plant at Shippingport, Pennsylvania, The First Commercial Demonstration Plant in the U.S., Completed December 2, 1957[22]

A. *The Nuclear Fuel Cycle*

The nuclear fuel cycle is dirty, long, complex and dangerous. Engineers generally classify nuclear fuel cycles into two types: "once-through" and "closed-loop" cycles. Conventional reactors operate on a "once-through"

[19] INT'L ENERGY AGENCY, KEY WORLD ENERGY STATISTICS 17 (2007), http://www.iea.org/Textbase/npsum/WEO2007SUM.pdf.
[20] *Id.*
[21] *Id.*
[22] *Id.*

mode that discharges spent fuel directly into disposal.[23] Reactors with reprocessing in a "closed" fuel cycle separate waste products from unused fissionable material so that they can be recycled as fuel.[24] Reactors operating on closed cycles extend fuel supplies and have clear advantages to conventional nuclear facilities in terms of waste storage and disposal, but have disadvantages in terms of cost, short-term reprocessing issues, proliferation risks, and safety—issues explored in detail below.[25]

> Despite these differences, both once-through and closed[-loop nuclear] fuel cycles involve at least five interconnected stages that constitute the nuclear lifecycle:
> [1.] The "frontend" of the cycle, where uranium fuel is mined, milled, converted, enriched, and fabricated;
> [2.] The construction of the plant itself;
> [3.] The operation and maintenance of the facility;
> [4.] The "backend" of the cycle where spent fuel is conditioned, (re)processed, and stored;
> [5.] The final stage where plants are decommissioned and abandoned mines returned to their original state.[26]

1. The Frontend

Nuclear power plants run primarily on uranium. Uranium is found in minute quantities in the earth's crust and oceans, but rare concentrations exist which constitute ore.[27] Uranium is mined, and after extraction "is crushed, ground into a fine slurry, and leeched in sulfuric acid."[28] Liquid uranium is first converted into solid uranium oxide—"yellow cake"—then transformed into uranium hexafluoride—"hex"—and heated into a gaseous state.[29] Hex vapors cool and condense into a solid in cylinders.[30] The uranium is then enriched "through gaseous diffusion or [in a] gas centrifuge."[31]

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[23] MASSACHUSETTS INST. OF TECH., THE FUTURE OF NUCLEAR POWER: AN INTERDISCIPLINARY MIT STUDY 4 (2003), http://web.mit.edu/nuclearpower/pdf/nuclearpower-summary.pdf.
[24] *Id.*
[25] *Id.* at 4-5. *See infra* Part II.
[26] Benjamin K. Sovacool, *Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey*, 36 ENERGY POL'Y 2950, 2951 (2008).
[27] *Id.*
[28] *Id.*
[29] *Id.*
[30] *Id.*
[31] *Id.*

Uranium mining is dangerous and extremely damaging to the environment. Mines are either open pits up to 250 meters deep, or underground caverns similar to conventional coal shafts.[32] Another extraction "technique involves subjecting natural uranium to *in situ* leaching where hundreds of tons of sulfuric acid, nitric acid, and ammonia are injected into the [uranium-rich rock deep in the earth's] strata and then pumped up again after three to twenty-five years, yielding uranium that has been leached over time from treated rocks."[33] "Mined uranium must undergo a series of metallurgical processes to crush, screen, and wash the ore" before a series of chemical processes are conducted to remove remaining impurities.[34] "After enrichment, about 85% . . . [is discarded] as waste in the form of depleted hex, known as 'enrichment tails.'"[35] These toxic wastes must be stored under specific conditions to prevent leaks into the natural environment.[36] "Each year, . . . France [alone] creates 16,000 tons of enrichment tails that are then exported to Russia or added to the existing 200,000 ton [sic] of depleted uranium stored within the country."[37]

2. Construction

"The construction phase of the nuclear lifecycle involves the fabrication, transportation, and use of materials to build generators, turbines, cooling towers, control rooms, and other [necessary] infrastructure" in a nuclear power plant.[38] It is not hyperbole to state that an average nuclear power plant contains over a million separate parts, any one of which could fail at any time. A typical nuclear plant, for example, usually contains approximately fifty miles of piping that has been welded at 25,000 different points, and 900 miles of electrical cables.[39] The electrical system has thousands of necessary components.[40] The cooling system is equally complex.[41] The structural integrity of the plant must be maintained at the highest level in order to allow for the safe storage of spent nuclear material as well as the immediate and complete function of back up and safety systems

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[32] Sovacool, *supra* note 26, at 2951.
[33] *Id.*
[34] *Id.*
[35] *Id.* at 2952.
[36] *Id.* at 2953.
[37] Sovacool, *supra* note 26, at 2952.
[38] *Id.*
[39] *Id.*
[40] *Id.*
[41] *Id.*

in case of even the most minor nuclear accident.[42] "Temperatures, pressures, power levels, radiation levels, flow rates, cooling water chemistry, and equipment performance must all be constantly monitored" by redundant systems that vastly multiply the complexity of any nuclear facility that hopes to operate safely.[43]

3. Operation & Maintenance

"The heart of the operating nuclear facility is the reactor, which generates electricity through the fission, or splitting, of uranium and plutonium isotopes."[44] Nuclear power plants and nuclear weapons explosions differ only by degree. In a nuclear weapon detonation, all of the energy embodied in the nuclear reaction is released in one awesome and terrifying moment.[45] In a nuclear power plant, this same energy is released slowly over the lifetime of the plant.[46] "Most nuclear reactors around the world have an expected operating lifetime of [thirty to forty] years, but produce electricity at full power for no more than [twenty-four] years."[47]

4. The Backend

In this phase spent fuel must be processed, stored for an interim period, and then permanently sequestered. "Spent fuel must be conditioned for reactors operating on a once-through fuel cycle, and reprocessed for those employing a closed fuel cycle."[48] For both cycles, once fuel rods are spent, they must be stored and cooled at the reactor site for at least ten years.[49] After the interim storage period, the spent rods are transferred into "large concrete casks that provide air-cooling, shielding, and physical protection."[50] Once in the concrete casks, the final stage of the backend cycle takes place: permanent storage of the radioactive waste. Permanent

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[42] *Id.*
[43] Sovacool, *supra* note 26, at 2952.
[44] *Id.* at 2953.
[45] KENNETH D. BERGERON, TRITIUM ON ICE 6 (MIT Press 2002) (describing a the fission that takes place in a nuclear bomb); *see also* Rethinaraj, *supra* note 14, at 5.
[46] BERGERON, *supra* note 45, at 37-38 (describing the fission which takes place in a nuclear reactor); *see also* Rethinaraj, *supra* note 14, at 5.
[47] Sovacool, *supra* note 26, at 2953 (quoting DAVID FLEMING, THE LEAN GUIDE TO NUCLEAR ENERGY: A LIFE-CYCLE IN TROUBLE 7 (2007), http://www.theleaneconomy connection.net/nuclear/Nuclear.pdf).
[48] *Id.*
[49] *Id.*
[50] *Id.*

geological repositories serve as the final storage cites. These depositories are chosen based on their ability to protect against "every plausible scenario in which radionuclides might reach the biosphere or expose human populations to dangerous levels of radiation."[51] The main concern is "groundwater seeping into the repository, corrosion of waste containers, leaching of radionuclides" which could then enter the food and water supplies through drinking water or for water used for agriculture.[52]

5. Decommissioning and Land Reclamation

"The last stage of the fuel cycle involves the decommissioning and dismantling of the reactor, as well as reclamation of the uranium mine site."[53]

When the energy required for construction of a nuclear facility is added to the energy consumed in decommissioning as well as the energy required to mine, mill and enrich the uranium fuel, the nuclear fuel cycle consumes nearly half of all the electricity that a typical reactor is expected to produce during its lifetime, and this number does not include the energy needed to store spent fuel for thousands of years.[54] This consumption is important because an accurate account of both the per kilowatt hour ("kWh") cost of nuclear power as well as any estimates of total carbon output from a nuclear facility must acknowledge that a majority of a nuclear reactor's generation is consumed by the nuclear lifecycle before a single kWh is available for use by electricity consumers.

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[51] *Id.*
[52] *Id.*
[53] Sovacool, *supra* note 26, at 2953.
[54] HELEN CALDICOTT, NUCLEAR POWER IS NOT THE ANSWER 3-18 (2006), http://www.dolphinblue.com/pg-Forum-Caldicott-Nuclear-Power.html. Caldicott estimates that "[e]ven utilizing the richest ores available, a nuclear power plant must operate at ten full load operating years before it has paid off its energy debts." *Id.* at 16. Based on this estimation, several known facts can modify the model: not all plants use the richest ores, plants operate at full capacity for an average of twenty years, most plants are decommissioned within thirty or forty years. Accordingly, a plant using average richness uranium, operating at full capacity for twenty years out of a thirty five year life span will only generate about twice as much energy as "consumed" by the plant.

Utilizing a similar technique called an "energy payback ratio," or the ratio of total energy produced compared to the energy needed to build and operate an energy system, Luc Gagnon found that nuclear power plants have a very low energy payback ratio. Luc Gagnon, *Civilization and Energy Payback*, 36 ENERGY POL'Y 3317, 3317-20 (2008). He estimated that hydroelectric, wind, and biomass power plants are at least 1.5 to twenty times more efficient from an energy payback perspective than nuclear reactors. *Id.* at 3320.

B. *Generation IV Nuclear R&D*

Nuclear engineers describe four generations of nuclear plant design since the technology was discovered in the early 1940s.[55] The first generation refers to the experimental reactors designed in the 1940s and 1950s.[56] These "rather small Atoms-for-Peace-era plants" are now almost all shutdown.[57] Only six Generation I units still operated in 2007, a series of small 250 MW gas-cooled nuclear power plants in the United Kingdom.[58]

The second generation of nuclear plants refers to most commercial reactors now in operation, including the light water reactor fleet found in the U.S. and Europe, predominately comprised of pressurized water reactors and boiling water reactors.[59] These reactors were mostly designed in the 1960s and built in the 1970s.[60]

The third generation encompasses advanced reactor designs that operate at slightly higher temperatures or according to different designs, such as Pebble Bed Modular Reactors ("PBMR"),[61] Canadian Deuterium Uranium reactors ("CANDU"),[62] European Pressurized Water Reactors ("EPWR"),[63] and Advanced Boiling Water Reactors ("ABWR").[64] These advanced reactors, sometimes referred to as "Generation III" or "Generation III+" technology, emerged from public-private research in the 1980s and early 1990s.[65] While Generation III reactors are not currently used widely by the industry, their use is expected to grow significantly between 2020 and 2040.[66] The difference between Generation III and Generation IV

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[55] Gail H. Marcus, *Considering the Next Generation of Nuclear Power Plants*, 37 PROGRESS IN NUCLEAR ENERGY 5, 8 (2000).

[56] *Id.*

[57] *Id.*

[58] INTERACADEMY COUNCIL, LIGHTING THE WAY: TOWARD A SUSTAINABLE ENERGY FUTURE 83 (IAC Secretariat ed., 2007), *available at* http://www.interacademycouncil.net/Object.File/Master/12/065/3.%20Energy%20Supply.pdf.

[59] Marcus, *supra* note 55, at 7-8.

[60] *Id.* at 8.

[61] *See* Claassen, *supra* note 15, at 6 (discussing the South African state utility, ESKOM's operation of a small 165 MW helium-cooled experimental PBMR testing facility near Koeberg).

[62] CANDU Owners Group, Highlights of CANDU History, http://www.candu.org/candu_reactors.html#history (last visited Oct. 15, 2008).

[63] *See* J. Czech et al., *European Pressurized Water Reactor: Safety Objectives and Principles*, 187 NUCLEAR ENGINEERING AND DESIGN 25, 25 (1999).

[64] GE Energy, Advanced Boiling Water Reactor (ABWR), http://www.gepower.com/prod_serv/products/nuclear_energy/en/new_reactors/abwr.htm (last visited Oct. 16, 2008).

[65] Marcus, *supra* note 55, at 8.

[66] B. Frois, *Advances in Nuclear Energy*, 752 NUCLEAR PHYSICS A 611c, 611c (2005).

designs is sometimes blurred by Generation III proponents attempting to receive Generation IV R&D funds.[67]

Research on the fourth generation of nuclear reactors, often called "Generation IV" systems, began in the late 1990s under the Advanced Fuel Cycle Initiative, previously called the Advanced Accelerator Applications Program.[68] Under the Advanced Fuel Cycle Initiative, the U.S. started researching advanced reactor designs and fuel cycles along with Belgium, China, The Czech Republic, France, Germany, Hungary, India, Japan, The Netherlands, Poland, the Russian Federation, South Korea, Switzerland, and the European Commission.[69] The program morphed into the Nuclear Energy Research Initiative ("NERI") in 1999,[70] a project headed by the U.S. Department of Energy ("DOE") to explore R&D in four areas, explained in Table 1.

TABLE 1—NERI OBJECTIVES[71]

NERI R&D Areas of Emphasis	**Objective in each Area of Emphasis**
Construction	moving away from onsite construction of power plants to a more standardized manufacturing approach with simplified designs that would be more suited to mass production

[67] *See* World Nuclear Association, Advanced Nuclear Power Reactors, http://www.world-nuclear.org/info/inf08.html (last visited Oct. 16, 2008). Generation IV funding has been available since 2001 and has been dedicated to "six reactor concepts for further investigation with a view to commercial deployment by 2030." *Id.* Generation III+ plants are scheduled to be operational by 2015. *Id.* Therefore, Generation IV funding could have been diverted to advance concepts applied in Generation III+ plants.
[68] ADVANCED FUEL CYCLE INITIATIVE, ADVANCED FUEL CYCLE INITIATIVE PROGRAM PLAN 3-4 (2005).
[69] The U.S. has shared fuel cycle research with many countries, particularly information from the Advanced Fuel Cycle Initiative. *See* Carter Savage, *Overview of the United States P&T Program*, *in* NUCLEAR ENERGY AGENCY, ACTINIDE AND FISSION PRODUCT PARTITIONING AND TRANSMUTATION: EIGHTH INFORMATION EXCHANGE MEETING LAS VEGAS, NEVADA, UNITED STATES 9-11 NOVEMBER 2004 49-56 (2005), http://www.nea.fr/html/pt/docs/iem/lasvegas04/nea-6024-pt.pdf; *Annex 2: List of Participants*, *in* NUCLEAR ENERGY AGENCY, note 63, at 141-56. The U.S. also participates in Global Nuclear Energy Partnership ("GNEP") where the Advanced Fuel Cycle Initiative is part of a shared international research agenda. Global Nuclear Energy Partnership, Welcome to the Global Nuclear Energy Partnership, http://www.gneppartnership.org/index.htm (last visited Oct. 17, 2008).
[70] Marcus, *supra* note 55, at 8-9.
[71] *Id.* at 9.

Proliferation resistance	creating fuel core designs that operate for at least fifteen years without refueling to minimize the risk of theft of fissile materials
Safety	improving operational procedures and maintenance requirements to minimize the incidence of human operator error
Waste disposal	designing new fuel cycles to minimize the creation of nuclear waste and operate on alternative forms of fuel

Under NERI, the DOE alone sponsored forty-six research projects involving the national laboratories, universities, industry, and foreign R&D partners.[72]

The DOE's approach to Generation IV R&D transformed once again in 2002, when President Bush and the DOE announced a nuclear program aptly called the "Generation IV International Forum" ("the GIF").[73] At the heart of the GIF lies the Global Nuclear Energy Partnership ("GNEP"), a program created in 2006 to promote nuclear energy abroad by exploring export opportunities for American technology firms.[74] Ten countries currently announce and share their research efforts annually at the GIF: Argentina, Brazil, Canada, France, Japan, South Korea, South Africa, Switzerland, United Kingdom, and the United States.[75]

Generation IV R&D initially started by considering a slate of twenty different reactor designs,[76] but has since been narrowed to only six designs: Very High Temperature Reactors, Gas-Cooled Fast Reactors, Sodium-Cooled Fast Reactors, Super-Critical-Water-Cooled Reactors, Lead-Cooled Reactors, and Molten Salt Reactors.[77] These designs, while differing

[72] *Id.*

[73] Spencer Abraham, *The Bush Administration's Approach to Climate Change*, SCIENCE, Jul. 30, 2004, at 616-17.

[74] Global Nuclear Energy Partnership, http://www.gnep.energy.gov/ (last visited Oct. 4, 2008) ("the United States and its GNEP partners are *working* toward establishing international structures intended *to prevent the uncontrolled spread of nuclear technologies and materials*." (emphasis added)).

[75] Frois, *supra* note 66, at 617c.

[76] *Id.* at 611c-22c, 613c fig.2, and 619c fig.4 (detailing three designs specifically, mentioning twelve in Figure 2 and eight in Figure 4).

[77] *See* T. A. Lennox, D. N. Millington & R. E. Sunderland, *Plutonium Management and Generation IV Systems*, 49 PROGRESS IN NUCLEAR ENERGY 589, 590-93 (2007) (introducing the R&D agenda for the Generation IV program); K. L. Murty & I. Charit, *Structural*

in specific engineering, have four common themes[78] that build from the eight stated technology goals of the GIF.[79] The common themes among the designs help achieve the GIF goals in the six following ways:

> 1) The designs are intended to produce reactors operating either at very high temperatures or in a fast neutron/breeder fuel cycle that attempts to recycle spent fuel;
> 2) The designs attempt to improve the environmental performance of reactors by minimizing the need for mined uranium and lessening the environmental footprint of power plants;
> 3) The designed plants plan to improve waste management by recycling or minimizing the fuel that they do use;[80]
> 4) They try to enhance proliferation resistance by making it impossible to steal weapons grade material;
> 5) They intend to improve safety and reliability;
> 6) They attempt to minimize financial risk and improve the economics of plant construction and operation.

In short, the theory is that future Generation IV nuclear technology would operate differently than conventional units by utilizing fuel cycles which operate at higher temperatures or use different forms of fuel, minimizing damage and the creation of waste, decreasing the amount of fissile material from the fuel cycle available for weapons, improving safety, and improving the economics of nuclear power plants.[81] However, Generation IV reactors are also the farthest from commercialization. They are completely experimental, with engineers and scientists still working out theoretical

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Materials for Gen-IV Nuclear Reactors: Challenges and Opportunities, J. NUCLEAR MATERIALS (forthcoming 2008) (manuscript at 1-2, on file with the Journal of Nuclear Materials) (describing different Gen-IV Nuclear Reactor Systems in Table 1).

[78] *See Id.* at 591.

[79] *Id.* at 590 (citing U.S. DOE NUCLEAR ENERGY RESEARCH ADVISORY COMMITTEE AND THE GENERATION IV INTERNATIONAL FORUM, A TECHNOLOGY ROADMAP FOR GENERATION IV NUCLEAR ENERGY SYSTEMS: TEN NATIONS PREPARING TODAY FOR TOMORROW'S ENERGY NEEDS 6 (2002)).

[80] Though fuel recycling is not mentioned as a specific goal, it contributes to the achievement of several GIF goals. One of the key ideas being promoted by Generation IV R&D proponents is Accelerator Transmutation of Waste ("ATW"), a method of treating spent fuels. Marcus, *supra* note 55, at 9-10. The plan involves designing a reactor that would not produce any power but would specifically remove radiotoxic isotopes from the waste. *Id.*

[81] Lennox, *supra* note 77, at 590-91.

concepts, most of which have not been proven in practice.[82] The next stage in Generation IV research, if possible, would likely be the construction of experimental reactors around 2015 or 2020.[83] Then, if successful, commercialization and wide scale deployment of Generation IV technologies would begin by 2040 at the earliest.[84]

C. *Three Factors Pushing the Nuclear Renaissance*

Why have ten countries spent billions of dollars collaborating on Generation IV nuclear technology? Of all the daunting global challenges facing the electricity sector, three seem the most significant: the need to provide basic energy services to the world's poor, the need to find sources of energy that are less greenhouse gas intensive, and the need to keep costs low, both to ratepayers and to governments. Proponents of nuclear power believe it is the only technology that can satisfy all three of these critical needs.

First, denying electricity and the services it can provide to those in need promotes discrimination in the vein of what Reverend Benjamin Chavis, Jr., called "environmental racism."[85] The United Nations reports that at least one billion people—roughly one-sixth the global population—have little to no access to electricity.[86] Without electricity, millions of women and children are typically forced to spend significant amounts of time searching for firewood, and then combusting wood and charcoal

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[82] *See* TIM ABRAM & SUE ION, GENERATION-IV NUCLEAR POWER 3 (2006), http://www.foresight.gov.uk/Energy/GenerationIVnuclearpower.pdf.
[83] GEN-IV INTERNATIONAL FORUM, 2007 ANNUAL REPORT 22 (2007), http://www.gen-4.org/PDFs/annual_report2007.pdf.
[84] Ann MacLachlan, *CEA Chairman Pleads for EPR Order, Calls Wait for Gen IV 'Unrealistic,'* NUCLEONICS WEEK, Sept. 25, 2003, at 7.
[85] *See, e.g.,* HUMAN RIGHTS COMMISSION, CITY AND COUNTY OF SAN FRANCISCO, ENVIRONMENTAL RACISM: STATUS REPORT & RECOMMENDATIONS 21-24 (2003) (discussing the injustice and racism created as a consequence of shutting down a power plant in a poorer San Francisco area). *See* Noel Wise, *To Debate or to Rectify Environmental Injustice: A Review of Faces of Environmental Racism*, 30 ECOLOGY L. Q. 353, 355 (2003). *See generally* COMMISSION FOR RACIAL JUSTICE, UNITED CHURCH OF CHRIST, TOXIC WASTES AND RACE IN THE UNITED STATES (1987) (Reverend Chavis defining environmental racism).
[86] UNITED NATIONS DEVELOPMENT PROGRAM, ENERGY AFTER RIO: PROSPECTS AND CHALLENGES 1 (1997). Just 64 percent of the population in developing countries as a whole have access to electricity, and in Asia and Africa, the numbers are even lower: 40.8 percent for South and Southeast Asia; 34.3 percent for Africa; 22.6 percent for Sub-Saharan Africa. *See* INTERNATIONAL ENERGY AGENCY, WORLD ENERGY OUTLOOK 2002 373, 377, 380 (2002).

indoors to heat their homes or prepare meals.[87] The health consequences alone of this combustion are monumental. Scientists estimate that indoor air pollution kills 2.8 million people every year—almost equal with the number dying annually from HIV/AIDS.[88] Close to one million of these deaths—910,000—occur in children under the age of five that must suffer their final months of life dealing with debilitating respiratory infections, chronic obstructive pulmonary disease, and lung cancer.[89]

Those poorer developing countries that do attempt to provide energy services have to spend a larger proportion of their income on them merely because they have fewer resources than wealthier populations. Increases in the cost of oil, for example, mean that the foreign exchange required for fossil fuel imports creates an unfair balance of trade for many developing countries.[90] The United Nations estimates that while developed countries spend just one percent of their Gross Domestic Product ("GDP") on energy supplies, those in the developing world spend 4.5 to 9 percent.[91] Higher prices for oil also tend to drive up the costs for transporting that very oil,[92] hitting developing countries twice: once for costlier barrels of oil, and again for inflated transportation costs that reflect the higher oil costs. In essence, nuclear power is seen as one of the few options that can prevent a form of "energy apartheid" where people in the Western world use large amounts of energy, have higher standards of living and longer life expectancies while those in undeveloped nations have no access and die earlier.[93]

Second, proponents of nuclear power believe that it is a much better option for generating power without releasing significant amounts of

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[87] Benjamin K. Sovacool, *Using Distributed Generation and Renewable Energy Systems to Empower Developing Countries*, 2 INT'L J. ENVTL. CULTURAL ECON. & SOC. SUSTAINABILITY 77, 78, 82-83 (2006).

[88] Bjorn Lomborg, *Wasteful Efforts to Curb Global Warming*, BBC NEWS, Sept. 19, 2006, http://news.bbc.co.uk/2/hi/business/5346734.stm (last visited Oct. 31, 2008).

[89] Majid Ezzati, et al., *Energy Management and Global Health*, 29 ANN. REV. ENV'T & RESOURCES 383, 392-93 (2004).

[90] *See* INTERNATIONAL ENERGY AGENCY, ANALYSIS OF THE IMPACT OF HIGH OIL PRICES ON THE GLOBAL ECONOMY 5 (2004), http://www.iea.org/Textbase/Papers/2004/High_Oil_Prices.pdf.

[91] UNITED NATIONS DEVELOPMENT PROGRAM, *supra* note 86, at 39.

[92] David Fisk, *Transport Energy Security: The Unseen Risk* 2 (Fondazione Eni Enrico Mattei, Working Paper 118.04, 2004), *available at* http://www.feem.it/NR/rdonlyres/ADC3EF51-39BF-4BB3-9A73-7342E0C65E57/1268/11804.pdf (noting "the increasing inelasticity of demand for oil-based products in the transport sector of the world's economies").

[93] Denis E. Beller, *Atomic Time Machines: Back to the Nuclear Future*, 24 J. LAND RESOURCES & ENVTL. L. 41, 43 (2004).

greenhouse gases or toxic pollution. According to the International Energy Agency's ("IEA") 2002 *World Energy Outlook*, greenhouse gas emissions will increase approximately 135% in the United States and Canada by 2030 from today's levels under a business as usual scenario.[94] As Robert K. Dixon, Head of the Technology Policy Division at the IEA, declared in 2008, "Without substantial technology and policy changes, fossil fuels will remain 'fuels of choice' well into the future."[95]

The impacts of an impending climate change crisis wrought by continued emissions of greenhouse gases will likely be severe. In its most recent report, the Intergovernmental Panel on Climate Change ("IPCC") concluded that continued emissions of greenhouse gases will contribute directly to the risk of severe water shortages for millions of people, the bleaching of coral reefs, the disappearance of suitable ecosystems for "migratory birds, mammals and higher predators," a significant loss of agricultural and fishery productivity, increased damage from floods and severe storms in coastal areas especially, deaths arising from changes in disease vectors, and an increase in the number of heat waves, floods, and droughts.[96] The Pew Center on Global Climate Change estimates that in the Southeast and Southern Great Plains alone, the financial costs of climate change could reach as high as $138 billion by 2100.[97]

Advocates of nuclear power have therefore framed nuclear energy as an important part of any solution aimed at fighting climate change and reducing greenhouse gas emissions. The Nuclear Energy Institute, discussing India and China for example, reminds the public that, "it is important to influence them to build emission-free sources of energy like nuclear"[98]

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[94] INTERNATIONAL ENERGY AGENCY, WORLD ENERGY OUTLOOK 2002 425 (2002) (nothing that in 2000, 6175 metric tons ("Mt") of CO_2 were emitted, while 8327 Mt are projected in 2030).

[95] *Quoted in* Benjamin K. Sovacool, Hans H. Lindboe & Ole Odgaard, *Is the Danish Wind Energy Model Replicable for Other Countries?*, ELEC. J., Mar. 2008, at 27, 29.

[96] *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT SUMMARY FOR POLICYMAKERS 3, 10-14, 19 (2007), http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf. The IPCC is a forum made up of hundreds of the world's top climate scientists tasked with providing objective information on climate change to policy makers. Intergovernmental Panel on Climate Change, About IPCC, http://www.ipcc.ch/about/index.htm (last visited Sept. 12, 2008).

[97] Eileen Claussen & Janet Peace, *Energy Myth Twelve-Climate Policy Will Bankrupt the U.S. Economy*, *in* ENERGY AND AMERICAN SOCIETY-THIRTEEN MYTHS 311, 322 (Benjamin K. Sovacool & Marilyn A. Brown eds., 2007) *citing* JOEL B. SMITH, A SYNTHESIS OF POTENTIAL CLIMATE CHANGE IMPACTS ON THE U.S. 12 (2004), http://www.pewclimate.org/docUploads/Pew-Synthesis.pdf.

[98] Posting of David Brandish to NEI Nuclear Notes, http://neinuclearnotes.blogspot.com/2007/11/world-energy-outlook-2007.html (Nov. 19, 2007, 22:15 EST) (*commenting on* INT'L ENERGY AGENCY, WORLD ENERGY OUTLOOK 2007 (2007)).

and that nuclear power is a "carbon-free electricity source."[99] When President George W. Bush signed the Energy Policy Act in August 2005, he remarked that "only nuclear power plants can generate massive amounts of electricity without emitting an ounce of air pollution or greenhouse gases."[100] The late Mr. Nicholas Ridley, former Secretary of State for the Environment in the United Kingdom, was even more explicit, stating on BBC television that, "There is absolutely no doubt that if you want to arrest the Greenhouse Effect you should concentrate on a massive increase in nuclear generating capacity. Nuclear power stations give out no sulfur and carbon dioxide, so they are the cleanest form of power generation."[101]

Even some former nuclear power skeptics have embraced the efficacy of nuclear power as a solution to global climate crisis. Patrick Moore, co-founder of Greenpeace and once a vocal opponent of nuclear power, has publicly stated that "nuclear energy . . . remains the only practical, safe and environmentally-friendly means of reducing greenhouse gas emissions and addressing energy security."[102] Similarly, Judith M. Greenwald of the Pew Center on Global Climate Change concluded that "the imperative to decarbonise the future world energy economy to mitigate climate change provides strong motivation to keep the nuclear power option open."[103]

Third, nuclear power is believed to produce low-cost electricity over the lifetime of each power plant. Looking at the historic levelized cost of electricity ("LCOE")—the cost over the life of a generator divided by the numbers of kWh it will produce—a recent study conducted by the Virginia Center for Coal and Energy Research found that nuclear plants produced the second cheapest form of power.[104] Table 2 summarizes the findings.

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[99] Press Release, Nuclear Energy Institute, Energy Department's FY99 Budget Request Recognizes Nuclear Energy's Value as Carbon-Free Electricity Source (Feb. 2, 1998), *available at* http://nei.org/newsandevents/fy99budgetrequest/.

[100] Press Release, Office of the White House Press Secretary, President Signs Energy Policy Act (Aug. 8, 2005), *available at* http://www.whitehouse.gov/news/releases/2005/08/20050808-6.html.

[101] Nigel Mortimer, *World Warms to Nuclear Power*, 74 SCRAM SAFE ENERGY J., Dec. 1989-Jan. 1990, *available at* http://www.no2nuclearpower.org.uk/ articles/mortimer_se74.php.

[102] *Nuclear Power's Place in a National Energy Policy: Hearing Before H. Subcomm. on Energy and Resources of the H. Comm. on Government Reform*, 109th Cong. (2005) (statement of Patrick Moore, Chair, Greenspirit Strategies Ltd.).

[103] Judith M. Greenwald, *Judith M. Greenwald Discusses Keeping the Nuclear Power Option Open*, OXFORD ENERGY FORUM, May 2005, at 6, *available at* http://www.pewclimate.org/docUploads/Oxford%20Energy%20Forum.pdf.

[104] THE VA. CTR. FOR COAL AND ENERGY RESEARCH VA. POLYTECHNIC INST. AND STATE UNIV., A STUDY OF INCREASED USE OF RENEWABLE ENERGY RES. IN VA. 20-21 (2005), http://www.energy.vt.edu/Publications/Incr_Use_Renew_ Energy_VA_rev1.pdf.

TABLE 2: HISTORIC LEVELIZED COST OF ELECTRICITY (LCOE) FOR POWER PLANTS IN VIRGINIA, $2007[105]

Technology	**Capital Cost, $/kW**	**Fixed O&M, $/kW per year**	**Variable O&M, $/MWh**	**Capacity Factor**	**Nominal LCOE, $2007 (¢/kWh)**
Landfill Gas	1571	105.82	0.01	90%	4.1
Adv. Nuclear	2049	62.88	0.46	92%	4.9
Wind	1187	28.07		35%	5.6
IGCC	1468	35.82	2.7	80%	6.7
Biomass	1842	49.4	3.1	83%	6.9
Scrubbed Coal	1270	25.51	4.25	70%	7.2
Adv. Gas/Oil Combined Cycle ("CC")	584	10.84	1.85	45%	8.2
Gas/Oil CC	594	11.56	1.92	45%	8.5
IGCC with Carbon Capture	2100	42.15	4.11	80%	8.8
Adv. Gas/Oil CC with Carbon Capture	1166	18.43	2.72	45%	12.8
Adv. Combustion Turbine	392	9.75	2.93	4%	32.5
Combustion Turbine	414	11.22	3.31	4%	35.6
Solar PV	4678	10.83		17%	39

As Table 2 shows, nuclear power plants have produced power at about 4.9¢/kWh when the cost of construction, fuel, maintenance, and operation are divided by the amount of electricity those plants generated. They appear to be second only to landfill gas generation in terms of cost per unit of energy produced.

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[105] *Id.* Figures have been updated to $2007 using change the Nominal GDP per capita from 2005 to 2007 of approximately 9%. *See* Louis D. Johnston and Samuel H. Williamson, MeasuringWorth, What Was the U.S. GDP Then?, http://www.measuringworth.org/usgdp (last visited Oct. 18, 2008) (using $41,913 for 2005 and $45,707 for 2007).

Other technologies, such as natural gas, coal, hydrogen, and fusion, are seen as too expensive, dirty, or unlikely to play a significant role in power generation anytime soon.[106] From 2002 to 2005, for example, operation and maintenance expenses for utilities in the U.S. rose by nearly $26 billion.[107] Ninety-six percent of this increase was driven by rising fossil fuel prices, not because parts or labor had gotten more expensive.[108] Aggregate fossil fuel costs nearly doubled between 2002 and 2005, from 2.3¢/kWh to 4.4¢/kWh.[109] The overbuilding of gas-fired peaking plants has resulted in skyrocketing demand for natural gas, which, in turn caused gas prices to surge.[110] Between 1995 and 2005, natural gas prices rose by an average of fifteen percent *per year*.[111] Coal, an even greater source of fuel for electricity generation, has not escaped the inflation in fossil fuel prices. In October 2003, the cost of coal in Central Appalachia was over thirty-five dollars per ton.[112] By August 2008, the price for a ton of coal in the same region had quadrupled to one-hundred-forty dollars a ton.[113] There is little likelihood, given increasing demands and low reserve margins,[114] that fossil fuel prices are likely to return to historic lows.

The much-touted "hydrogen economy" is no answer either. Hydrogen faces tenacious infrastructural challenges: inability to manufacture cost effective fuel cells, as well as problems extracting, compressing, storing,

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[106] Patrick Moore, *Going Nuclear-A Green Makes the Case*, WASH. POST, Apr. 16, 2006, at B1; Jeff Wise, *The Truth About Hydrogen*, POPULAR MECHANICS, Nov. 1, 2006, at 82; Benjamin K. Sovacool, The Power Production Paradox: Revealing the Socio-Technical Impediments to Distributed Generation Technologies 94 (Apr. 17, 2006) (unpublished Ph.D. dissertation, Virginia Polytechnic Institute and State University) (on file with the Newman Library, Virginia Polytechnic Institute and State University).

[107] Alden Hathaway, The Impact of a Renewable/EE Portfolio Standard on Future Rate Hikes in Va. 11 (Oct. 17, 2006), *available at* http://web.archive.org/web/20061113165058/www.energyvacon.com/Program/PDF/Track4/The_Impact_of_a_Renewable_EE_Portfolio_Standards_on_Future_Rate_Hikes_in_Virginia_Hathaway.pdf.

[108] *Id.*

[109] *Id.* at 12.

[110] THE BRATTLE GROUP, WHY ARE ELECTRICITY PRICES INCREASING?: AN INDUSTRY-WIDE PERSPECTIVE 41-42 (The Edison Foundation 2006).

[111] Hathaway, *supra* note 107, at 16.

[112] Energy Information Administration, Coal News and Markets: Week of October 5, 2003, http://tonto.eia.doe.gov/FTPROOT/coal/newsmarket/coalmar031005.html (last visited Oct. 18, 2008).

[113] Energy Information Administration, Coal News and Markets, Aug. 4, 2008, http://tonto.eia.doe.gov/FTPROOT/coal/newsmarket/coalmar080801.html (last visited Oct. 18, 2008).

[114] THE BRATTLE GROUP, *supra* note 110, at 25, 108.

and distributing hydrogen-based fuels.[115] And fusion power "is still at least [thirty] years away from commercialization. . . ."[116]

The historical record suggests that not even energy efficiency practices and demand-side reduction programs alone will be able to offset steady increases in electricity demand. Onsite electricity consumption per household in the U.S. dropped twenty-seven percent between 1978 and 1997, yet the number of households grew by thirty-three percent.[117] Between 1970 and 1990, electricity's share of household energy consumption actually increased from twenty-three percent to thirty-five percent.[118] The Energy Information Administration's *International Energy Outlook* also noted "[r]apid additions to commercial floorspace, the continuing penetration of new telecommunications technologies and medical imaging equipment, and increased use of office equipment are projected to offset efficiency gains for electric equipment in the sector."[119] Therefore, despite the significant gains made by energy efficiency improvements, efficiency improvements are unlikely to outpace increases in electricity demand.

D. *Current Plans for Global Nuclear Expansion*

Consequently, many believe that nuclear power is set for rapid expansion—and nuclear power plants are already being planned or constructed in the U.S., Europe, and Asia.

Here in the U.S., over the past two decades, nuclear power plants have been quietly but surely expanding their generating capacity. The Nuclear Regulatory Commission ("NRC") approved 2200 megawatts ("MW") of capacity upgrades to existing nuclear plants between 1988 and 1999, and nuclear facilities are seeking approval for another 842 MW.[120]

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[115] *See* COMM. ON ALTERNATIVES AND STRATEGIES FOR FUTURE HYDROGEN PRODUCTION AND USE, THE HYDROGEN ECONOMY: OPPORTUNITIES, COSTS, BARRIERS, AND R&D NEEDS 37 (2004); BRENT D. YACOBUCCI & AIMEE E. CURTRIGHT, CRS REPORT FOR CONGRESS, A HYDROGEN ECONOMY AND FUEL CELLS: AN OVERVIEW 1 (2004).

[116] Sovacool, *supra* note 106, at 173 (quoting Jack Barkenbus).

[117] PAULA BERINSTEIN, ALTERNATIVE ENERGY: FACTS, STATISTICS, AND ISSUES 3 (2001) (citing ENERGY INFO. ADMIN., A LOOK AT RESIDENTIAL ENERGY CONSUMPTION IN 1997 (1999), http://www.eia.doe.gov/pub/pdf/consumption/063297.pdf).

[118] *Id.* at 4.

[119] ENERGY INFO. ADMIN., INTERNATIONAL ENERGY OUTLOOK 66 (2005), http://tonto.eia.doe.gov/ftproot/forecasting/0484(2005).pdf.

[120] Neil J. Numark & Robert D. MacDougal, *Nuclear Power in Deregulated Markets: Performance to Date and Prospects for the Future*, 14 TUL. ENVTL. L.J. 463, 465-66 (2000-2001).

Following the unveiling of the Department of Energy's "Nuclear Power 2010 Program," targeted at demonstrating "new regulatory processes leading to a private sector decision by 2005 to order new nuclear power plants for deployment in the United States in the 2010 timeframe," three large utilities—Exelon, Entergy, and Dominion—filed early site permits for the construction of new nuclear plants in Illinois, Texas, and Virginia respectively.[121] The Energy Policy Act of 2005, as well, significantly bolstered plans for nuclear power by extending liability limits for nuclear accidents under the Price-Anderson Act for another twenty years, authorizing the construction of new DOE research reactors, and establishing hefty loan and insurance programs to make the construction of new nuclear reactors more attractive.[122] After passage between 2005 and 2007, the NRC received notice of application for at least twenty-eight new nuclear units from a plethora of utilities and energy consortia,[123] and thirty applications for new reactor units are expected to be filed by the end of 2009.[124]

In Europe, utilities operate 145 nuclear reactors throughout fifteen of the twenty-seven countries in the European Union, for a total of 131,820 MW of installed capacity which provided 31% of electricity generated in 2007.[125] "France plans to replace fifty-eight reactors with new [Generation III Pressurized Water Reactors] at a rate of 1600 MW per year."[126] Even Ukraine, the place of the worst nuclear accident in the technology's history, is planning to construct twenty-two new nuclear power plants by 2030.[127]

"In East and South Asia there are 109 nuclear power reactors in operation, [eighteen] under construction and plans to build another 110."[128] If one takes government proclamations at face value, 319 new nuclear power plants have been planned and proposed totaling 325,488 MW of

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[121] Thomas B. Cochran, Dir. of the Natural Resources Def. Council's Nuclear Program, The Future Role of Nuclear Power in the United States, Presentation to the Western Governors' Association North American Energy Summit (Apr. 15, 2004), *available at* http://www.nrdc.org/nuclear/pnucpwr.asp.

[122] Energy Policy Act of 2005, Pub. L. No. 109-58, §§ 601-57, 119 Stat. 594, 779-814 (2005).

[123] Luis E. Echávarri, *Is Nuclear Energy at a Turning Point?*, ELECTRICITY J., Nov. 2007, at 89, 90-91.

[124] Paul W. Benson & Fred Adair, *Nuclear Revolution: How to Ease the Coming Upheaval in the Nuclear Power Industry*, PUB. UTIL. FORT., July 2008, at 46.

[125] D. Haas & D.J. Hamilton, *Fuel Cycle Strategies and Plutonium Management in Europe*, 49 PROGRESS IN NUCLEAR ENERGY 574, 575 (2007).

[126] Claassen, *supra* note 15, at 3.

[127] *Why is the EBRD Tacitly Backing Ukraine's Nuke-Centric, Inefficient Energy Plans?*, BANKWATCH MAIL (CEE Bankwatch Network on International Financial Flows, Czech Republic), May 2008, at 1.

[128] Jayaraman, *supra* note 10, at 25.

capacity that would need more than 64,000 additional tons of uranium each year to operate.[129] The fastest growth in nuclear generation is expected to occur in China, India, Japan, and South Korea. China formally plans "to build [twenty-seven] 1000 MW reactors over the next [fifteen] years,"[130] and the Chinese Academy of Sciences has even embarked on an ambitious public relations campaign to make nuclear power more popular. Figure 2 illustrates this. Chinese operators already have five units under construction and fifty proposed by 2020, and they plan to quadruple nuclear capacity from 7.6 GW in 2008 to more than 40 GW by 2020.[131]

Figure 2: A Chinese "Joy-Joy Snap-Together" Toy Nuclear Reactor Being Promoted by the Chinese Academy of Sciences[132]

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[129] Andrew Symon, *Southeast Asia's Nuclear Power Thrust: Putting ASEAN's Effectiveness to the Test?*, 30 CONTEMP. SOUTHEAST ASIA 118, 123 (2008).
[130] Claassen, *supra* note 15, at 3.
[131] Jayaraman, *supra* note 10, at 35.
[132] *Id.* at 34.

India, which meets only three percent of electricity demand with nuclear power, plans a ten-fold increase, from 700 MW to 7280 MW, by 2010.[133] Japan, which currently operates fifty-five commercial light water reactors, is seeking to increase its share of nuclear electricity from about thirty percent in 2008 to forty percent over the next two decades.[134] Japanese utilities thus have two plants under construction and eleven more planned.[135] South Korea, which "currently operates sixteen reactors, has six under construction and eight more planned by 2015—implying a 100 percent increase in nuclear power generation . . . ."[136]

Even developing countries in Southeast Asia are attempting to embrace nuclear power. Under a Regional Cooperative Agreement signed in 1972, Australia, Bangladesh, China, India, Indonesia, Japan, South Korea, Malaysia, Mongolia, Myanmar, New Zealand, Pakistan, Philippines, Singapore, Sri Lanka, Thailand and Vietnam have agreed to promote "cooperative R&D and training in nuclear-related fields."[137] Thailand is planning to install four GW of nuclear capacity by 2020; Vietnam is aiming for their first nuclear plant by 2015; Malaysia has plans for their first nuclear power plant by 2020; Indonesia's four GW Mt. Muria plant will start construction in 2011 and is scheduled to become operational by 2018.[138]

In other parts of the world, thirty nuclear plants are being built in twelve countries,[139] with additional units in the planning stages for Argentina, Brazil, Czech Republic, Finland, France, Mexico, Peru, Romania, and Russia.[140]

II. A DISASTROUS DUD—THE CASE AGAINST NUCLEAR POWER

Despite all of the recent efforts to research, design, plan, construct, operate, and upgrade nuclear power plants, transitioning to an energy economy based on significant expansions in nuclear power would bring disastrous consequences. This section will document how nuclear power plants create massive external costs not subsumed by ratepayers or even present generations. Nuclear facilities rely almost entirely on government

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[133] Claassen, *supra* note 15, at 3; Rethinaraj, *supra* note 14, at 15.
[134] Rethinaraj, *supra* note 14, at 13.
[135] Jayaraman, *supra* note 10, at 28.
[136] Beller, *supra* note 93, at 52.
[137] Jayaraman, *supra* note 10, at 45-46.
[138] *See* Andrew T.H. Tan, The Security of the ASEAN Energy Supply Chain, Seminar on Sustainable Development and Energy Security 21 (Apr. 22-23, 2008) (on file with author).
[139] Claassen, *supra* note 15, at 3.
[140] Beller, *supra* note 93, at 53-54.

subsidies for construction, storage, and liability. While, historically, the costs of nuclear power plants appear to be low, in the near future the cost of building new nuclear plants will be outrageously high, and the promise of Generation IV reactors are entirely theoretical and will require billions of dollars of further R&D before the industry can construct even an *experimental* reactor.

A. Cost

Nuclear plants are grotesquely capital intensive and expensive at almost all stages of the fuel cycle, especially construction, fuel reprocessing, waste storage, decommissioning, and R&D on new nuclear technology. These exceptionally high costs are connected, in part, to the history of nuclear power itself, as neither the United States nor France—two countries largely responsible for developing nuclear power—pursued nuclear power generators for their cost effectiveness.

In the United States, the Eisenhower Administration decided to develop nuclear power plants in the 1950s for entirely political reasons, seeking to demonstrate a positive aspect of nuclear energy after World War II and instigate a technology race with the Soviet Union.[141] The federal government had to completely create demand for nuclear energy, investing more than $20 billion in R&D and severely limiting liability for electric utilities before they would even consider operating nuclear plants.[142] In France, Charles de Gaulle promoted nuclear power plants as a mechanism to reconstruct French national identity.[143] The end of World War II left France humiliated and defeated, and the country lacked infrastructure, food, and political influence. French technical and scientific experts offered solutions to these dilemmas by linking technological advancement to French radiance, or identity.[144] Nuclear technology was seen by French policymakers as a way to simultaneously rebuild French infrastructure and reestablish its role as a world leader.[145] After the creation and demonstration of the atomic bomb, "nuclear technology became a quintessential symbol of modernity and national power."[146] French policymakers desired

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[141] Hirsh & Sovacool, *supra* note 12, at 3.
[142] *Id.* at 9.
[143] GABRIELLE HECHT, THE RADIANCE OF FRANCE: NUCLEAR POWER AND NATIONAL IDENTITY AFTER WORLD WAR II 2 (1998).
[144] *Id.*
[145] *Id.*
[146] *Id.*

to promote nuclear power so much that one-fourth of household income throughout the country went to the construction of the first fifty nuclear plants.[147] In both the French and American cases, government created a market for nuclear power, rather than the other way around.

1. Construction

Nuclear power plants have long construction lead times and meet with a plethora of uncertainties during the construction process, making planning and financing difficult, especially when the balance of supply and demand for electricity can change rapidly within a short period of time. Long construction times become significant because costs mount quickly during construction delays. Halting construction of a nuclear power plant for two years, for example, adds about fifteen percent to the final cost of electricity.[148] The nuclear demonstration plant at Shippingport, Pennsylvania, for instance, was budgeted at forty-eight million dollars in the early 1950s, but ended up costing eighty-four million dollars by the time it was completed on December 2, 1957, and that *excludes* government subsidies and R&D costs.[149]

In the 1970s and 1980s excessively high forecasts of growth in demand for electricity led to overbuilding of generating plants and massive electric system cost over-runs in many states. One infamous example was in Washington State, where the Washington Public Power System ("WPPS") began a construction program for as many as seven new nuclear power plants in the early 1970s.[150] WPPS believed that regional electricity requirements "would grow by 5.2 percent each year" well into the 1990s and started building nuclear power plants to meet their projections.[151]

At the same time, the massive backlog of nuclear power plant orders after the 1973 oil crisis caused a severe shortage of skilled nuclear engineers and architects; sixty-nine plants were ordered in 1973 and 1974.[152] "[P]roblems of plant design, poor craftsmanship, and labor strikes caused

[147] Interview with Ruth Brand, Berlin Office Manager, Enercon (Jul. 28, 2008) (on file with author).
[148] Jim Giles, *When the Price is Right: Chernobyl and the Future*, 440 NATURE 984, 984 (2006).
[149] Hirsh & Sovacool, *supra* note 12, at 10.
[150] *See* Stephen Salsbury, *Facing the Collapse of the Washington Public Power Supply System*, *in* SOCIAL RESPONSES TO LARGE TECHNICAL SYSTEMS: CONTROL OR ANTICIPATION 61-97 (Todd La Porte ed., 1991).
[151] *Id.* at 69.
[152] *Id.* at 68.

even longer delays; five-year construction estimates lengthened to ten- or twelve-year periods."[153] One WPPS project started in 1970 was not finished until 1984,[154] and the WPPS annual report in 1981 projected that $23.7 billion was needed to complete one of its plants after $5 billion had already been expended,[155] all the while electricity growth dropped significantly below original projections.[156] By the mid-1980s, WPPS faced financial disaster and all but one of the plants was cancelled, leading to the country's largest municipal bond default.[157] The entire experience came to be called the "WHOOPS" fiasco, as a play on the WPPS acronym, and is an enduring lesson of the risk associated with investing in large power plants. Consumers across the Northwest are still paying for WHOOPS in their monthly electricity bills.[158]

"While WHOOPS is perhaps the most spectacular example, . . . similar 'boom and bust' cycles in nuclear power plant construction and cost-overruns occurred in many states during . . . [the 1980s], and directly produced the high electricity rates . . . [that spurred] the 'electric restructuring' movement of the mid-1990s."[159] "[B]etween 1972 and 1984, . . . more than $20 billion in construction payments flowed into 115 nuclear power plants that were subsequently abandoned by their sponsors."[160] The Shoreham Nuclear Power Plant adjacent to the Wading River in East Shoreham, New York cost ratepayers $6 billion, but was closed by protests in 1989 before the plant could generate a single kWh of electricity.[161] Indeed, an assessment recently undertaken by the Congressional Budget Office of the actual construction costs for seventy five of the existing

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[153] *Id.* at 69.
[154] *Id.*
[155] *Id.* at 61.
[156] Salsbury, *supra* note 150, at 69 (noting the significant drop in electricity growth rates).
[157] *Id.* at 73-75. As of October 2008, Jackson County Alabama was poised to default on $3.2 billion of municipal bonds. William Selway, *Alabama County to Vote on Extending Debt Forbearance With Banks*, BLOOMBERG.COM, Oct. 1, 2008, http://www.bloomberg.com/apps/news?pid=20601015&sid=acUHV8NBvV_E (last visited Oct. 31, 2008). This default would surpass the WPPSS default. ProducersWeb, Alabama County Could See Largest Municipal Bond Default, http://www.producersweb.com/r/WIRE/d/contentFocus/?adcID=7d38b2a3c99c3deed55aa6dd1f9fe863 (last visited Oct. 20, 2008).
[158] Edward Vine, Marty Kushler & Dan York, *Energy Myth Ten-Energy Efficiency Measures are Unreliable, Unpredictable, and Unenforceable*, *in* ENERGY AND AMERICAN SOCIETY—THIRTEEN MYTHS 265, 267 (Benjamin K. Sovacool & Marilyn A. Brown eds., 2007).
[159] *Id.*
[160] Ralph C. Cavanagh, *Least-Cost Planning Imperatives for Electric Utilities and Their Regulators*, 10 HARV. ENVTL. L. REV. 299, 302 (1986).
[161] *See* Samuel McCracken, *Shoreham and the Environmental Guerrillas*, NAT'L REV., June 24, 1988, at 14.

nuclear power plants in the United States documented that they exceeded anticipated costs by more than 300 percent. The quoted cost for these plants by the industry was $2312 per installed kW—totaling $89.1 billion, but the real cost was an astronomical $7294 per installed kW—exceeding $283.8 billion.[162] The estimated and actual costs of the seventy-five U.S. nuclear plants can be found in Appendix Table A. Across the border in Canada, delays and cost overruns on nuclear power plants accounted for 15 billion of the nearly 20 billion Canadian dollars of "stranded debt" created by Ontario Hydro.[163]

The risk of construction cost overruns is not relegated to the past. Modern nuclear plants are the most expensive and capital intensive structures ever built and they are the lynchpin of an industry that is already the most capital intensive in the entire U.S. economy.[164] Luis Echávarri, head of the Nuclear Energy Agency ("NEA"), reports that initial construction of a new nuclear reactor consumes close to 60% of the project's total investment, compared to about 40% for coal and 15% for natural gas power plants.[165] Even assuming the low-end of industry averages, new reactors would cost around $2000 per installed kW—meaning a 4 GW plant will cost $8 billion to build.[166] The price tag for building 190 reactors in the U.S. at this rate would exceed $380 billion.

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[162] Congressional Budget Office, Nuclear Power's Role in Generating Electricity 17 (2008), *available at* http://www.cbo.gov/ftpdocs/91xx/doc9133/05-02-Nuclear.pdf (using 1986 dollars, adjusted per note 105); Affidavit of Bruce Biewald at 29, In the Matter of Excelon Generation Co., LLC Early Site Permit for Clinton ESP Site, Atomic Safety and Licensing Board, Docket No. 52-007-ESP (Apr. 5, 2005), *available at* http://www.synapse-energy.comDownloads/SynapseTestimony.2005-04.ELPC.Environ-Impacts-and-Economic-Costs-of-Nuclear-Power-and-Alts.04-53.pdf. Biewald's 1990 dollars adjusted to 2007 dollars per note 105.

[163] MARK WINFIELD ET AL., NUCLEAR POWER IN CANADA: AN EXAMINATION OF RISKS, IMPACTS AND SUSTAINABILITY 4 (Pembina Institute ed., 2006), *available at* http://pubs.pembina.org/reports/Nuclear_web.pdf.

[164] *See* Jeffrey R. Pain, *Will Nuclear Power Pay For Itself?*, 33 SOC. SCI. J. 459, 463-64 (1996); INTERNATIONAL ENERGY AGENCY, ENERGY TECHNOLOGICAL ESSENTIALS 1 (2008), http://www.iea.org/Textbase/techno/essentials4.pdf. Historically, the capital-intensity of nuclear projects has made them very expensive. Bill Keepin & Gregory Kats, *Greenhouse Warming: Comparative Analysis of Nuclear and Efficiency Abatement Strategies*, 16 ENERGY POL'Y 538, 541 (1988). In Argentina, the 698 MW Attucha II reactor cost $6017 per installed kilowatt and the Brazilian 626 MW Angra I reactor cost $2874. *Id.* at 546. Reactor projects that were started but never finished in Egypt and Iran have cost around $4000 per installed kilowatt. *Id.*

[165] Echávarri, *supra* note 123, at 91-92.

[166] Pam Radtke Russell, *Prices Are Rising: Nuclear Cost Estimates Under Pressure*, ENERGYBIZ INSIDER, May-June 2008, at 22.

It gets worse. New evidence suggests that the estimate of $2000 per installed kW reported by the industry is extremely conservative and woefully out of date. Researchers from the Keystone Center, a nonpartisan think tank, consulted with representatives from twenty-seven nuclear power companies and contractors, and concluded in June 2007 that the cost for building new reactors would be between $3600 and $4000 per installed kW, with interest.[167] Projected operating costs for these plants would be remarkably expensive: 30¢/kWh for the first thirteen years until construction costs are paid followed by 18¢/kWh over the remaining lifetime of the plant.[168] Just a few months later, in October 2007, Moody's Investor Service projected even higher operating costs, an assessment easily explained by the quickly escalating price of metals, forgings, other materials, and labor needed to construct reactors.[169] They estimated total costs for new plants, including interest, at between $5000 and $6000 per installed kW.[170] Florida Power & Light informed the Florida Public Service Commission in December 2007 that they estimated the cost for building two new nuclear units at Turkey Point in South Florida to be $8000 per installed kW, or a shocking $24 billion.[171] Most recently, in early 2008, Progress Energy pegged its cost estimates for two new units in Florida to be about $14 billion plus an additional $3 billion for transmission and distribution ("T&D").[172]

Inflated construction costs are not limited to the United States. One survey of the real construction costs of nuclear power facilities at sixteen operational reactors in Canada, China, Japan, United Kingdom, and the United States found that many of the construction costs quoted by industry representatives, promotional bodies, plant vendors, and utilities were unreliable, inconstant, and conservative.[173] Many of these estimates excluded interest during construction and borrowing fees as well as the expense of decommissioning and fuel storage.[174] The survey concluded that the average costs for building nuclear power plants were much higher

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[167] THE KEYSTONE CENTER, NUCLEAR POWER JOINT FACT-FINDING 7, 34 (2007), *available at* http://www.keystone.org/spp/documents/FinalReport_NJFF6_12_2007(1).pdf.
[168] Russell, *supra* note 166.
[169] *Id.*
[170] *Id.*
[171] *Id.*
[172] *Id.*
[173] STEVE THOMAS, THE ECONOMICS OF NUCLEAR POWER: ANALYSIS OF RECENT STUDIES 12 (PSIRU ed., 2005), *available at* http://www.psiru.org/reports/2005-09-E-Nuclear.pdf.
[174] *Id.*

than what the industry reported, with construction costs ranging from $933 to $5600 per installed kW, with a minimum build time of 60 months—with some plants taking 80 and 120 months.[175]

A similar survey of the overnight construction costs for 9 light water reactors recently built in South Korea and Japan documented that the cost of building new plants would likely be significantly higher.[176] The study warned that constraints in the manufacturing of nuclear components, lack of skilled construction teams, and long lead times meant that a new nuclear plant would cost about $4200 per installed kW.[177] Even with a carbon tax of $30 per ton on carbon dioxide and requirements for carbon sequestration, the study concluded that new nuclear power plants would have no economic advantage over fossil fueled or renewable energy technologies.[178]

Furthermore, researchers at Georgetown University, the University of California at Berkeley, and the Lawrence Berkeley National Laboratory ("LBNL") assessed financial risks for advanced nuclear power plants utilizing a three-decade historical database of delivered costs from each of 99 conventional nuclear reactors operating in the United States.[179] Their assessment found a significant group of plants with extremely high costs: 16 percent in the more than 8¢/kWh category.[180] The study pointed out two unique attributes of advanced nuclear power plants that make them prone to unexpected increases in cost: (1) their dependence on operational learning, a feature not well suited to rapidly changing technology and market environments subject to local variability in supplies, labor, technology, public opinion, and the risks of capital cost escalation; and (2) difficulty in standardizing new nuclear units, or the idiosyncratic problems of relying on large generators whose specific site requirements do not allow for mass production.[181] Past technology development patterns suggest that many high-cost surprises will occur in the planning and deployment process for new nuclear units.[182] These "hidden" but inevitable

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[175] *Id.* at 21, 24-25 (converting £ to $ at the rate of 2.273 $/£).

[176] Jim Harding, *Economics of Nuclear Power and Proliferation Risks in a Carbon-Constrained World*, ELEC. J., Dec. 2007, at 66-68.

[177] *Id.* at 67 (converted to per 2007 dollars per note 105).

[178] *Id.* at 66.

[179] Nathan E. Hultman, Jonathan G. Koomey & Daniel M. Kammen, *What History Can Teach Us About the Future Costs of U.S. Nuclear Power*, ENVTL. SCI. & TECH., Apr. 1, 2007, at 2088-93.

[180] *Id.* at 2090.

[181] *Id.* at 2089-91.

[182] *Id.* at 2091.

cost overruns may be one reason why most investors have shied away from financing Generation IV reactors.[183]

Finally, a July 2008 survey from two energy consultants estimated that the total cost of building new nuclear units would range from $5500 per installed kW to $8100, or $6 to $9 billion for each 1,100 MW plant.[184] The explanation for such rapidly rising costs was connected to more expensive components, such as steel, copper, and concrete, and an extremely limited capacity of engineering firms with necessary experience and equipment.[185] Only two companies in the world, for instance, have the heavy forging capability to create the largest reactor components.[186] In the 1970s, more than 400 suppliers of nuclear plant components existed, but the number has dropped to eighty suppliers today.[187] The consultants also found that the construction costs quoted by industry suppliers are misleadingly incomplete because they excluded expenses related to procuring land, building cooling towers and switchyards, interest during construction, inflation, cost overruns, and contingency fees.[188] The study noted that when these excluded items are included, they can often *double* the price of a nuclear power plant.[189]

2. Reprocessing

In the early days of the nuclear era, plutonium was considered a possible "silver bullet" solution to the world's energy problems.[190] "Continuous burning, breeding and recycling" through a collection of reactors was to eliminate the need for uranium mining and enrichment and one day replace fossil fuels altogether.[191] This idea pushed two related R&D programs in the early 1950s: separation of plutonium from spent uranium oxide fuel, known as 'reprocessing,' and the development of fast reactor systems, utilizing a process known as 'breeding.'[192] When they initially

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[183] *Id.* at 2092; Healthy Environment Alliance of Utah, Nuclear Reactors in Green River?, http://healutah.org/nuclearutah/energy/greenriverreactors (last visited Oct. 20, 2008).
[184] DAVID SCHLISSEL & BRUCE BIEWALD, NUCLEAR POWER PLANT CONSTRUCTION COSTS 2 (Synapse Energy Economics ed., 2008), *available at* http://www.synapse-energy.com/Downloads/SynapsePaper.2008-07.0.Nuclear-Plant-Construction-Costs.A0022.pdf.
[185] *Id.* at 5-7.
[186] *Id.* at 6.
[187] *Id.*
[188] *Id.* at 3-4.
[189] *Id.* at 3.
[190] Haas & Hamilton, *supra* note 125, at 574.
[191] *Id.*
[192] *Id.*

designed American reactors, nuclear engineers took these views into consideration and expected that the plutonium from spent fuel would be recycled at reprocessing centers or removed and reused in fast-neutron reactors.[193]

The first option, reuse at fast-neutron reactors or fast breeders reactors, was rejected by political overseers on national security grounds.[194] Because of the link between plutonium and nuclear weapons, the potential application of fast breeders led to concern that nuclear power expansion would usher in an era of uncontrolled weapons proliferation.[195] The U.S. signed the Nuclear Non-Proliferation Treaty in 1968 partially to address the issue, but India's unexpected test of a nuclear device in 1977 took the U.S. by surprise and culminated in President Carter's non-proliferation policy which banned civilian reprocessing of nuclear fuel.[196]

The U.S. federal government did begin efforts on commercial reprocessing of nuclear waste in 1966 at a facility in West Valley, New York, but the operation ended in disaster.[197] The plant was repeatedly criticized for lax security measures and for exposing its employees to dangerously high doses of radiation, exceeding federal regulations dictated by the Occupational Safety and Health Administration, established in 1970.[198] As well, the project ran into insurmountable logistical problems. The cost of reprocessing was originally estimated to be $15 million but was later reported to be $600 million, the probability of a major earthquake in the area was deemed too great a risk to justify continued operation, and in practice the reprocessing plant was far less efficient than engineers had originally estimated.[199] After reprocessing only 640 tons of spent fuel, while accumulating more than 600,000 gallons of high-level waste, the facility was closed in 1972.[200] It was not until 2002 that the West Valley

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[193] *Id.* at 574-75.

[194] *See* Jungmin Kang, *Analysis of Nuclear Proliferation Resistance*, 47 PROGRESS IN NUCLEAR ENERGY 672, 673 (2005). Fast neutron-reactors are also called "fast-breeders" because they were designed to produce more plutonium than they consumed. World Nuclear Association, Fast Neutron Reactors, http://www.world-nuclear.org/info/inf98.html (last visited Oct. 31, 2008).

[195] Kang, *supra* note 194, at 672-73.

[196] *Id.* at 673.

[197] U.S. DEP'T OF ENERGY, PLUTONIUM RECOVERY FROM SPENT FUEL REPROCESSING BY NUCLEAR FUEL SERVICES AT WEST VALLEY, NEW YORK FROM 1966 TO 1972 1 (1996), *available at* https://www.osti.gov/opennet/document/purecov/nfsrepo.html.

[198] HARVEY WASSERMAN & NORMAN SOLOMON, KILLING OUR OWN: THE DISASTER OF AMERICA'S EXPERIENCE WITH ATOMIC RADIATION 133-134 (1982).

[199] John L. Campbell, *The State and the Nuclear Waste Crisis: An Institutional Analysis of Policy Constraints*, 34 SOC. PROBS. 18, 24 (1987).

[200] Dan Watkiss, *The Middle Ages of Our Energy Policy-Will the Renaissance be Nuclear?*,

facility was stabilized to the point that it could be safely decommissioned.[201] However, remaining cleanup was estimated in 2008 to cost an additional $5 billion and take another forty years.[202]

In other countries, such as France and the United Kingdom, reprocessing still continues.[203] Spent uranium is stored for hopeful use at a later date in fast breeder reactors, plutonium is recycled into mixed-oxide ("MOX"),[204] and the remaining fissile waste is vitrified—chemically transformed into a glass to make the waste inert.[205] This method of reprocessing, plutonium uranium extraction ("PUREX"), involves chemically separating uranium and plutonium.[206] A significant fraction of these plutonium stockpiles is intended to be used for MOX fuel fabrication at two industrial scale facilities: Areva's Melox plant in Marcoule, France and British Nuclear Group's Sellafield MOX plant in the UK.[207] These facilities blend uranium and plutonium powders at high temperatures to create MOX pellets that are then loaded into fuel assemblies.[208]

MOX reprocessing, however, suffers from five serious shortcomings. First, it produces dangerous levels of plutonium waste that can be used for weapons, meaning facilities must be guarded and nuclear fuel stored.[209] Second, the quality of recycled fuel significantly decreases the more it is reprocessed.[210] A reduction in quality occurs each time fuel is reprocessed and recycled, and as fuel quality degrades, more energy is needed to enrich fuel rods, which makes the fuel even more dangerous, due to greater emission of neutron and gamma radiation that lead to higher overall burn-up rates and drastically less efficient fuel.[211] Third, reactors cannot run on

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ELEC. LIGHT & POWER, May 2008.

[201] *Id.*

[202] *Id.*

[203] Haas & Hamilton, *supra* note 125, at 577.

[204] Frois, *supra* note 66, at 615c-17c.

[205] World Nuclear Association, Mixed Oxide (MOX) Fuel, http://www.world-nuclear.org/info/inf29.html (last visited Oct. 21, 2008).

[206] Daniel C. Rislove, *Global Warming v. Non-Proliferation: The Time Has Come For Nations to Reassert their Right to Peaceful Use of Nuclear Energy*, 24 WIS. INT'L L.J. 1069, 1089-90 (2006-2007). The prodigious amounts of plutonium produced in the process is one reason President Carter banned it. President Jimmy Carter, Presidential Directive on Nuclear Non-Proliferation Policy, PD-8 (Mar. 24, 1977), *available at* http://www.fas.org/irp/offdocs/pd/pd08.pdf.

[207] Haas & Hamilton, *supra* note 125, at 577.

[208] *Id.*

[209] *See infra* Part III.G.

[210] Haas & Hamilton, *supra* note 125, at 574.

[211] *Id.* at 578.

entirely recycled fuel. The industry standard is 30% MOX and 70% fresh uranium.[212] Plants still need significant supplies of natural uranium that must be mined from depleting stores of diminishing levels of quality ore. Fourth, reprocessing capacity is constrained. The two largest reprocessing facilities can process only 320 out of 2500 tons of waste per year combined, a mere 12.8% of the nuclear waste created in Europe each year.[213] Fifth, since plants must shutdown to load MOX fuel, reprocessing has led to loading problems as operators are reluctant to power down units that will have to be offline thirty seven days to refuel.[214]

Researchers have recently proposed a newer method of reprocessing called uranium extraction plus ("UREX+"), which keeps uranium and plutonium together in the fuel cycle to avoid separating out pure plutonium.[215] This method, however, is both unproven and absurdly expensive. The DOE estimated in 1999 that it would cost $279 billion over a 118-year period to fully implement a reprocessing and recycling program for the existing inventory of U.S. spent fuel relying on UREX+.[216] The National Academies concurred, and noted in 2008 that "[t]here is no economic justification for going forward with [a UREX+] program at anything approaching a commercial scale. . . . [UREX+] is [not] at a stage of reliability and understanding that would justify commercial-scale construction at this time. Significant technical problems remain to be solved."[217] The nonpartisan Congressional Budget Office warned that GNEP's plan to reprocess spent fuel would cost 25% more than a wide range of other storage and direct disposal options.[218] Researchers at the Commissariat à l'Energie Atomique in France looked at five Generation IV reactors and theoretical models of their associated fuel cycles from 2000 to 2150. They found that Generation IV reactors entailed much higher reprocessing and disposal

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[212] *Id.* at 577.

[213] Haas & Hamilton, *supra* note 125, at 577; PAOLO PIERINI, EUROPEAN STUDIES FOR NUCLEAR WASTE TRANSMUTATION 1, *available at* http://wwwsrf.mi.infn.it/publications/papers/2004/files/ICFA-Pierini.pdf.

[214] Nuclear Energy Institute, Fuel/Refueling Outages, http://www.nei.org/resourcesandstats/nuclear_statistics/fuelrefuelingoutages (last visited Oct. 18, 2008).

[215] Rislove, *supra* note 206, at 1090.

[216] DEP'T OF ENERGY, A ROADMAP FOR DEVELOPING ACCELERATOR TRANSMUTATION OF WASTE (ATW) TECHNOLOGY: A REPORT TO CONGRESS 7-2, 2-3 (1999), *available at* http://www.wipp.energy.gov/science/adtf/ATW.pdf.

[217] NATIONAL RESEARCH COUNCIL, REVIEW OF DOE'S NUCLEAR ENERGY RESEARCH AND DEVELOPMENT PROGRAM 5 (2008).

[218] *Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel Before the Comm. on Energy and Natural Resources*, 110th Cong. (2007) (statement of Peter R. Orszag, Director, Congressional Budget Office).

costs compared to conventional recycling and fuel disposal and estimated that the Generation IV pathway would cost 30% to 45% more than business as usual.[219]

An economic analysis of reprocessing in the United States conducted by the Congressional Budget Office reached similar conclusions. The analysis estimated that reprocessing spent nuclear fuel would cost $585 to $1300 per kilogram, an upper amount more to twice as much as direct disposal.[220] For the roughly 2200 metric tons of spent fuel produced each year in the United States, the study projected that employing reprocessing as an alternative would likely cost at least an extra $5 billion.[221]

3. Storage

The cost of temporarily and permanently storing nuclear waste is also prohibitively expensive. As of 2007, not a single country had yet completed the construction of a long-term geologic repository for nuclear waste.[222] The responsibility for permanently storing America's nuclear waste falls exclusively to the federal government, but it is clearly failing in its role. The Nuclear Waste Policy Act ("NWPA") of 1982 obligated utilities to pay a fixed annual fee—a tenth of a cent for every kWh from nuclear generation—that would be collected in a Nuclear Waste Fund to cover the costs of waste disposal.[223] In return, the federal government and DOE were required to take and dispose of spent nuclear fuel in a permanent geologic repository beginning in 1998.[224] Pursuant to the NWPA, nine states were initially identified as potential sites for long-term repositories, but, for political reasons, regulators quickly abandoned all but one of these sites: Yucca Mountain in Nevada.[225]

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[219] Aude Le Dars & Christine Loaec, *Economic Comparison of Long-Term Nuclear Fuel Cycle Management Scenarios: The Influence of the Discount Rate*, 35 ENERGY POL'Y 2995, 2999-3000 (2006).

[220] *Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel: Hearing Before the S. Comm. on Energy & Natural Resources*, 110 Cong. (2007) (statement of Peter R. Orszag, Director, Congressional Budget Office), *available at* http://www.cbo.gov/ftpdocs/88xx/doc8808/11-14-NuclearFuel.pdf.

[221] *Id.*

[222] INTERACADEMY COUNCIL, *supra* note 58, at 87.

[223] U.S. Dep't of Energy, OCRWM: Budget and Funding (Aug. 2008), http://www.ocrwm.doe.gov/about/budget/index.shtml (last visited Oct. 31, 2008).

[224] Watkiss, *supra* note 200. The fund has since collected over $27 billion, an average of $1.05 billion per year. *See* U.S. Dep't of Energy, *supra* note 223.

[225] Watkiss, *supra* note 200.

Ironically, scientists had deemed Yucca the least optimal of the nine sites. The National Academies of Science reported it had the greatest risk of releasing dangerous levels of radiation.[226] Still, because it was the only alternative, the federal government began funding a permanent storage facility at Yucca Mountain in 1985.[227] In 2008, the project had already cost $13.5 billion[228] and was some 20 years behind schedule, underfunded, and, according to Nevada Senator Harry Reid, who opposes it, "a dying beast."[229] Even if miraculously completed, Yucca would have only enough space for 70,000 tons of spent fuel, leaving 35,000 tons of radioactive waste that would require storage by 2035, assuming the existing fleet of nuclear reactors continued to operate.[230]

Worried that the government would not meet its responsibility to build a permanent storage facility, several electric utilities operating commercial nuclear reactors went before the D.C. Circuit Court in 1996 to seek a ruling on the extent of the government's obligations under the NWPA. In that case, *Indiana Michigan Power v. DOE*, the court ruled that the government had to unconditionally accept waste by January 31, 1998.[231] Without seeking a rehearing, the government "nonetheless informed utilities that it would not accept the deadline."[232] Facing growing quantities of nuclear waste and limited storage space, utilities responded and petitioned the U.S. Court of Appeals for a writ of mandamus to require the federal government to begin accepting highly radioactive spent fuel from the utilities by the following January.[233] The government refused, and by 2006, about twenty utilities had suits pending against the DOE in Federal Claims Court for damages which could total in the tens of billions of dollars.[234] By February 2008, the number of lawsuits pending against the DOE re-

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[226] *Id.*
[227] U.S. DEP'T OF ENERGY, OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT, FISCAL YEAR 2007 CIVILIAN RADIOACTIVE WASTE MANAGEMENT FEE ADEQUACY ASSESSMENT REPORT 2 (2008), *available at* http://www.ocrwm.doe.gov/about/pm/pdf/2008_Fee_Adequacy =_7-30-08.pdf.
[228] *Id.* at 2.
[229] Watkiss, *supra* note 200.
[230] Benjamin K. Sovacool, *Think Again: Nuclear Energy*, FOREIGN POLICY, (Sept. 2005).
[231] Ind. Mich. Power Co. v. Dep't of Energy, 88 F.3d 1272, 1277 (D.C. Cir. 1996); *see also* Lawrence Flint, *Shaping Nuclear Waste Policy at the Juncture of Federal and State Law*, 28 B. C. ENVTL. AFF. L. REV. 163, 164 (2000).
[232] Flint, *supra* note 231, at 164 (citing N. States Power Co. v. Dep't of Energy, 128 F.3d 754, 757 (D.C. Cir. 1997) ("delay . . . was unavoidable.") (internal citation omitted)).
[233] *N. States Power*, 128 F.3d at 755-56.
[234] MARK HOLT, CIVILIAN NUCLEAR WASTE DISPOSAL, CRS REPORT FOR CONGRESS 3 (2006).

lated to nuclear storage had jumped to sixty, with a potential total liability almost too high to predict.[235]

The DOE has relied upon on-site storage as a stop-gap remedy until Yucca Mountain is finalized or the U.S. finds a long-term solution to nuclear waste. As a result, about 30,000 tons of spent nuclear fuel are scattered in dry casks and storage pools in thirty-four states.[236] "[T]wenty-six reactors were projected to be out of pool storage space in 1998 . . .[and eighty] will reach maximum pool capacity by 2010."[237] One ton of highly radioactive waste is generated for every four pounds of usable uranium, and each reactor consumes an average 32,000 fuel rods over the course of its lifetime.[238] The costs of expanding on-site storage are, therefore, enormous, with each dry cask running about $35,000 to $65,000 per ton.[239]

When Congress requested in 2007 that the DOE study the potential for making temporary storage of high-level nuclear waste more permanent, ostensibly to demonstrate that the nation was capable of "moving forward" with some element of a nuclear waste policy, the DOE uncharacteristically demurred.[240] Stating that interim storage was "clearly not the solution," the DOE argued that the NWPA legally prevented them from taking spent fuel until after Yucca Mountain was completed.[241] Based on its interpretation of the law, though contrary to court order, the DOE refused to accept any nuclear waste. All the while, the costs of completing Yucca Mountain continue to escalate. The Congressional Budget Office noted in 2007 that they expected the construction of Yucca Mountain to take another century and exceed $57 billion.[242] Just one year later, the U.S. Department of Energy offered an updated estimate that the cost of

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[235] Watkiss, *supra* note 200.

[236] Jason Hardin, *Tipping the Scales: Why Congress and the President Should Create a Federal Interim Storage Facility for High-Level Radioactive Waste*, 19 J. LAND RESOURCES & ENVTL. L. 293, 299 (1999).

[237] *Id.*

[238] *See* Peter Diehl, Uranium Milling and Milling Wastes: An Introduction, http://www.wise-uranium.org/uwai.html (last visited Oct. 18, 2008) ("The amount of sludge produced is nearly the same as that of the ore milled."); Citizens Awareness Network, Nuclear Power: Dirty from Start to Finish, http://www.nukebusters.org/ node/205 (last visited Nov. 5, 2008) ("About 32,000 fuel rods make up the operating core of a typical medium sized nuclear reactor.").

[239] Hardin, *supra* note 236200, at 300-01.

[240] Watkiss, *supra* note 200.

[241] *Id.*

[242] *The Federal Government's Liabilities Under the Nuclear Waste Policy Act: Hearing Before the H. Comm. on the Budget*, 110 Cong. (2007) (statement of Kim Cawley, Natural and Physical Resources Cost Estimate Unit, Congressional Budget Office), *available at* http://www.cbo.gov/ftpdocs/86xx/doc8675/10-04-NuclearWaste.pdf.

building and operating Yucca Mountain would exceed $96 billion, and this staggering price tag only covers the expense of building the facility and transporting nuclear waste until 2133.[243]

Canada has seen projected times for the construction of their centralized storage facility grow even longer. The federally sponsored Nuclear Waste Management Organization reported in 2006 that it will need more than 300 years to implement its approach to "containing" spent nuclear fuel at an expense of at least 24 billion Canadian dollars.[244]

Regardless of whether the nuclear waste problem is resolved in favor of onsite or centralized storage, the costs will not be borne solely by this generation, or even by generations over the next millennium. Typically, a single nuclear plant will produce thirty tons of high-level waste each year, and this waste can be radioactive for as long as 250,000 years.[245] Assuming just one-tenth of that time (25,000 years), and assuming the cost of storing the thirty tons of nuclear waste created per year was just $35,000 per ton, the lowest end of existing estimates, each nuclear plant in the U.S. assumes an additional cost of $26.3 billion on top of its already enormous price tag.[246]

4. Decommissioning

The price of energy inputs and environmental costs of every nuclear power plant continue to increase long after the facility has finished generating its last useful kilowatt of electricity. Both nuclear reactors and uranium enrichment facilities must also be tediously decommissioned—a process that is freakishly expensive, time-consuming, dangerous for workers, and hazardous to the natural environment. "After a cooling off period that may last as long as [fifty to one hundred] years, reactors must be dismantled and cut into small pieces to be packed in containers for final disposal."[247] Nuclear plants often have an operating lifetime of forty years, but the industry reports that decommissioning takes an average of sixty years.[248] "While it will vary along with technique

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[243] Cited in *Nuclear Waste: Distant and Expensive Mirage*, ELEC. J., Aug./Sept. 2008, at 24.
[244] WINFIELD, *supra* note 163, at 3, 85.
[245] Rhodes & Beller, *supra* note 6, at 37. The half-life of Uranium-234 is 250,000 years. ALLIANCE FOR NUCLEAR ACCOUNTABILITY, WATER REPORT 246 (2004), *available at* http://www.ananuclear.org/Portals/0/documents/Water%20Report/waterreportglossary.pdf.
[246] *See* Hardin, *supra* note 236, at 300-01; Rhodes & Beller, *supra* note 6, at 37; ALLIANCE FOR NUCLEAR ACCOUNTABILITY, *supra* note 245.
[247] Sovacool, *supra* note 26, at 2943.
[248] *Id.*

and reactor type, the total energy required for decommissioning can be as much as [fifty percent] *more* than the energy needed for original construction."[249]

Indeed, every nuclear facility in operation now and every nuclear plant that will ever come online will eventually reach the end of its useful life and will begin the long and arduous task of decommissioning, or returning the facility, its parts and surrounding land to a safe enough level to be entrusted to other uses. This decommissioning process includes all of the administrative and technical actions associated with ceasing operations, removing spent or unused fuel, reprocessing or storing radioactive wastes, deconstructing and decontaminating structures and equipment, shipping contaminated equipment off-site, and remediating the land, air and water around the reactor site.[250] In most cases, the decommissioning process takes twice as long as the time the reactor is actually in use and costs anywhere from $300 million to $5.6 billion.[251]

Because decommissioning involves the dismantling and transport of substantial amounts of radioactively contaminated material, it presents new opportunities for accidents or sabotage even beyond the useful generating cycle of the facility. And because decommissioning involves a substantial shift in the normal operating procedures of the facility, it risks the introduction of unforeseen human error at every step in the process.[252]

In the United States, there are currently thirteen nuclear power plant units that have permanently shut down and are in some phase of the decommissioning process, but *not a single one* of them has completed it.[253] For example, Peach Bottom Unit 1 was shut down in October 1974,

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[249] *Id.* (emphasis added) (citing Fleming, *supra* note 47, at 7).

[250] *See* UNITED KINGDOM ATOMIC ENERGY AUTHORITY, DECOMMISSIONING FACT SHEET 2 (2005), *available at* http://www.ukaea.org.uk/downloads/misc/Decom_factsheet_Dec05.pdf.

[251] *See* Nuclearinfo.net, Cost of Nuclear Power, http://nuclearinfo.net/Nuclearpower/WebHomeCostOfNuclearPower (last visited Oct. 21, 2008).

[252] *See* NUCLEAR ENERGY AGENCY, THE REGULATORY CHALLENGES OF DECOMMISSIONING NUCLEAR REACTORS 15, 18 (2003), *available at* http://www.nea.fr/html/nsd/reports/nea4375-decommissioning.pdf. Major dismantlement may require, for example, the construction of a new, temporary control room and a dedicated, offsite electrical power supply. *Id.* at 18.

[253] *See* UNITED STATES NUCLEAR REGULATORY COMMISSION, DECOMMISSIONING NUCLEAR POWER PLANTS 4-9 (2008). As of 2008, according to the NRC the thirteen U.S. plants in the process of decommissioning are: Dresden Nuclear Power Station, Unit 1; GE VBWR (Vallecitos); Humboldt Bay Power Plant, Unit 3; Fermi 1 Power Plant; Indian Point Unit 1; LaCrosse Boiling Water Reactor; Millstone Nuclear Power Station, Unit 1; N.S. Savannah; Peach Bottom Unit 1; Rancho Seco Nuclear Generating Station; San Onofre Nuclear Generating Station, Unit 1; Three Mile Island Nuclear Station, Unit 2; Zion Nuclear Power Station, Units 1 and 2.

but will not even begin decommissioning until 2034.[254] The Humboldt Bay nuclear facility was shut down in July 1976, but will not be completely decommissioned until 2012 or 2013.[255] Zion Units 1 and 2 were permanently shut down in 1998, but the plant will not begin decommissioning until 2013.[256] Further, unless license extensions are granted, all licenses for commercial nuclear reactors in the United States will expire by 2038 and more than 100 reactors will enter the decommissioning phase, requiring billions of dollars with little or no generating capacity to offset these costs.[257]

Decommissioning at nuclear sites that have experienced an accident is far more expensive and time consuming. At Three Mile Island, Unit 2, which shutdown permanently after an accident in 1979, will not start the decommissioning process until 2014.[258] Fuel rods at Chernobyl, the site of the world's deadliest nuclear accident to date, are still being removed and operators expect it to take until at least 2038 to 2138 before the power plant is completely decommissioned.[259]

Decommissioning of uranium enrichment facilities—large complexes of buildings with thousands of pieces of equipment, enrichment cascades, piping, and electrical wiring—requires a precarious six stage and very labor-intensive process: careful characterization of every square centimeter of each building, disassembly, removal of uranium deposits from process equipment, decontamination, melt refining and recycling of metals, and treatment of wastes.[260] The process generates its own low-level radioactive and hazardous wastes and can further contaminate soil and groundwater.[261] The Capenhurst gaseous diffusion plant in the United Kingdom, decommissioned by the British Nuclear Fuels Corporation in

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[254] *Id.* at 8.
[255] *Id.* at 7.
[256] *Id.* at 9.
[257] *See* ANIBAL TABOAS, A. ALAN MOGHISSI & THOMAS S. LAGUARDIA, THE DECOMMISSIONING HANDBOOK 1-40 (2004) (displaying the number of nuclear reactors that could be shut down per year by 2035).
[258] World Nuclear Association, Decommissioning Nuclear Facilities (Dec. 2007), http://www.world-nuclear.org/info/inf19.html (last visited Oct. 31, 2008).
[259] Chernobyl: A Chronology of Disaster, REUTERS, Dec. 15, 2000, *available at* http://archives.cnn.com/2000/WORLD/europe/12/15/chernoboyl.timeline.reut/index.html.
[260] U.S. GEN. ACCOUNTING OFFICE, REPORT TO CONGRESSIONAL COMMITTEES, URANIUM ENRICHMENT: DECONTAMINATION AND DECOMMISSIONING FUND IS INSUFFICIENT TO COVER CLEANUP COSTS 1 (2004); NATIONAL RESEARCH COUNCIL, COMMITTEE ON DECONTAMINATION AND DECOMMISSIONING OF URANIUM ENRICHMENT FACILITIES, AFFORDABLE CLEANUP?: OPPORTUNITIES FOR COST REDUCTION IN THE DECONTAMINATION AND DECOMMISSIONING OF THE NATION'S URANIUM ENRICHMENT FACILITIES 49, 50 (1996).
[261] National Research Council, *supra* note 260, at 51.

1994, required the entire facility to be treated with gaseous chlorine trifluoride ("ClF_3") to remove deposits of uranium on equipment before every piece of the plant was extracted, cut up into pieces, and decontaminated using a series of aqueous chemical baths.[262]

Decommissioning of the three enrichment facilities in the United States—all of the gaseous diffusion type, with one retired facility located near Oak Ridge, Tennessee; one operating facility near Paducah, Kentucky; and another retired one near Portsmouth, Ohio—will require the same ClF_3 treatment, because deposits of highly enriched uranium have become littered throughout the process buildings.[263] This radioactive debris is accompanied by significant amounts of asbestos and polychlorinated biphenyls, which is probably why the National Research Council estimated that decommissioning the facilities will cost $27.3 to $67.2 billion, with an additional $2 to $5.8 billion to cover disposal of a large inventory of depleted uranium hexafluoride, which must be converted to uranium oxide ("U_3O_8").[264]

The U.S. GAO recently surveyed how well the decommissioning process was going at these enrichment facilities, and found that the earliest it will be completed for all three plants is 2044.[265] By then, the GAO warned that the cost of decommissioning, funded by taxpayers, will have *exceeded* the plants' revenues by at least $4 billion to $6.6 billion in 2007 dollars.[266] As of 2004, these plants, heavily contaminated with radioactive particles and large caches of spent hexafluoride fuel, still require extensive cleanup of "30 million square feet of space, miles of interconnecting pipes, and thousands of acres of land . . . ."[267] The Nuclear Decommissioning Authority in the United Kingdom has since reported similar problems with decommissioning their units, the costs of which are now estimated to be more than £73 billion.[268] One of the companies responsible for decommissioning in the United Kingdom, the state-owned British Nuclear Fuels Limited, reported £356 million of shareholder funds in 2001 but £35 billion in liabilities from decommis-

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262 *Id.* at 53-54.
263 *Id.*
264 *Id.* at 4.
265 U.S. GEN. ACCOUNTING OFFICE, *supra* note 260, at 4.
266 *Id.*; *see also* Johnston & Williamson, *supra* note 105 (using $39,796 for 2004 and $45,707 for 2007).
267 *Id.* at 1.
268 David Thorpe, *Tidal vs. Nuclear*, SCITIZEN, July 4, 2008, http://scitizen.com/stories/Climate-Change/2008/07/-Tidal-vs-Nuclear/ (last visited Oct. 22, 2008).

sioning reprocessing plants, underscoring the immensity of cleanup costs.[269]

5. Nuclear R&D

Advanced nuclear R&D is also costly and highly uncertain. The National Research Council of the National Academies issued a highly critical assessment of GNEP and the Generation IV program, arguing that its rapid deployment schedule entailed considerable financial and technical risks and prematurely narrowed the selection of acceptable reactor designs.[270] The report also faulted the DOE for not seeking sufficient independent peer reviewers for projects and for failing to adequately address waste management challenges.[271] For example, because higher temperature reactors tend to burn up more of their fuel at faster rates, they operate less efficiently than conventional units, and result in more radioactive waste per unit of energy generated.[272]

A study commissioned by the Office of Science and Innovation in the United Kingdom found that R&D on "all of the [Generation IV] systems face several key challenges" that will require considerable expense and ingenuity to overcome.[273] The report identified significant gaps in materials technology, especially in designing materials that can resist irradiation and neutron damage while operating at high temperatures and minimizing stress-corrosion cracking.[274]

Fast reactor systems will likely use fuels containing significant quantities of trans-uranium elements, necessitating a shift away from uranium assembles to ones based on nitride or carbide fuels.[275] The manufacturing processes for these fuels, however, have not yet even been established.[276]

Current modeling and simulation programs are insufficient to map the potential scenarios involving the higher actinides expected to be pro-

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[269] VACLAV SMIL, ENERGY AT THE CROSSROADS: GLOBAL PERSPECTIVES AND UNCERTAINTIES 312 (MIT Press, 2003).
[270] NATIONAL RESEARCH COUNCIL, *supra* note 217, at 54-55.
[271] *Id.* at 5-6.
[272] Steven J. Piet, et al., On-Going Comparison of Advanced Fuel Cycle Options, Presentation to Americas Nuclear Energy Symposium 9-10, (Oct. 4, 2004), *available at* http://www.osti.gov/bridge/servlets/purl/839342-4aGvCr/native/839342.pdf.
[273] ABRAM & ION, *supra* note 82, at 6.
[274] *Id.* at 6-8.
[275] *Id.* at 7.
[276] *Id.* at 6-7.

duced by Generation IV reactors.[277] The report also noted that "proliferation resistance" has only been demonstrated under laboratory conditions, and that it is unclear how Generation IV technology would be deployed at larger scales while avoiding dangerous scenarios for nuclear fuel diversion to unstable governments or extra-governmental regimes.[278] Also unknown is how fuels containing high quantities of minor actinides and possibly long-lived fission products will behave, how to design the proper shielding facilities for such substances, and whether conventional waste storage facilities can even handle these unconventional waste streams.[279]

Similarly, researchers at North Carolina State University concluded that the materials used in conventional reactors will not be suitable for Generation IV technology.[280] Zirconium alloys, for instance, are currently used as fuel cladding in light and heavy water reactors, but will not work under the higher temperature environments envisioned by Generation IV proponents.[281] Other core components made from low alloy ferric steels, such as pressure valves, will no longer suffice and pressure vessels needed to handle expected temperatures from Generation IV reactors would likely *double* the size of existing reactors.[282] The researchers noted that a lack of fast spectrum irradiation facilities and high temperature testing facilities greatly restricts the ability of scientists and engineers to even design, test, and evaluate the necessary structural materials for advanced reactors.[283] In short, the Generation IV strategy relies on inventing new materials for individual components before the reactor design itself can even be tested, and may explain why some analysts have called them "paper reactors"—technologies that have yet to be built and exist only on paper.[284]

Researchers for the European Commission agreed and stated in 2007 that an unexpected technological breakthrough must occur before Generation IV technology would become feasible, stating that they found it "inconceivable that the long-term objective of sustainable development of nuclear fission energy" could be met with existing technology.[285] Exelon, similarly, invested a 12.5% share in a Generation III+ reactor project in

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[277] *Id.* at 7-8.
[278] *Id.* at 8.
[279] ABRAM & ION, *supra* note 82, at 6-8.
[280] Murty & Charit, *supra* note 77, at 7-8.
[281] *Id.* at 2.
[282] *Id.*
[283] *Id.* at 8.
[284] *See* ROBERT POOL, BEYOND ENGINEERING: HOW SOCIETY SHAPES TECHNOLOGY 140 (1997).
[285] Haas & Hamilton, *supra* note 125, at 582.

South Africa only to bail out a few years later, citing the project's astronomical costs as the main concern.[286] Another independent international task force studying the feasibility of Generation IV reactors argued that the technical and financial risks seemed too difficult to overcome.[287]

6. Complete Reliance on Subsidies

Because of their capital intensity and financial risk, nuclear power plants are only cost competitive when they are underwritten with gargantuan public subsidies. Simply put, 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."[288] From 1947 to 1999, federal subsidies for nuclear power in the U.S. totaled "$145.4 billion (in 1999$ . . .), or more than 96 percent of cumulative Federal subsidies for wind, solar and nuclear power during this period."[289] "Even in fiscal year 1979, when subsidies for renewable energy peaked in the U.S. at $1.5 billion,"[290] the DOE devoted more than 58% of its R&D budget to nuclear power.[291] The same is true globally, as nuclear power has received more public research funding than any other source since the 1970s.[292] See Figure 3.

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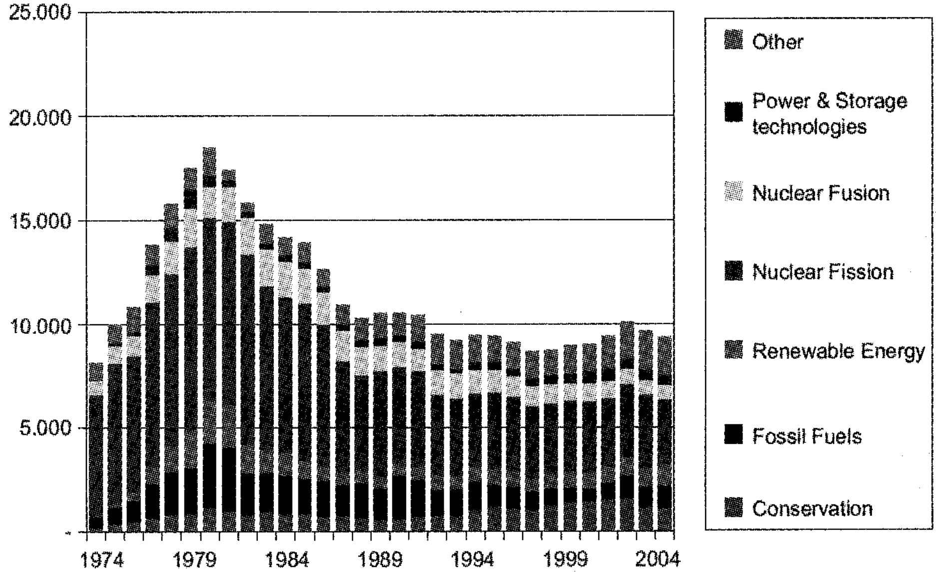
[286] Timothy J.V. Walsh, *Turning Our Backs: Kyoto's Mistaken Nuclear Exclusion*, 16 GEO. INT'L ENVTL. L. REV. 147, 166 (2003).
[287] Lori A. Burkhart, *Changing the Fuel Mix: Time for a Nuclear Rescue?*, PUB. UTIL. FORT., Sept. 2002, at 16, 19.
[288] Giles, *supra* note 148, at 986.
[289] Janet L. Sawin, The Role of Government in the Development and Diffusion of Renewable Energy Technologies: Wind Power in the United States, California, Denmark, and Germany, 1970-2000 104 (Sept. 2001) (unpublished Ph.D. dissertation, Fletcher School of Law and Diplomacy—Tufts University) (on file with the University of Queensland).
[290] Benjamin K. Sovacool, *Renewable Energy: Economically Sound, Politically Difficult*, ELECTRICITY J., June 2008, at 21.
[291] David W. Orr, *Problems, Dilemmas, and the Energy Crisis*, *in* SOCIAL AND POLITICAL PERSPECTIVES ON ENERGY POLICY 3, 7-8 (Karen M. Gentemann ed., 1981).
[292] *See* Aviel Verbruggen, *Renewable and Nuclear Power: A Common Future?*, 36 ENERGY POL'Y 4036, 4045.

Figure 3: Public R&D Funding in OECD Countries 1974 to 2004 (in millions of U.S. Dollars)[293]



Not much has changed recently. The GAO notes that in 2004, nuclear energy still received about 8% of direct R&D subsidies in the U.S. while energy efficiency and renewable energies *together* received only 6%.[294] From 1992 to 2007, nuclear power received twenty-three times the amount of subsidies spent on wind energy.[295] During 2002 to 2007, nuclear power received 54%, or $6.2 billion out of $11.5 billion, of all DOE related R&D subsidies, and the amount given to nuclear significantly increased by 59% over the same period, from $775 million in 2002 to $1.2 billion in 2007.[296] The entire class of renewable power technologies, by contrast,

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[293] *Id.*

[294] U.S. GOV'T ACCOUNTABILITY OFFICE, DEPARTMENT OF ENERGY: KEY CHALLENGES REMAIN FOR DEVELOPING AND DEPLOYING ADVANCED ENERGY TECHNOLOGIES TO MEET FUTURE NEEDS 9 (2006).

[295] Alan Nogee, Director, Clean Energy Program, Union of Concerned Scientists, Renewable Energy: Potential and Challenges, Presentation at the Spring National Committee and Task Force Meeting, The Council of State Governments 23, 24 (June 11, 2007), *available at* http://www.csg.org/pubs/Documents/Nogee-CSG.pdf.

[296] U.S. GOV'T ACCOUNTABILITY OFFICE, FEDERAL ELECTRIC SUBSIDIES: INFORMATION ON RESEARCH FUNDING, TAX EXPENDITURES, AND OTHER ACTIVITIES THAT SUPPORT ELECTRICITY PRODUCTION 2 (2007).

received a miserly 12%, or $1.4 billion.[297] The DOE's budgetary request for 2009—shockingly—intends to worsen the bias, and seeks a 44% increase in R&D funding for nuclear power while it *cuts* R&D appropriations for renewables.[298] Again, these numbers underestimate the amount awarded to nuclear power because they exclude subsidies such as limited nuclear liability provided under the Price-Anderson Act and low-cost financing given to federal power entities that operate nuclear power plants.[299]

The Energy Policy Act of 2005 only worsened the disparity by lavishing the nuclear industry with expensive new subsidies, including $13 billion worth of loan guarantees covering up to 80% of project costs; $3 billion in R&D; $2 billion of insurance against delays, amounting to, ironically, taxpayers footing the bill even for legitimate opposition to nuclear projects in their communities; $1.3 billion in tax breaks for decommissioning; an extra 1.8¢/kWh in operating subsidies for the first eight years a nuclear plant is in operation, equivalent to about $842 per installed kW; funding for licensing; compensation for project delays for the first six reactors to be developed; and limited liability for accidents, capped at $10.9 billion.[300] 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.[301] The subsidy established by the Price-Anderson Act, which practically charges taxpayers for liability insurance against nuclear accidents that could kill them, alone is possibly estimated to be worth more than twice the *entire* DOE R&D budget.[302]

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[297] *Id.* at 3.

[298] *What GAO Found*, in *Advanced Energy Technologies: Budget Trends and Challenges for DOE's Energy R&D Program: Hearing Before the Subcomm. on Energy and Environment, H. Comm. on Science and Technology*, 110th Cong. (2008) (testimony of Mark E. Gaffigan, Acting Director, Natural Resources and Environment, United States Government Accountability Office), *available at* http://www.gao.gov/new.items/d08556t.pdf.

[299] Lovins, *supra* note 7, at 4 n.7, 13 n.13. *But see* Michael G. Faure & Tom Vanden Borre, *Compensating Nuclear Damage: A Comparative Economic Analysis of the U.S. and International Liability Schemes*, 33 WM. & MARY ENVTL. L. & POL'Y REV. 219 (2008) (arguing that the U.S. nuclear industry is only subsidized by the Price-Anderson Act if the cost of domestic nuclear accident exceeds $10.76 billion).

[300] Amory B. Lovins, *Energy Myth Nine—Energy Efficiency Improvements Have Already Reached Their Potential*, *in* ENERGY AND AMERICAN SOCIETY—THIRTEEN MYTHS 239, 259-60 (2007); Watkiss, *supra* note 200.

[301] Lovins, *supra* note 300, at 260.

[302] *See* Anthony Heyes, *Determining the Price of Price-Anderson*, REGULATION, Winter 2002-2003, at 26; Climate Progress, Nuclear Pork: Enough is Enough, http://climateprogress.org/2008/05/09/nuclear-subsidies-enough-is-enough/ (last visited Nov. 6, 2008). Climate

It is no surprise, then, that a Massachusetts Institute of Technology study concluded that only by imposing a carbon tax of up to $200 per ton on conventional power plants could advanced nuclear reactors be cost competitive with existing conventional technologies.[303] Similarly, after assessing the recent spikes in construction cost, operational safety, radioactive waste disposal, and public acceptance, even economists at the pro-nuclear IAEA concluded that a global expansion of nuclear power was unlikely, and projected that it will likely lose market share by 11.6 percent by 2020.[304] And, as noted in detail below, despite enormous government subsidies, nuclear plants still suffer from a host of other insidious and inescapable challenges related to fuel availability, land use, water consumption, greenhouse gas emissions, safety, and security.

B. Fuel Availability

Accidents, severe weather, and bottlenecks can all prevent uranium from being adequately distributed to nuclear facilities in desperate need of fuel. Nuclear plants increase a country's dependence on imported uranium and subject electricity consumers to large price spikes. The cost of uranium, for instance, jumped from $7.25 per pound in 2001 to $47.25 per pound in 2006, an increase of more than 600%.[305] The NEA reports 200 metric tons of uranium are required annually for every 1000 MW reactor and that uranium fuel accounts for 15% of the lifetime costs of a nuclear plant, meaning that price spikes and volatility can cost millions of dollars.[306]

In 2000, the DOE "quietly acknowledged that domestic uranium production is currently at about 10% of its historical peak, and that most of the world's uranium reserves are becoming 'stranded,' and therefore

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Progress estimates that the benefit of Price Anderson ranges from $237 million to $3.5 billion a year. *Id.* This $3.5 billion per year mark is more than the DOE budget for R&D, which was 1.3 billion for 2007. AAAS, Research Funding Falls in 2008 Budget Despite ACI Gains; Development Hits New Highs, http://www.aaas.org/spp/ rd/prel08p.htm (last visited Nov. 6, 2008).

303 MIT, *supra* note 23, at 7.

304 Ferenc L. Toth & Hans-Holger Rogner, *Oil and Nuclear Power: Past, Present, and Future*, 28 ENERGY ECON. 1, 21 (2006).

305 *Uranium: Glowing*, THE ECONOMIST, Aug. 17 2006, at 53.

306 MIT, *supra* note 23, at 103; NEA & IAEA, Projected Costs of Generating Electricity: 2005 Update 43-45, *available at* http://www.iea.org/textbase/nppdf/free/2005/ElecCost.pdf (indicating fuel costs can be as high as 15% of total costs).

much more difficult to extract."[307] The result is that investments in new nuclear plants would only make the U.S. more dependent on foreign deposits of uranium in Africa, Russia, Canada, and Australia.[308] Admittedly, the chance that Canada and Australia will band together to become the new "OPEC of uranium" is as unlikely as it sounds, but Kazakhstan, Namibia, Niger, and Uzbekistan together were responsible for more than 30% of the world's uranium production in 2006.[309] Over the past several years these countries have suffered from autocratic rule and political instability.[310] It is not inconceivable to imagine a scenario in which unstable or hostile regimes controlling only 30% of the world's supply of uranium could nonetheless induce price spikes and volatility in uranium supplies that could have devastating consequences to the West.

The entire nuclear fuel cycle is dependent on incredibly long lead times and geographically separated facilities. The time needed to bring major uranium mining and milling projects into operation averages five or more years for exploration and discovery, with an additional eight to ten years for production.[311] Moreover, uranium conversion facilities currently only operate in Canada, France, the United Kingdom, the U.S., and

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[307] Benjamin K. Sovacool, *Coal and Nuclear Technologies: Creating a False Dichotomy for American Energy Policy*, 40 POL'Y SCI. 101, 116-17 (2007).

[308] *See* INTERNATIONAL ATOMIC ENERGY AGENCY, ANALYSIS OF URANIUM SUPPLY TO 2050 34-39 (2001), *available at* http://www-pub.iaea.org/MTCD/publications/PDF/Pub1104_scr.pdf (comparing the "reasonably assured" uranium resources and projected production capabilities by country, identifying abundant uranium resources in Canada, Australia, Russia, and several African nations).

[309] *See* World Nuclear Association, World Uranium Mining, http://www.world-nuclear.org/info/inf23.html (last visited Oct. 31, 2008) (their combined 2006 production was 14040 tonnes of the world's 39429).

[310] Kazakhstan has had one ruler since 1989. Freedom House, Nations in Transit, Country Report, Kazakhstan (2008), http://www.freedomhouse.org/template.cfm?page=47&nit=477&year=2008 (last visited Oct. 31, 2008) (noting that President Nursultan Nazarbaev has held power in country since 1989 and in 2007 "indicated his desire to become president for life after the Parliament removed a two-term limit on the first president."). Namibia is experiencing a minor civil war in the Caprivi region. *See* Lawrence S. Flint, *State-Building in Central Southern Africa: Citizenship and Subjectivity in Barotseland Caprivi*, 36 INT'L J. OF AFRICAN HIST. STUD. 393 (2003). In Niger as recently as 2006, Taureg rebels caused six months of violence. BBC News, *Country Profile: Niger*, http://news.bbc.co.uk/2/hi/africa/country_profiles/1054396.stm (last visited Oct. 23, 2008). In Uzbekistan, Islam Karimov has ruled the country since 1989. LIBRARY OF CONGRESS, FEDERAL RESEARCH DIVISION, COUNTRY PROFILE: UZBEKISTAN 2-3 (2007), *available at* http://lcweb2.loc.gov/frd/cs/profiles/Uzbekistan.pdf.

[311] *See* INTERNATIONAL ATOMIC ENERGY AGENCY, *supra* note 308, at 5.

Russia.[312] Consequently, it typically takes between five and seven years before uranium from the ground actually reaches a nuclear reactor.[313]

The IAEA classifies uranium broadly into two categories: "primary supply," including all newly mined and processed uranium, and "secondary supply," encompassing uranium from reprocessing inventories, including highly enriched uranium, enriched uranium inventories, mixed oxide fuel, reprocessed uranium, and depleted uranium tails.[314] The IAEA expected primary supply to cover 42% of demand for uranium in 2000, but acknowledges that the number will drop to between 4% and 6% of supply in 2025, as low-cost ores are expended and countries are forced to explore harder to reach and more expensive sites.[315]

But here lies a conundrum: the IAEA calculates that secondary supply can only contribute 8 to 11% of world demand.[316] "As we look to the future, presently known resources fall short of demand," the IAEA stated in 2001, and "it will become necessary to rely on very high cost conventional or unconventional resources to meet demand as the lower cost known resources are exhausted."[317]

There simply will not be enough uranium to go around, even under current demand. Interestingly, however, the IAEA refused to state this obvious conclusion. While "the agency recorded the total amount of uranium at around 3.6 gigagrams ("Gg") in 2001, the number inexplicably jumped to 4.7 Gg in 2006."[318] "The increase is due not to new discoveries or improved technologies, but simply because of a clever redefinition of what the agency counts as uranium. The IAEA included in its new estimate the category of uranium that costs [$80 to $130 per kilogram]."[319]

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312 World Nuclear Association, Uranium Enrichment, http://www.world-nuclear.org/info/inf28.html (last visited Oct. 23, 2008).

313 *See* Tim Gitzel, Executive Vice-President AREVA, Challenging or Easy? Natural Uranium Availability to Fuel a Nuclear Renaissance, Presentation at the World Nuclear Association Annual Symposium, at 11 (Sept. 9, 2005), *available at* http://www.world-nuclear.org/sym/2005/pdf/Gitzel.pdf.

314 INTERNATIONAL ATOMIC ENERGY AGENCY, *supra* note 308, at 2.

315 *Id.* at 2, 5.

316 *Id.* at 2.

317 *Id.* at 5.

318 Sovacool, *supra* note 3. The 2003 and 2005 NEA "Red Books" both report numbers which are similar to these, but not identical. *See also* NEA & IAEA, URANIUM 2003: RESOURCES, PRODUCTION & DEMAND (2003); NEA & IAEA, URANIUM 2005: RESOURCES, PRODUCTION & DEMAND (2005).

319 Sovacool, *supra* note 3; *Executive Summary*, *in* LUIS E. ECHÁVARRI & YURI SOKOLOV, URANIUM 2005: RESOURCES, PRODUCTION AND DEMAND 9 (2006).

This class comprises uranium ores of relatively low grades and of greater depths that have been so much harder to mine and would require such longer transport that the agency historically has not even counted them as usable stocks of uranium at all.[320]

Such pessimism was confirmed recently by a study on available uranium resources at ninety-three deposits and fields located in Argentina, Australia, Brazil, Canada, Central African Republic, France, Kazakhstan, Malawi, Mongolia, Namibia, Niger, Russia, South Africa, United States and Zambia.[321] The study reached a number of troubling conclusions. It documented that the ore grade of mined and milled uranium is greatly diminishing. The quality of mined uranium peaked during the nuclear weapons programs of the 1940s and 1950s, when the highest grade deposits were depleted.[322] A long-term decline in the average uranium ore grade for almost all suppliers was documented. In the United States, for example, the quality of uranium dropped from an average of 0.28 percent U_3O_8 to 0.09 percent, a decline of one-third despite improvements in technology.[323] No "world class" discoveries of uranium have occurred since the 1980s, and all increases in uranium mining and milling between 1988 and 2005 have resulted from increased drilling at known deposits.[324] The study also warned that uranium miners are having to go deeper and use more energy and water to extract uranium resources as the overall quality of ore declines, resulting in greater greenhouse gas emissions.[325]

Another October 2008 assessment reported that the world presently consumes 160 million pounds of uranium per year to fuel existing reactors, but only produces 100 million pounds.[326] The difference is largely made up from stored inventories of mined uranium, unused fuel from decommissioned plants, and diluted nuclear weapons, but these reserves are largely being exhausted.[327] As one example, the United States produced

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320 Sovacool, *supra* note 3; Wise Uranium Project, Uranium Ore Deposits, http://www.wise-uranium.org/uod.html (last visited Oct. 23, 2008).

321 Gavin M. Mudd & Mark Disendorf, *Sustainability of Uranium Mining and Milling: Toward Quantifying Resources and Eco-Efficiency*, 42 ENVTL. SCI. & TECH. 2624, 2626, 2629 (2008).

322 *Id.* at 2626.

323 *Id.* at 2629.

324 *Id.*

325 *Id.*

326 Paul Wenske, *Uranium Supply Questions: Finding Fuel for an Expanded Fleet*, ENERGY BIZ INSIDER, Sept./Oct. 2008, at 16, *available at* http://energycentral.fileburst.com/EnergyBizOnline/2008-5-sep-oct/Financial_Front_Uranium.pdf.

327 *Id.*

4.5 million pounds in 2007 but had to import 47 million pounds, or ten times as much, from other countries.[328] The assessment concluded that enough high-grade uranium ore existed to supply the needs of the current fleet for forty to fifty years, but warned that if the construction of new nuclear power plants accelerated so that all coal plants were replaced, existing resources would not last more than ten years.[329]

C. *Land and Waste Storage*

Proponents of nuclear power are fond of pointing out that one kilogram of uranium can produce 50,000 kWh of electricity, while one kilogram of coal can only produce three kWh of electricity.[330] Put another way, the energy released by one gram of uranium-235 that undergoes fission is equal to 2.5 million times the energy released in burning one gram of coal. What they don't tell you is that because nothing is burned or oxidized during the fission process, nuclear plants convert almost all their fuel to waste with little reduction in mass.

Both commercial fuel cycles are very wasteful. In the open fuel cycle, used predominately by the U.S., Sweden, and Finland,[331] fuel is burned in reactors and not reused, meaning that about 95% of it is wasted.[332] In the closed fuel cycle, utilized by Belgium, France, Germany, the Netherlands, Spain, and the United Kingdom,[333] plutonium is extracted from spent fuel, recycled, and reprocessed, but 94% of the fuel is still wasted.[334] Since about 85% of global reactors operate on the open fuel cycle, about 10,000 tons of heavy metal spent nuclear fuel are discharged every year from nuclear power plants.[335] Nuclear power plants thus have at least five waste streams that contaminate and degrade land:

1. They create spent nuclear fuel at the reactor site;
2. They produce tailings and uranium mines and mills;
3. They routinely release small amounts of radioactive isotopes during operation;

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[328] *Id.*
[329] *Id.* at 17.
[330] Jayaraman, *supra* note 10, at 6.
[331] Haas & Hamilton, *supra* note 125, at 576; *Costs of Reprocessing Versus Directly Disposing of Spent Nuclear Fuel*, *supra* note 218.
[332] Rethinaraj, *supra* note 14, at 11.
[333] Haas & Hamilton, *supra* note 125, at 576.
[334] Rethinaraj, *supra* note 14, at 11.
[335] *Id.* at 17.

4. They can catastrophically release large quantities of pollution during accidents; and
5. They create plutonium waste.[336]

Even reprocessing creates waste. France, for example, which reprocesses spent fuel to separate fissile material (pure waste) from usable plutonium, has contributed to about 1710 cubic meters of high level waste globally, a number that is expected to jump to 3600 cubic meters by 2020.[337]

Each 1000 MW reactor, regardless of its fuel cycle, has about fifteen billion curies of radioactivity,[338] equivalent to the total amount of natural radiation found in all of the oceans.[339] High level nuclear waste will take at least 10,000 years before it will reach levels of radiation considered safe for human exposure.[340] See Figure 4.

Even if it is perfected, future Generation IV technology will not solve the problem of radioactive waste. The radiotoxicity for the most hazardous forms of spent nuclear fuel is at least 100,000 years.[341] Partitioning and transmutation are considered theoretical ways of reducing the waste, but even if technically mastered through some sort of breakthrough, their potential is severely limited.[342] Nuclear engineers at the CEA in France have warned that radiotoxicity can only be reduced by a factor of ten if all plutonium is recycled, and by a factor of 100 if all minor actinides are burned.[343] This means, at a minimum, that spent fuel will remain dangerously radioactive for at least 1000 to 10,000 years. That is ten centuries, presuming a best case scenario. Also, the technologies needed to attain this level of waste reduction, either fast reactors or Accelerator Driven Systems, will require technological breakthroughs in separating actinides,

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[336] FLEMING, *supra* note 47, at 4, 6-7.

[337] Jean-Marie Gras et al., *Perspectives on the Closed Fuel Cycle—Implications for High-Level Waste Matrices*, 362 J. NUCLEAR MATERIALS 383, 385 (2007).

[338] *Radioactive Wreck: The Unfolding Disasters of U.S. Irradiated Nuclear Fuel Policies*, NUCLEAR MONITOR 643, Mar. 17, 2006, at 2, *available at* http://www.nirs.org/mononline/nm643.pdf.

[339] T.S. Gopi Rethinaraj, Address at the Lee Kuan Yew School of Public Policy, National University of Singapore: Nuclear Safety Issues Review 11 (Apr. 22, 2008) (on file with author).

[340] *See* Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada, 73 Fed. Reg. 61256, 61256 (Oct. 15, 2008).

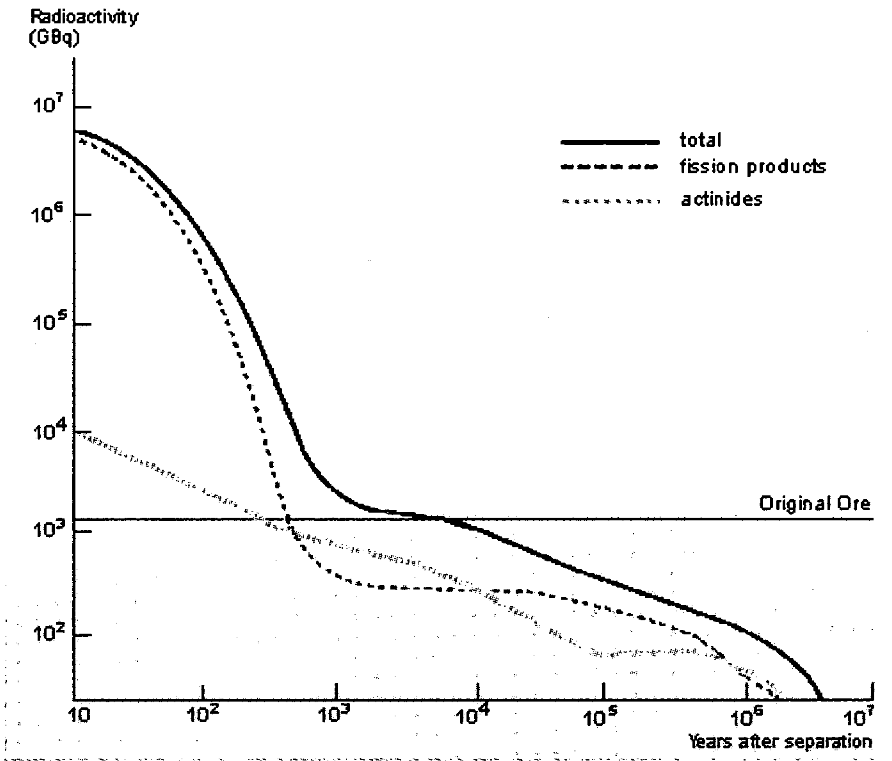
[341] *See* Public Health and Environmental Radiation Protection, 73 Fed. Reg. at 61256.

[342] *See* Massimo Salvatores, *Nuclear Fuel Cycle Strategies Including Partitioning and Transmutation*, 235 NUCLEAR ENGINEERING & DESIGN 805, 812 (2005).

[343] *Id.* at 806.

reprocessing advanced fuels, and coupling transmutation technologies to existing reactors.[344] As one study concluded, no single country has successfully deployed Partitioning and Transmutation technologies, and no attempt has been made to pursue serious regional or international cooperation on these efforts.[345]

Figure 4: Decay in Radioactivity of High-Level Nuclear Waste (from Reprocessing One Ton of Spent Pressurized Water Reactor Fuel)[346]



The straight line shows the radioactivity of the corresponding amount of uranium ore.

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344 *Id.* at 810-12.
345 *Id.* at 812.
346 Rethinaraj, *supra* note 339, at 11.

The issue of nuclear waste could be why physicist Alvin M. Weinberg compared nuclear power to a "Faustian bargain," since it creates an unbreakable commitment where society receives electricity only in exchange for yielding political power to a small cadre of technocrats and national security agencies.[347] "Unlike Faust, however, who was ultimately able to renege on the bargain, society . . .[has bonded] itself in perpetuity . . .[to] the remarkable belief that it can devise social institutions that are stable for periods equivalent to geologic ages," exhibiting supreme confidence in the ability of human organizations to outlast radioactive waste.[348] Nuclear waste will remain dangerously radioactive for hundreds of thousands of years—longer than our civilization has practiced Catholicism, or cultivated agriculture.[349] "The half-life of uranium-238, one of the largest . . . [components of spent fuel], is about the same as the age of the earth: 4.5 billion years."[350]

D. *Water*

With electricity demand expected to grow by approximately fifty percent in the next twenty-five years, continuing to rely on nuclear generators could create a water scarcity crisis. In 2006, the DOE warned that consumption of water for electricity production could more than double by 2030 to 7.3 billion gallons per day in the U.S., if new power plants continue to be built with evaporative cooling.[351] This amount is equal to the entire country's water consumption in 1995.[352]

The nuclear industry's vast appetite for water has serious consequences, both for human consumption and the environment. Assuming the latest Census Bureau projections, the U.S. population is expected to grow by about seventy million people in the next twenty-five years.[353] Such population growth is already threatening to overwhelm existing supplies of

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[347] Alvin M. Weinberg, *Social Institutions and Nuclear Energy*, *in* ENERGY AND THE WAY WE LIVE 305, 311-12 (1980).
[348] Orr, *supra* note 291, at 8.
[349] *Farming Origins Gain 10,000 Years*, BBC News, June 23, 2004, http://news.bbc.co.uk/2/hi/science/nature/3826731.stm (last visited Oct. 31, 2008).
[350] FLEMING, *supra* note 47, at 2.
[351] U.S. DEP'T OF ENERGY, ENERGY DEMANDS ON WATER RESOURCES: REPORT TO CONGRESS ON THE INTERDEPEDENCY OF ENERGY AND WATER 10-11 (2006).
[352] *Id.* at 11.
[353] *See* U.S. CENSUS BUREAU, INTERIM PROJECTIONS OF THE TOTAL POPULATION FOR THE UNITED STATES AND STATES: APRIL 1, 2000 TO JULY 1, 2030 (2005), *available at* http://www.census.gov/population/projections/SummaryTabA1.pdf.

fresh and potable water. "Few new reservoirs have been built since 1980 . . .[and] some regions have seen groundwater levels drop as much as 300 to 900 feet over the past fifty years."[354] Further, "most state water managers expect either local or regional water shortages within the next 10 years," according to a recent survey, even under "normal" conditions.[355] In fact, about forty-eight percent of the continental U.S. reported drought conditions during the summer of 2002.[356]

Three stages of the nuclear fuel cycle—uranium milling and mining, plant operation, and nuclear waste storage—consume, withdraw, and contaminate water supplies. As a result of this vast need for water, most nuclear facilities cannot operate during droughts[357] and in some cases can actually cause water shortages.[358]

1. Uranium Mining and Leeching

Uranium mining, the process of extracting uranium ore from the ground, is extremely water intensive. Since the necessary concentrations of uranium are mostly prevalent at very low concentrations, uranium mining is volume intensive. The problem is that such mining practices can greatly damage and degrade local water supplies. Early mining techniques were very similar to other hard rock mining such as copper, gold, and silver, and involved the creation of underground mines. Open-pit mining, the most prevalent type of uranium extraction in the world today, ceased in the U.S. in 1992 due to concerns about environmental contamination and the quality of uranium, as most ore found in the U.S. was lower grade uranium from sandstone deposits.[359] Currently, uranium miners use only one type of technique to extract uranium ore in Wyoming, Nebraska, and Texas: in-situ leaching.[360]

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[354] U.S. DEP'T OF ENERGY, *supra* note 351, at 10.
[355] *Id.*
[356] U.S. DEP'T OF COM., NAT'L CLIMACTIC DATA CTR., U.S. NATIONAL DROUGHT OVERVIEW: CLIMATE OF 2002-AUGUST (2002), http://www.ncdc.noaa.gov/oa/climate/research/2002/aug/drought-national-overview.html (last visited Oct. 31, 2008).
[357] Mitch Weiss, *Drought Could Force Nuke-Plant Shutdowns*, ASSOCIATED PRESS, Jan. 24, 2008.
[358] *Id.* (plants "rely on submerged intake pipes to draw billions of gallons of water . . .").
[359] *See* U.S. ENVTL. PROT. AGENCY, OFFICE OF RADIATION AND INDOOR AIR RADIATION PROT. DIV., TECHNICAL REPORT ON TECHNOLOGICALLY ENHANCED NATURALLY OCCURRING RADIOACTIVE MATERIALS FROM URANIUM MINING ES-1, 1-8, 3-5 to -9, 5-1 (2006), *available at* http://www.epa.gov/radiation/docs/tenorm/402-r-08-005-voli/402-r-08-005-v1.pdf.
[360] World Nuclear Association, In Situ Leach (ISL) Mining of Uranium (Mar. 2008), http://www.world-nuclear.org/info/inf27.html (last visited Oct. 31, 2008).

Uranium miners perform in-situ leaching by pumping liquids into the area surrounding uranium deposits. These liquids often include acid or alkaline solutions to weaken the calcium or sandstone surrounding uranium ore.[361] Operators then pump the uranium up into recovery wells at the surface, where it is collected.[362] In-situ leaching was deemed more cost effective than underground mining because it avoids the significant expense of excavating underground sites and often takes less time to implement.[363]

In 2005, nuclear power plants produced an annual output of 781,986 MWh requiring more than thirty million gallons of water per day for uranium mining and processing around the world.[364] Even though the bulk of these mining and processing facilities are outside of the U.S., the DOE estimates that three to five million gallons of water per day are still associated with mining and processing of uranium within the country.[365]

2. Plant Operation

Nuclear reactors also require massive supplies of water to cool reactor cores and spent nuclear fuel rods, and they use the most water compared to all other electricity generating facilities, including conventional coal and natural gas facilities.[366]

Because much of the water used by nuclear plants is turned to steam, substantial amounts are lost to the local water cycle entirely. One nuclear plant in Georgia, for example, "withdraws an average of 57 million gallons every day from the Altamaha River . . .[but actually] 'consumes' 33 million gallons per day [from the local supply,] that is lost as water

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361 *Id.*

362 *Id.*

363 U.S. ENVTL. PROT. AGENCY, *supra* note 359, at 5-2.

364 U.S. DEP'T OF ENERGY, ENERGY INFO. ADMIN., NET GENERATION BY ENERGY PRODUCER 1995 THROUGH 2006 16 (2007), *available at* http://www.eia.doe.gov/cneaf/electricity/epa/epat1p1.html; *see* U.S. DEP'T OF ENERGY, *supra* note 351, at 38 (estimating consumption of 45-150 gallons of water per MWh energy produced, when used in nuclear mining and processing).

365 U.S. DEP'T OF ENERGY, *supra* note 351, at 23.

366 ELEC. POWER RESEARCH INST., WATER & SUSTAINABILITY (VOLUME 3): U.S. WATER CONSUMPTION FOR POWER PRODUCTION—THE NEXT HALF CENTURY 3-1 to -2 (2002), *available at* http://www.epriweb.com/public/000000000001006786.pdf. It is estimated about 25,000 to 60,000 gallons of water for every MWh generated is required to cool nuclear generating facilities. *Id.* at 3-2.

vapor"[367]—enough to service more than 179,000 Georgia homes.[368] The Shearon Harris nuclear reactor, operated by Progress Energy in New Hill, North Carolina, near Raleigh, sucks up thirty-three million gallons a day, and loses seventeen million gallons per day due to evaporation.[369] Duke Energy's McGuire Plant on Lake Norman, North Carolina, uses more than two billion gallons of water per day.[370] Southern Company's Joseph M. Farley nuclear plant in Dothan, Alabama, consumes about forty-six million gallons of water per day, primarily as evaporative loss.[371]

In the arid West, where water is scarce, the challenge of cooling nuclear plants is even more daunting. At the Palo Verde plant in Arizona, ninety million gallons of water must be brought to the plant site each day.[372] Plant operators must purchase treated effluent from seven cities in the Phoenix metropolitan area, and have had to construct a thirty-five mile pipeline to carry water from a treatment facility to the plant—which uses about twenty billion gallons of water every year.[373]

Nuclear plants do not just use water—they also contaminate it at multiple points of the cooling cycle: at the point of intake, at the point of discharge, and during unexpected accidents.

At the point of intake, nuclear plants bring water into the cooling cycle through filtering structures. To minimize the entry of debris, water is often drawn through screens.[374] Seals, sea lions, endangered manatees, American crocodiles, sea turtles, fish, larvae, shellfish, and other riparian

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[367] SARA BARCZAK & RITA KILPATRICK, ENERGY IMPACTS ON GEORGIA'S WATER RESOURCES 1 (2003), *available at* http://www.cleanenergy.org/pdf/GAwaterreport.pdf.

[368] American Water Works Association calculated that "[d]aily indoor per capita water use in the typical single family home is 69.3 gallons." American Water Works Association, Water Use Statistics, http://www.drinktap.org/consumerdnn/Default.aspx?tabid=85 (last visited Oct. 25, 2008). Assume the Georgia average household size is 2.65 persons. U.S. CENSUS BUREAU, GEORGIA: 2000 2 (2002), *available at* http://www.census.gov/prod/2002 pubs/c2kprof00-ga.pdf. Therefore, the following equation: 33,000,000 / 69.3 / 2.65 ≈ 179695.

[369] Weiss, *supra* note 357.

[370] *Id.*

[371] Press Release, S. Alliance for Clean Energy, Energy Group Urges Planning for Droughts: Avoid Nuclear and Coal Water Hogs (Oct. 25, 2007), *available at* http://www.cleanenergy .org/mediaroom/index.cfm?pressID=177&sortorder=pressdate&flow=1.

[372] PINNACLE WEST CAPITAL CORPORATION, 2006 RESPONSIBILITY REPORT: WATER MANAGEMENT (2006), http://www.pinnaclewest.com/main/pnw/AboutUs/commitments/ ehs/2006/ehs/water/default.html (last visited Oct. 31, 2008).

[373] *Id.*

[374] CLEAN AIR TASK FORCE & THE LAND AND WATER FUND OF THE ROCKIES, THE LAST STRAW: WATER USE BY POWER PLANTS IN THE ARID WEST 8 (2003), *available at* http://www.catf.us/ publications/reports/The_Last_Straw.pdf.

or marine organisms are frequently killed as they are trapped against the screens in a process known as impingement.[375] Organisms small enough to pass through the screens can be swept up in the water flow where they are subject to mechanical, thermal and toxic stress in a process known as entrainment.[376] Billions of smaller marine organisms, essential to the food web, are sucked into nuclear reactor systems and destroyed. Smaller fish, fish larvae, spawn, and a tremendous volume of other marine organisms are frequently pulverized by reactor condenser systems. One study estimated that more than 90% are scalded and discharged back into the water as lifeless sediment that clouds the water around the discharge area, blocking light from reaching the ocean or river floor, which further kills plant and animal life by curtailing photosynthesis and the production of oxygen.[377]

During periods of low water levels, power plants induce even more environmental damage. Nuclear plants must extend intake pipes further into rivers and lakes, but as they approach the bottom of the water source, "they [often] suck up sediment, fish, and other debris . . . ."[378] Impingement and entrainment consequently account for substantial losses of fish and exact severe environmental consequences during the riparian environment's most vulnerable times.

For example, federal environmental studies of entrainment during the 1980s at five power plants on the Hudson River in New York estimated grave year-class reductions in fish populations—the percent of fish killed within a given age class.[379] One study concluded that the power plants were responsible for age reductions as high as 79% for some species.[380] "An updated analysis [of entrainment] completed in 2000 at three of

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[375] LINDA GUNTER ET AL., LICENSED TO KILL: HOW THE NUCLEAR POWER INDUSTRY DESTROYS ENDANGERED MARINE WILDLIFE AND OCEAN HABITAT TO SAVE MONEY 7-9 (2001), *available at* http://www.beyondnuclear.org/files/beyondnuclear/Licensed%20to%20Kill%20full%20report.pdf.

[376] CLEAN AIR TASK FORCE & THE LAND AND WATER FUND OF THE ROCKIES, *supra* note 374, at 8.

[377] GUNTER, *supra* note 375, at 6.

[378] Weiss, *supra* note 357.

[379] L.W. Barnthouse et al., *Population Biology in the Courtroom: The Hudson River Controversy*, 34 BIOSCIENCE 14, 18 (1984).

[380] National Pollutant Discharge Elimination System-Proposed Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities, 67 Fed. Reg. 17122, 17138 (Apr. 9, 2002) (citing J. Boreman & C.P. Goodyear, *Estimates of Entrainment Mortality for Striped Bass and Other Fish Species Inhabiting the Hudson River Estuary*, *in* SCIENCE LAW AND HUDSON RIVER POWER PLANTS (Lawrence W. Barnthouse et al. eds., 1988)).

these plants estimated year-class reductions of 20 percent for striped bass, 25 percent for bay anchovy, and 43 percent for Atlantic tom cod . . . ."[381] Another study "evaluated entrainment and impingement impacts at nine . . . facilities along a 500 mile stretch of the Ohio River."[382] The authors estimated that approximately 11.6 million fish were killed annually through impingement and 24.4 million fish from entrainment.[383] The study calculated recreational related losses at about $8.1 million per year.[384]

The U.S. Environmental Protection Agency ("EPA") calculated impingement losses at the Delaware Estuary Watershed at more than 9.6 million age-one equivalents of fish *every* year, or a loss of 332,000 pounds of fishery yield.[385] The EPA calculated that entrainment related losses were even larger at 616 million fish, or a loss of sixteen million pounds of catch.[386] Put into monetary value, the recreational fishing loss from impingement and entrainment at nuclear facilities was estimated to be about $5 million per year.[387]

Scientists also calculated that the cooling intake systems at the Crystal River Power Plant in Florida, a joint nuclear and coal facility, kill about twenty-three tons of fish and shellfish every year.[388] Top predators, such as gulf flounder and stingray "have either disappeared or changed their feeding patterns."[389] In other parts of Florida, the economic losses induced from four power plants—Big Bend, PL Bartow, FJ Gannon, and Hookers Point—are estimated to be as high as $18.1 million.[390]

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381 *Id.*
382 *Id.* at 17139.
383 *Id.* at 17195.
384 *Id.* at 17195.
385 U.S. ENVTL. PROT. AGENCY, CASE STUDY ANALYSIS FOR THE PROPOSED SECTION 316(B) PHASE II EXISTING FACILITIES RULE B7-1 (2002), *available at* http://www.epa.gov/water science/ 316b/phase2/casestudy/chb7.pdf.
386 *Id.*
387 *Id.*
388 RIVERKEEPER, INC. ET AL., COMMENTS ON EPA'S PROPOSED REGULATION FOR COOLING WATER INTAKE STRUCTURES AT NEW FACILITIES UNDER SECTION 316(B) OF THE CLEAN WATER ACT 5 (2000), *available at* http://db1.spiderline.com/exec/redir?d=100214/aHR0cDovL3d3dy5yaXZlcmtlZXBlci5vcmcvZG9jdW1lbnQucGhwLzExOC9SaXZlcmtlZXBlcnNfQ28uZG9j.
389 ELLEN BAUM, CLEAN AIR TASK FORCE, WOUNDED WATERS: THE HIDDEN SIDE OF POWER PLANT POLLUTION 6 (2004), *available at* http://www.catf.us/publications/reports/Wounded_Waters.pdf.
390 *Id.*

Similarly, in Southern California, marine biologists and ecologists found "that the San Onofre nuclear plant impinged nearly 3.5 million fish in 2003 . . . ."[391]

As a less noticed but equally important impact, water intake and discharge often alter natural patterns of water levels and flows. Such flows, part of the hydrological cycle, have a natural variability that differs daily, weekly, and seasonally.[392] Plants and animals have adapted to these fluctuations, and such variability is a key component of ecosystem health.[393] Withdrawals and discharges alter this natural cycle by removing water during drought conditions or discharging it at different times of the year with potentially serious, albeit not well-understood, consequences to ecosystem and habitat health.[394]

Interestingly, in some cases the environment has fought back, literally. "In September 1984, a flotilla of jellyfish 'attacked' the St. Lucie nuclear plant in Florida, forcing both of its reactors to shut down for several days due to lack of cooling water."[395]

At the point of discharge, nuclear plant operators often treat cooling water with chlorine, anti-fouling, anti-microbial, and water conditioning agents "to limit the growth of mineral and microbial deposits that reduce . . . [its] heat transfer efficiency,"[396] while "re-circulating water is treated with chlorine and biocides" to improve efficiency and eliminate nuisance organisms.[397] What makes such treated water so effective in killing unwanted species, however, also makes it a potent "kill[er of] non-target organisms as well."[398] Chlorine, biocides, and "their byproducts . . . present in discharged water plumes . . . [are often] toxic to aquatic life even at low concentrations."[399] In addition, discharged cooling water is usually higher in temperature than intake waters, "making electric utilities the largest thermal discharger in the U.S."[400] Significant temperature differences between the intake water and its discharge, or temperature deltas, "can contribute to destruction of vegetation, increased algae growth,

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[391] DAVID LOCHBAUM, UNION OF CONCERNED SCIENTISTS, GOT WATER? 12 (2007), *available at* http://www.ucsusa.org/assets/documents/nuclear_power/20071204-ucsbrief-gotwater.pdf.

[392] SANDRA POSTEL & BRIAN RICHTER, RIVERS FOR LIFE: MANAGING WATER FOR PEOPLE AND NATURE 43 (2003).

[393] *Id.* at 50.

[394] *Id.*

[395] LOCHBAUM, *supra* note 391, at 5.

[396] BAUM, *supra* note 389, at 8.

[397] *Id.*

[398] *Id.*

[399] *Id.*

[400] *Id.* at 6.

oxygen depletion and strain the temperature range tolerance of organisms."[401] Further, "[i]mpacts can be multiple and widespread, affecting numerous species at numerous life cycle stages."[402]

"In some cases, plants and animals are not able to survive in or adapt to higher temperature waters . . . ."[403] In other cases, "warmer temperatures can send the wrong signals to species," disrupting natural cycles, while some species that thrive in warmer waters "move into the plume and then become susceptible to the 'cold shocks' that occur during periodic plant shutdowns."[404] In still other cases, the warmer temperature plumes attract invasive or unwanted species that drive out indigenous species and alter habitats, sometimes irreparably.[405] Both spikes of high temperature and the persistent, increasing stress of fluctuations in temperature affect aquatic organisms.[406] The problem is especially acute in "shallower waters that turn over more slowly [and therefore] have a harder time absorbing thermal impact[s]."[407]

In some cases, the thermal pollution from nuclear plants can induce eutrophication—a process where the warmer temperature alters the chemical composition of the water, resulting in a rapid increase of nutrients such as nitrogen and phosphorous.[408] Rather than improving the ecosystem, such alterations usually cause "algal blooms, surface scums, floating plant mats" and other weedy growths that severely reduce water quality.[409] In riparian environments, the enhanced growth of such choking algae and vegetation can collapse entire ecosystems.[410] "This form of thermal pollution has been known to decrease the aesthetic and recreational value of rivers, lakes, and estuaries and complicate drinking water treatment."[411]

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[401] *Id.*
[402] BAUM, *supra* note 348, at 6.
[403] *Id.*
[404] *Id.*
[405] *See* T.E.L. LANGFORD, ECOLOGICAL EFFECTS OF THERMAL DISCHARGES 299-308 (1990) (detailing the significant changes in fish diet during warmer temperature plumes as a result of the availability of variable food species).
[406] BAUM, *supra* note 389, at 6.
[407] *Id.* at 7.
[408] WORLD HEALTH ORGANIZATION, TOXIC CYANOBACTERIA IN WATER: A GUIDE TO THEIR PUBLIC HEALTH CONSEQUENCES, MONITORING AND MANAGEMENT 13 (Ingrid Chorus & Jamie Bartram eds., 2003), *available at* http://www.who.int/water_sanitation_health/resourcesquality/toxcyanobacteria.pdf.
[409] *Id.*
[410] *Id.* at 100-02.
[411] CHRISTOPHER COOPER & BENJAMIN K. SOVACOOL, RENEWING AMERICA: THE CASE FOR FEDERAL LEADERSHIP ON A NATIONAL RENEWABLE PORTFOLIO STANDARD (RPS) 100 (2007),

3. Nuclear Waste Storage

At reactor sites, even when not generating a single kWh of electricity, nuclear plants must use water continuously—often about ten percent of the water needed for normal operation—to cool spent nuclear fuel rods.[412] Even after the complete shutdown of a nuclear reactor, it continues to produce residual heat of 2250 MWh and takes days to decay significantly.[413] Nuclear plants need water "to remove the decay heat produced by the reactor core and also to cool the equipment and buildings used to provide the core's heat removal."[414] Service water must lubricate oil coolers for the main turbine and chillers for air conditioning, in essence cooling the equipment that in turn cools the reactor.[415] Even when plants are not producing electricity, service water needs can be quite high: 52,000 gallons of water are needed *per minute* in the summer to merely service the Hope Creek plant in New Jersey; 30,000 gallons per minute for the Milestone Unit 2 in Connecticut; and 13,500 gallons per minute for the Pilgrim plant in Massachusetts.[416]

Nuclear power generation also creates wastewater contaminated with radioactive tritium and other toxic substances that can leak into nearby groundwater sources. In December 2005, for example, Exelon Corporation reported to authorities that its Braidwood reactor in Illinois had since 1996 released millions of gallons of tritium-contaminated waste water into the local watershed, prompting the company to distribute bottled water to surrounding communities while local drinking water wells were tested for the pollutant.[417] When caught for their mistake, rather than admit responsibility, Exelon ran a sleek advertising campaign to convince citizens of Illinois that the tritium exposure was natural and could

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available at http://www.newenergychoices.org/dev/uploads/RPS%20Report_Cooper_Sovacool _FINAL_HILL.pdf (citing WORLD HEALTH ORGANIZATION, *supra* note 408, at 13-16).

[412] S. Alliance for Clean Energy, *supra* note 371.

[413] Tammy L. Stoops, An Investigation of How Powerful a Nuclear Reactor Can Be 15, 55 (May 10, 1996) (unpublished B.S. & M.Sc. thesis, Massachusetts Institute of Technology) (on file with MIT libraries), *available at* http://dspace.mit.edu/bitstream/handle/1721.1/38818/35823450.pdf;jsessionid=FE91A95068B96E1B624020781709EB70?sequence=1.

[414] LOCHBAUM, *supra* note 391, at 1.

[415] *Id.* at 8.

[416] *Id.*

[417] *Illinois Sues Exelon for Radioactive Tritium Releases Since 1996*, ENV'T NEWS SERVICE, Mar. 21, 2006, http://www.ens-newswire.com/ens/mar2006/2006-03-21-02.asp (last visited Oct. 31, 2008) [hereinafter *Illinois Sues Exelon*].

be found in all water sources.[418] The incident led to a lawsuit by the Illinois Attorney General and the State Attorney for Will County who claimed that "Exelon was well aware that tritium increases the risk of cancer, miscarriages and birth defects and yet they made a conscious decision not to notify the public of their risk of exposure."[419]

Similarly, in New York, Entergy's Indian Point Nuclear Plant, on the Hudson River, emptied thousands of gallons of radioactive waste into underground lakes from 1974 to 2005.[420] The NRC accused Entergy of not properly maintaining two spent fuel pools that leaked tritium and strontium-90, cancer-causing radioactive isotopes, into underground watersheds, with as much as fifty gallons of radioactive waste seeping into water sources per day.[421]

Nuclear wastewater ponds and lagoons that do not leak can still cause serious environmental damage to migrating birds.[422] Ecologists and biologists have documented advanced morbidity and mortality among bird populations exposed to excessive levels of sodium, selenium, and avian botulism resulting from ingesting contaminated water at these sites.[423]

E. Lifecycle Emissions of Pollutants

From a climate-change standpoint, nuclear power is not much of an improvement over conventional coal-burning power plants, despite

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418 Press Release, Exelon, Update: Tritium Reduction efforts Net Positive Results (Jan. 29, 2008), *available at* http://www.trans2.motionpoint.net/exelon/enes/24/_www_exeloncorp_com/aboutus/news/pressrelease/powergen/pr+2008+01+29.htm. The utility noted that

> Tritium is an isotope of hydrogen that produces a weak level of radiation. It is produced naturally in the upper atmosphere when cosmic rays strike atmospheric gases and is produced in larger quantities as a by-product of the nuclear energy industry. When combined with oxygen, tritium has the same chemical properties as water. Tritium can be found at very low levels in nearly all water sources.

Id.

419 *Illinois Sues Exelon, supra* note 417.

420 Abby Luby, *Leaks at Indian Point Created Underwater Lakes*, NORTH COUNTY NEWS, Feb. 28, 2008, *available at* http://www.abbylu.com/pdfs/ENVIRONMENT/indianpoint leaks.pdf.

421 *Id.*

422 BAUM, *supra* note 389, at 10.

423 *Id.* (citing PEDRO RAMIREZ, JR., U.S. FISH & WILDL. SERV. CONTAM. REP. NO. R6/703C/92, TRACE ELEMENT CONCENTRATIONS IN FLUE GAS DESULFURIZATION WASTEWATER FROM THE JIM BRIDGER POWER PLANT, SWEETWATER COUNTY, WYOMING 2,7 (1992), *available at* http://www.fws.gov/mountain-prairie/contaminants/ papers/r6703c92.pdf).

recent claims by the Nuclear Energy Institute that nuclear power is the "Clean Air Energy."[424] Reprocessing and enriching uranium requires a substantial amount of electricity, often generated from fossil fuel-fired power plants, and uranium milling, mining, leeching, plant construction, and decommissioning all produce substantial amounts of greenhouse gas.[425] In order to enrich natural uranium, for example, it is converted to uranium hexafluoride, UF_6, and then diffused through permeable barriers.[426] "In 2002, the Paducah [uranium] enrichment plant [in Kentucky] released over 197.3 metric tons of Freon [, a greenhouse gas far more potent than carbon dioxide,] through leaking pipes and other equipment."[427] Data collected from one uranium enrichment company revealed that it takes a 100 MW power plant running for 550 hours to produce the amount of enriched uranium needed to fuel a 1000 MW reactor, of the most efficient design currently available, for just one year.[428] According to the *Washington Post*, "[t]wo of the nation's most polluting coal plants, in Ohio and Indiana, produce electricity primarily for uranium enrichment."[429]

When one takes into account the carbon-equivalent emissions associated with the entire nuclear lifecycle, nuclear plants contribute significantly to climate change and will contribute even more as stockpiles of high-grade uranium are depleted. An assessment of 103 lifecycle studies of greenhouse gas equivalent emissions for nuclear power plants found that the average CO_2 emissions over the typical lifetime of a plant are around sixty-six grams for every kWh, or the equivalent of some 183 million metric tons of CO_2 in 2005.[430] If the global nuclear industry were taxed at a rate of $24 per ton for the carbon equivalent emissions associated with

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[424] *See* Posting of Eric McErlain to NEI Nuclear Notes, http://neinuclearnotes.blogspot.com/2007/09/clean-air-energy-ad-run-begins.html (Sept. 12, 2007, 15:17 EST).

[425] Sovacool, *supra* note 26, at 2960.

[426] ARJUN MAKHIJANI, LOIS CHALMERS & BRICE SMITH, INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH, URIANIUM ENRICHMENT: JUST PLAIN FACTS TO FUEL AN INFORMED DEBATE ON NUCLEAR PROLIFERATION AND NUCLEAR POWER 8 (2004), *available at* http://www.ieer.org/reports/uranium/enrichment.pdf.

[427] *Id.* at 11.

[428] *See id.* at 26. The calculation works like this: it takes approximately 55 kWh of electricity to enrich one separative work unit ("SWU") of uranium; it also takes 100,000 SWU to produce 1000 MW of electricity. Therefore, it means that 5500 MWh are needed to generate 1000 MW of electricity.

[429] Peter Asmus, *Nuclear Dinosaur*, WASH. POST, July 6, 2005, at A17, *available at* http://www.washingtonpost.com/wp-dyn/content/article/2005/07/05/AR2005070501291.html.

[430] Sovacool, *supra* note 26, at 2950-51.

its lifecycle, the cost of nuclear power would increase by about $4.4 billion per year.[431]

The carbon equivalent emissions of the nuclear lifecycle will only get worse, not better, because, over time, reprocessed fuel is depleted necessitating a shift to fresh ore, and reactors must utilize lower quality ores as higher quality ones are depleted.[432] The Oxford Research Group projects that because of this inevitable eventual shift to lower quality uranium ore, if the percentage of world nuclear capacity remains what it is today, by 2050 nuclear power would generate as much carbon dioxide per kWh as comparable gas-fired power stations.[433] This bears repeating: at current levels of generation, by 2050 nuclear plants will be producing as much greenhouse gas as some fossil fuel plants.

In addition, the capital intensity of the nuclear fuel cycle—immense construction, reprocessing, storage, decommissioning, and R&D costs—may make it all but impossible to mobilize nuclear power plants quickly enough to fight climate change.[434] In order for advanced nuclear plants to even maintain the 19% share of power generation held by conventional nuclear units in the United States, an additional 190 GW of new capacity would have to be built.[435] Taking an average reactor size of 1000 MW, this equates to bringing online about six nuclear plants per year, every year until 2040.[436] The historical record suggests that this task is insurmountable. France, which currently generates 78% of its electricity from nuclear units, has the fastest record for deploying nuclear plants in history: fifty-eight between 1977 and 1993, or an average of 3.4 reactors per year, close

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[431] *See id.* at 2950. The calculation works like this: In 2005, 435 nuclear plants supplied 16% of the world's power, constituting 368 GW of installed capacity generating 2768 TWh of electricity. With every TWh of nuclear electricity having carbon-equivalent lifecycle emissions of 66,000 tons of CO_2, these plants emitted a total of some 182.7 million tons. If each ton costs $24, the grand total would be about $4.4 billion every year.

[432] *Id.* at 2961.

[433] Storm van Leeuwen, *supra* note 9, at 40.

[434] Sovacool, *supra* note 3.

[435] The calculation works as follows: according to the EIA, electricity demand will grow at about 1.3 percent per year, from 3821 billion kWh in 2006 to 5149 billion kWh by 2030, or from 1075 GW to 1873 GW. Press Release, Energy Information Administration, New EIA Outlook Reflects Ongoing Transition in Energy Markets (Dec. 12, 2007) (on file at http://www.eia.doe.gov/neic/press/press293.html). A 19 percent share of 1,873 GW is 356 GW, minus existing capacity expected to operate until 2030, thereby amounting to 190 GW that will need to be constructed.

[436] 190 GW between 2008 and 2040 is 6 GW per year for 32 years, or six 1,000 MW nuclear plants a year.

to half the six per year needed to address U.S. climate change.[437] In addition, 190 new nuclear plants would require the additional construction of four large enrichment plants, five fuel fabrication plants, and three waste disposal sites, each the size of Yucca Mountain.[438]

F. Safety

While the Chair of the Public Information Committee of the American Nuclear Society has publicly stated that "the industry has proven itself to be the safest major source of electricity in the Western world,"[439] the history of nuclear power proves otherwise. The safety record of nuclear plants is lackluster at best. For one salient example, consider that Ukraine still has a Ministry of Emergency, some twenty-two years after the Chernobyl nuclear disaster warranted its creation.[440] No less than seventy-six nuclear accidents, defined as incidents that either resulted in the loss of human life or more than $50,000 of property damage, totaling more than $19 billion in damages have occurred worldwide from 1947 to 2008.[441] See Table B.

One survey of major energy accidents from 1907 to 2007 found that nuclear plants ranked first in economic cost among all energy accidents, accounting for 41% of all accident related property damage, or $16.6 billion in property loss, even though nuclear power plants did not even begin commercial operation until the 1950s.[442] These numbers translate to more than one incident and $332 million in damages every year for the past three decades. Forty-three accidents have occurred since the Chernobyl disaster in 1986, and almost two-thirds of all nuclear accidents have occurred in the U.S., refuting the notion that severe accidents are relegated to the past or to countries without America's modern technologies or

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[437] World Nuclear Association, Nuclear Power in France, http://www.world-nuclear.org/info/inf40.html (last visited Oct. 26, 2008).

[438] *See* Sovacool, *supra* note 3. For every 700 new nuclear plants that are constructed, eleven to twenty-two enrichment plants, eighteen fuel fabrication plants, and ten waste disposal sites the size of Yucca Mountain need to be built. THE KEYSTONE CENTER, *supra* note 167, at 23.

[439] Beller, *supra* note 93, at 41.

[440] *See* The Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chernobyl Catastrophe, The Main Tasks of the Ministry, http://www.mns.gov.ua/ministerstvo/zavdannya.en.php?m=3&l=en (last visited Sept. 25, 2008).

[441] *See infra* Appendix Table B.

[442] Benjamin K. Sovacool, *The Costs of Failure: A Preliminary Assessment of Major Energy Accidents, 1907-2007*, 36 ENERGY POL'Y 1802, 1807 (2008).

industry oversight.[443] Even the most conservative estimates find that nuclear power accidents have killed 4100 people,[444] or more people than have died in commercial U.S. airline accidents since 1982.[445] "[N]uclear power accidents have involved meltdowns, explosions, fires, and loss of coolant, and have occurred during both normal operation and extreme, emergency conditions such as droughts and earthquakes."[446] One index of nuclear power accidents that included costs beyond death and property damage—such as injuring and irradiating workers and malfunctions that did not result in shutdowns or leaks—documented 956 incidents from 1942 to 2007.[447]

Using some of the most advanced probabilistic risk assessment tools available, an interdisciplinary team at MIT identified possible reactor failures in the U.S. and predicted that the best estimate of core damage frequency was around one every 10,000 reactor years.[448] In terms of the expected growth scenario for nuclear power from 2005 to 2055, the MIT team estimated that at least four serious core damage accidents will occur and concluded that "both the historical and the PRA [probabilistic risk assessment] data show an unacceptable accident frequency."[449] Further, "[t]he potential impact on the public from safety or waste management failure . . . make it impossible today to make a credible case for the immediate expanded use of nuclear power."[450]

Another assessment conducted by the CEA in France tried to associate nuclear plant design with human error such that technical innovation could help eliminate the risk of human-induced accidents.[451] Two types of mistakes were deemed the most egregious: errors committed during

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[443] *See infra* Appendix Table B.

[444] *Id.*

[445] UNITED STATES TRANSPORTATION SAFETY BOARD, ACCIDENTS INVOLVING PASSENGER FATALITIES—U.S. AIRLINES (PART 121) 1982-PRESENT, http://www.ntsb.gov/aviation/Paxfatal.htm (last visited Oct. 26, 2008).

[446] Benjamin K. Sovacool, *The Cost of Failing Infrastructure: Tallying up Disasters*, ENERGYBIZ, Sept./Oct. 2008, at 32, *available at* http://energycentral.fileburst.com/EnergyBizOnline/2008-5-sep-oct/Financial_Front_Failing_Infrastructure.pdf; *see also infra* Appendix Table B.

[447] Christopher P. Winter, Accidents Involving Nuclear Energy http://www.chris-winter.com/Digressions/Nuke-Goofs/ (last visited Nov. 6, 2008).

[448] MIT, *supra* note 23, at 48.

[449] *Id.*

[450] *Id.* at 22.

[451] Bernard Papin & Patrick Quellien, *The Operational Complexity Index: A New Method for the Global Assessment of the Human Factor Impact on the Safety of Advance Reactors Concepts* 236 NUCLEAR ENGINEERING AND DESIGN 1113, 1113-21 (2006).

field operations, such as maintenance and testing, that can cause an accident, and human errors made during small accidents that cascade to complete failure.[452] There may be no feasible way to "design around" these risks. For example, when another group of CEA researchers examined the safety performance of advanced French Pressurized Water Reactors, they concluded that human factors would contribute to about one-fourth (twenty-three percent) of the likelihood of a major accident.[453]

Consider that the two most significant nuclear power accidents, Chernobyl and Three Mile Island, were human caused and then exacerbated by more human mistakes.

1. Chernobyl, Ukraine

On the evening of April 25, 1986, evening shift engineers at Chernobyl's number four reactor experimented with the cooling pump system to see if it could still function without auxiliary electricity supplies.[454] In order to proceed with the test, the operators turned off the automatic shutdown system.[455] At the same time, "they mistakenly lowered too many control rods into the reactor core," dropping plant output too quickly.[456] This stressed the fuel pellets, causing ruptures and explosions, bursting "the reactor roof and sweeping the eruption outwards into the sur-rounding atmosphere. As air raced into the shattered reactor, it ignited flammable carbon monoxide gas and created a radioactive fire that burned for nine days."[457] Immediately following the accident, 116,000 people were evacuated from a thirty square kilometer exclusive zone constituting parts of Belarus, Ukraine, and Russia.[458] The large city of Pripiat, Ukraine, had to be completely abandoned.[459]

The Chernobyl meltdown released more than two hundred times the radiation released by the atom bombs dropped on Nagasaki and

[452] *Id.* at 1113.
[453] *Id.* at 1113-14.
[454] *The Chernobyl Disaster—The Accident*, BBC NEWS, http://news.bbc.co.uk/2/shared/spl/hi/guides/456900/456957/html/nn2page1.stm. (last visited Sept. 25, 2008) [hereinafter *Chernobyl Disaster*].
[455] *Id.*
[456] Sovacool, *supra* note 442, at 1806; *Chernobyl Disaster*, *supra* note 454.
[457] Sovacool, *supra* note 442, at 1806.
[458] V.K. SAVCHENKO, THE ECOLOGY OF THE CHERNOBYL CATASTROPHE: SCIENTIFIC OUTLINES OF AN INTERNATIONAL PROGRAMME OF COLLABORATIVE RESEARCH 70 (1995).
[459] *Id.* at 71, Fig. 4.5.

Hiroshima.[460] More than five million people, including 1.6 million children, were exposed to dangerous levels of radiation, and about 246,000 square kilometers were contaminated with iodine-131, ruthenium-106, cerium-141 and -144, cesium-137, strontium-89 and -90, and plutonium-238—some of which will remain lethally radioactive for more than 10,000 years.[461] At least 350,000 more people had to be forcibly resettled from the area.[462] Cesium and strontium severely contaminated agricultural products, livestock, and soil as far away as Japan and Norway; some milk in Eastern Europe is still undrinkable.[463]

Human error after the initial accident also exacerbated the situation and needlessly exposed millions of people to unhealthy levels of radiation. For example, the Soviet government did not begin evacuations until April 28, two full days after the accident, because they had planned on covering up the accident until a Swedish radiation monitoring station 800 miles northwest of Chernobyl reported radiation levels forty percent higher than normal.[464] Russian and Ukrainian disaster managers mistakenly sent about 1000 buses contaminated with radioactive iodine during the evacuation back into public transportation service in Kiev.[465]

Some members of the Russian military personally contaminated themselves, and their families, by rushing back into the disaster area in what they believed was a sign of bravery.[466] The act extended a long tradition of Soviet troops exposing themselves to radiation as a sign of strength,

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[460] Hirsh & Sovacool, *supra* note 12, at 26.

[461] SAVCHENKO, *supra* note 458, at 70, 72.

[462] *The Chernobyl Disaster-The Environment*, BBC NEWS, http://news.bbc.co.uk/2/shared/spl/hi/guides/456900/456957/html/nn3page1.stm (last visited Sept. 26, 2008).

[463] International Atomic Energy Agency, Chernobyl: The True Scale of the Accident, http://www.bio-medicine.org/biology-news/Chernobyl-3A-The-true-scale-of-the-accident-1732-1l/ (last visited Nov. 6, 2008) (mentioning that radioactive contamination from Chernobyl remains most severe in "milk, meat and some plant foods"). MYKOLA LIABAKH & KATERYNA VOLOVYK, IMENNIA ZORI CHORNOBYL': FOTOAL'BOM [The Name of the Star is Chernobyl: Photo Album] 82 (1996) (translation on file with author) (mentioning that food, water, and dairy products were contaminated in Hungary, Japan, Norway, and Poland).

[464] History.com, This Day in History 1986: Nucler Disaster at Chernobyl, http://www.history.com/this-day-in-history.do?action=tdihVideoCategory&id=6879 (last visited Sept. 26, 2008).

[465] European Centre for Technology Safety, Chernobyl: History, http://www.tesec-int.org/chernobyl/History.htm (last visited Oct. 26, 2008).

[466] *See* Hugh Gusterson, Nuclear Terrorism: The New Day After, Bulletin of the Atomic Scientists, Jul. 23, 2007, *available at* http://www.thebulletin.org/web-edition/columnists/hugh-gusterson/nuclear-terrorism-the-new-day-after ("We know from . . . Chernobyl that some will commit suicidal acts of bravery.").

including tanks intentionally driving through nuclear weapons fallout and aircraft flying back into the fallout from atmospheric weapons testing.[467] In what could qualify as a scene from a National Lampoon's movie if the consequences were not so dire, a Russian helicopter crew quickly redeployed from Afghanistan, was assigned to drop boric acid on the exposed fissile material above Chernobyl's shattered reactor only to crash into it, causing yet another radioactive explosion.[468]

After these accidents, "traces of radioactive deposits unique to Chernobyl were found in nearly every country in the northern hemisphere."[469] The international community sponsored a $1.4 billion decontamination project, including the construction of a massive sarcophagus and 131 hydroelectric installations to prevent contaminated water from flowing downstream on the Pripiat and Dnieper rivers.[470] See Figure 4. Soviet authorities strongly urged as many as 400,000 abortions in an effort to mitigate the reporting of birth defects.[471] The International Atomic Energy Agency, working with the World Health Organization, attributed up to 4000 deaths to the Chernobyl nuclear accident,[472] whereas other studies put the numbers at 93,000 fatal cancer deaths throughout Europe, 140,000 in Ukraine and Belarus, and another 60,000 in Russia, for a total of 293,000.[473]

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[467] LIABAKH & VOLOVYK, *supra* note 463, at 53, 56 (commenting that many soldiers and workers went back into the Chernobyl disaster zone knowingly to their deaths, and that Russian military personnel sometimes viewed enduring radiation poisoning as a sign of bravery).

[468] *Fatal Flight over Reactor Number 4 at Chernobyl* (Discovery Channel 2004), *available at* http://www.liveleak.com/view?i=b54_1182420118.

[469] Sovacool, *supra* note 442, at 1806.

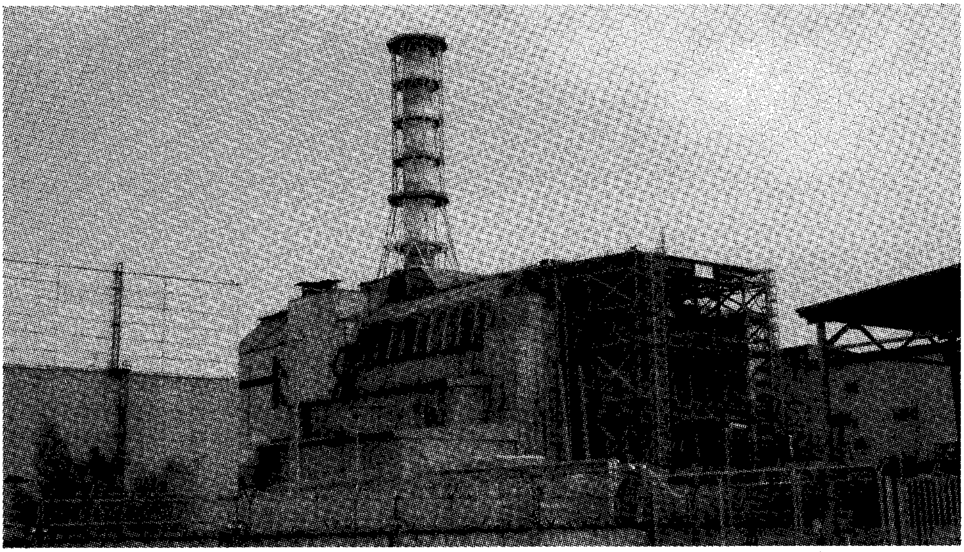
[470] Savchenko, *supra* note 458, at 69, 70; *see also* Chernobyl Children's Project International, Crumbling Chernobyl Sarcophagus: Repairs Please?, Oct. 8, 2007, http://chernobyl.typepad.com/chernobyl_childrens_proje/2007/10/crumbling-chern.html (estimating the cost of repairs at $1.39 billion).

[471] While there are no documented cases of forced abortions in the Soviet Union, the majority of women from the Chernobyl region who were pregnant at the time of the tragedy were subjected to significant pressure from their physicians and the community to consent to an abortion. For a personal account of the government's policy *see, e.g.*, Natalia Conova, *Spasenie s Privkosom Polyni* [Salvation with a Bitter Aftertaste], PROFIL, April 26, 2008, http://profil-ua.com/index.phtml?action=view&art_id=436 (last visited Oct. 26, 2008); *see also* LIABAKH & VOLOVYK, *supra* note 463, at 41.

[472] Press Release, World Health Organization, Chernobyl: the true scale of the accident, (Sep. 5, 2005), *available at* http://www.who.int/mediacentre/news/releases/2005/pr38/en/print.html (last visited Oct. 26, 2008).

[473] Press Release, Greenpeace, Greenpeace Releases Health Study of 1986 Nuclear Accident (Apr. 18, 2006), *available at* http://www.greenpeace.org/canada/en/press/press-releases/nuclear-accident (last visited Oct. 26, 2008).

Figure 5: Chernobyl Reactor Number Four in 2008, Still Highly Radioactive and Undergoing Multi-Billion Dollar Decommissioning



The consequences of the accident at Chernobyl, moreover, are far from over. Fallout from Chernobyl contaminated about six million hectares of forest in the Gomel and Mogilev regions of Belarus, the Kiev region of Ukraine, and the Bryansk region of the Russian Federation.[474] Three of the contaminants, cesium-137, strontium-90, and plutonium-239, are extraordinarily robust and extremely dangerous.[475] Ninety-five percent of these contaminants accumulated in living trees,[476] but 770 wildfires have occurred in the contaminated zone from 1993 to 2001,[477] each one releasing

[474] Sergey I. Dusha-Gudym, *Transport of Radioactive Materials by Wildland Fires in the Chernobyl Accident Zone: How to Address the Problem*, INT'L FOREST FIRE NEWS, Jan.-June 2005, at 119, *available at* http://www.fire.uni-freiburg.de/iffn/iffn_32/20-Dusha-Gudym.pdf.
[475] *Id.* at 120.
[476] Ryszard Szczygiel & Barbara Ubysz, *Chernobyl Forests, Two Decades After the Contamination*, PRZEGLAD POZARNICZY, May 2006, at 22, *available at* http://www.ppoz.pl/down/pwa/fr506a.pdf.
[477] Dusha-Gudym, *supra* note 474, at 119.

radioactive emissions far into the atmosphere.[478] A single, severe fire in 1992 burned five square kilometers of land contaminated by Chernobyl, including 2.7 square kilometers of highly contaminated Red Forest next to the reactor, carrying highly toxic cesium dust particles into the upper atmosphere,[479] distributing radioactive smoke particles thousands of kilometers, and exposing at least 4.5 million people to dangerous levels of radiation.[480] Radiation levels were so high after the 1992 fire that scientists throughout Europe initially thought there had been a second meltdown at Chernobyl Reactors One or Two, which remained in operation until 2000.[481]

2. Three Mile Island, Pennsylvania, United States

On March 28, 1979, equipment failures and operator error contributed to the loss of coolant and a partial core meltdown at the Three Mile Island ("TMI") nuclear reactor in Pennsylvania, causing $2.4 billion in property damages.[482] Technically, the meltdown at TMI was a "loss of coolant" accident.[483] The primary feed-water pumps stopped running at TMI Unit 2, preventing the large steam generators at the reactor site from removing necessary exhaust heat.[484] As the steam turbines and reactor automatically shut down, contaminated water poured out of open valves and caused the core of the reactor to overheat, inducing a partial core meltdown.[485]

A commission chartered by President Carter to study the accident, however, found that human error played the most significant factor in the meltdown.[486] The commission stated that the TMI operators were not well trained, operating procedures were confusing, and administrators had

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[478] *Id.* at 120.
[479] *Id.* at 122.
[480] *Id.* at 120.
[481] Szczygiel & Ubysz, *supra* note 476.
[482] Sovacool, *supra* note 442, at 1807.
[483] Hirsh & Sovacool, *supra* note 12, at 17.
[484] U.S. NUCLEAR REGULATORY COMM'N, FACT SHEET ON THE THREE MILE ISLAND ACCIDENT 1 (2007), *available at* http://www.nrc.gov/reading-rm/doc-collections/ fact-sheets/3mile-isle.pdf.
[485] *Id.* at 1-2.
[486] *Causes of the Accident*, *in* REPORT OF THE PRESIDENT'S COMMISSION ON THE ACCIDENT AT THREE MILE ISLAND (1979), *available at* http://www.pddoc.com/tmi2/kemeny/causes_of_the_accident.htm [hereinafter TMI COMMISSION].

failed to learn lessons in safety from past incidents at the plant.[487] The commission concluded that "we have stated that fundamental changes must occur in organizations, procedures, and above all, in the attitudes of people. No amount of technical 'fixes' will cure this underlying problem."[488]

Several American regulatory agencies conducted detailed studies of the radiological consequences of the accident, and a consensus has emerged that while the average dose of exposure from the accident was one millirem, or one-sixth the exposure from a full set of chest x-rays,[489] the situation came dangerously close to releasing catastrophic amounts of radioactivity.[490] For example, when federal investigators arrived on the scene, they discovered two pieces of alarming news that had not been widely reported. First, the reactor core was more badly damaged than previously thought.[491] Falling coolant levels in the reactor core exposed the tops of fuel rods to the air, causing oxidation of the cladding used to protect the rods.[492] The result was that radioactive gases like xenon-133, krypton-85 and iodine-131 seeped out of cracks in the reactor.[493] Second, a gas bubble nearly 1000 cubic feet in size had developed at the top of the reactor.[494] Apparently the reactor core had reached high enough levels that the coolant water had decomposed into its primary elements: hydrogen and oxygen.[495] Investigators feared that the bubble would continue to grow, forcing even more coolant water out of the reactor and allowing the core to reach temperatures of 5000 degrees.[496] At that point, the uranium fuel would begin to melt, risking a total core meltdown and a catastrophic release of the reactor's radioactive material.[497]

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487 *Id.*; Hirsh & Sovacool, *supra* note 12, at 18.

488 *A Warning, in* TMI COMMISSION, *supra* note 486, at 24; Hirsh & Sovacool, *supra* note 12, at 19.

489 U.S. NUCLEAR REGULATORY COMM'N, *supra* note 484, at 3.

490 American Experience, Meltdown at Three Mile Island: Jimmy Carter, http://www.pbs.org/wgbh/amex/three/peopleevents/pandeAMEX86.html (last visited Oct. 26, 2008) ("Walter Cronkite was speaking of a 'horror' that 'could get much worse.'").

491 *Danger of Day 3—Nuclear Shower If Core Melts, in* WASHINGTON POST, WHAT HAPPENED: CRISIS AND THREE MILE ISLAND (1999), *available at* http://www.washingtonpost.com/wp-srv/national/longterm/tmi/stories/ch6.htm.

492 *Id.*

493 *Id.*

494 *Id.*

495 *Id.*

496 *Id.*

497 *Danger of Day 3*, *supra* note 491.

Although the incident at Three Mile Island avoided this nightmare scenario, barely, it brought about sweeping changes to the industry and forced the permanent closure and decommissioning of TMI Unit 2.[498] After the accident, emergency response planning, reactor operator training, human factors engineering, radiation protection, and many other areas of nuclear power plant operations in the U.S. were radically reformed.[499]

3. Newer Reactors are the Riskiest

Unfortunately, safety risks such as those at Chernobyl and Three Mile Island are only *amplified* with new generations of nuclear systems. Nuclear engineer David Lochbaum has noted that almost all serious nuclear accidents occurred with recent technology, making newer systems the riskiest.[500] In 1959, the Sodium Research Experiment reactor in California experienced a partial meltdown fourteen months after opening.[501] In 1961, the Sl-1 Reactor in Idaho was slightly more than two years old before a fatal accident killed everyone at the site.[502] The Fermi Unit 1 reactor began commercial operation in August 1966, but had a partial meltdown only two months after opening.[503] The St. Laurent des Eaux A1 Reactor in France started in June 1969, but an online refueling machine malfunctioned and melted 400 pounds of fuel four months later.[504] The Browns Ferry Unit 1 reactor in Alabama began commercial operation in August 1974 but experienced a fire severely damaging control equipment six months later.[505] Three Mile Island Unit 2 began commercial operation in December 1978 but had a partial meltdown three months after it started.[506] Chernobyl Unit 4 started up in August 1984, and suffered the worst nuclear disaster in history on April 26, 1986 before the two-year anniversary of its operation.[507]

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[498] U.S. NUCLEAR REGULATORY COMM'N, *supra* note 484, at 3-4.
[499] *Id.*
[500] DAVID LOCHBAUM, UNION OF CONCERNED SCIENTISTS, U.S. NUCLEAR PLANTS IN THE 21ST CENTURY: THE RISK OF A LIFETIME 5 (2004), *available at* http://www.ucsusa.org/assets/documents/nuclear_power/nuclear04fnl.pdf.
[501] *Id.*
[502] *Id.*
[503] *Id.*
[504] *Id.*
[505] *Id.*
[506] LOCHBAUM, *supra* note 500, at 5.
[507] *Id.*

Safety risks may be especially acute for new reactors in the U.S. for three reasons. First, the pressure to build new generators on existing sites to avoid complex issues associated with finding new locations[508] only increases the risk of catastrophe, because there is a greater chance that one accident can affect multiple reactors. Second, Generation IV researchers continue to pursue breeder reactor designs that use liquid sodium as coolant.[509] Liquid sodium, however, can be dangerous, since it can immediately catch fire when exposed to water.[510] Third, the domestic nuclear industry lacks qualified and experienced staff and is losing much of the expertise that it does have to retirement, attrition and death.[511] The DOE has warned that the lack of growth in the domestic nuclear industry has gradually eroded important infrastructural elements such as experienced personnel in nuclear energy operations, engineering, radiation protection, and other professional disciplines; qualified suppliers of nuclear equipment and components, including fabrication capability; and contractor, architect, and engineer organizations with personnel, skills, and experience in nuclear design, engineering, and construction.[512] Since all commercial American reactors are light water reactors,[513] system operators have little experience with newer gas cooled and other advanced reactor designs used throughout the world. Moreover, the Nuclear Energy Institute warned in 2005 that "half of the industry's employees are over 47 years old, and more than a quarter . . .already are eligible to stop working," implying that the industry had far fewer available specialists with the requisite knowledge necessary to facilitate any rapid expansion of nuclear power, let alone a safe one.[514]

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508 U.S. DEP'T OF ENERGY ET AL., A ROADMAP TO DEPLOY NEW NUCLEAR POWER PLANTS IN THE UNITED STATES BY 2010: VOLUME II MAIN REPORT 6-10 to -16 (2001), *available at* http://www.ne.doe.gov/nerac/neracPDFs/NTDRoadmapVolII.PDF.

509 World Nuclear Association, Generation IV Nuclear Reactors, http://www.world-nuclear.org/info/inf77.html (last visited Oct. 26, 2008).

510 "Na" is the chemical symbol for sodium. Therefore, *see, e.g.*, BASF, SAFETY DATA SHEET: NA-METHYLATE SOL. 27 % 2 (2002), *available at* http://www.inorganics.basf.com/p02/CAPortal/en_GB/function/conversions:/publish/content/Produktgruppen/Alkoholate/Standard-Alkoholate/pdf/msds_nml27.pdf ("Reacts violently with water.").

511 *Cf.* Alison Go, *The New Hot Job: Nuclear Engineering*, U.S. NEWS. & WORLD REP., Aug. 14, 2008, http://www.usnews.com/articles/education/2008/08/14/the-new-hot-job-nuclear-engineering.html (last visited Oct. 26, 2008).

512 U.S. DEP'T OF ENERGY, A ROADMAP TO DEPLOY NEW NUCLEAR POWER PLANTS IN THE UNITED STATES BY 2010 7 (2001).

513 *Id.* at 33.

514 Benson & Adair, *supra* note 124, at 46.

Mistakes are not limited to reactor sites. Accidents at the Savannah River reprocessing plant have already released ten times as much radioiodine than the accident at Three Mile Island, and a fire at the Gulf United plutonium facility in New York in 1972 scattered an undisclosed amount of plutonium in the area, forcing the plant to shutdown permanently.[515] A similar fire at the Rocky Flats reprocessing plant in Colorado potentially released hundreds of pounds of plutonium oxide dust into the surrounding environment.[516]

On-site accidents, unfortunately, are not the only cause of concern. The August 2003 blackout on the U.S. East Coast revealed that fifteen nuclear reactors in the U.S. and Canada were not properly maintaining backup diesel generators.[517] In Ontario during the blackout, reactors designed to automatically unlink from the grid and remain in standby mode instead went into full automatic shutdown, with only two of twelve reactors shutting down as planned.[518] Since spent fuel ponds do not receive backup power from emergency diesel generators, when offsite power goes down, pool water cannot be re-circulated to prevent boiling, evaporation, and exposure of fuel rods.[519] The result is a significantly increased risk of pool fires and explosions.[520]

Dennis Berry, Director Emeritus of Sandia National Laboratories, explained that the problem with new reactors and accidents is twofold: scenarios arise that are impossible to plan for in simulations and humans make mistakes.[521] As he put it, "fabrication, construction, operation, and maintenance of new reactors will face a steep learning curve: advanced technologies will have a heightened risk of accidents and mistakes. The technology may be proven, but people are not."[522] See Figure 6.

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[515] AMORY B. LOVINS & L. HUNTER LOVINS, BRITTLE POWER: ENERGY STRATEGY FOR NATIONAL SECURITY 157-58 (1982).

[516] *Id.* at 158.

[517] PUBLIC CITIZEN, THE BIG BLACKOUT AND AMNESIA IN CONGRESS: LAWMAKERS TURN A BLIND EYE TO THE DANGER OF NUCLEAR POWER AND THE FAILURE OF ELECTRICITY DEREGULATION 4 (2003), *available at* http://www.tradewatch.org/documents/bigblackout.pdf.

[518] *Id.* at 7.

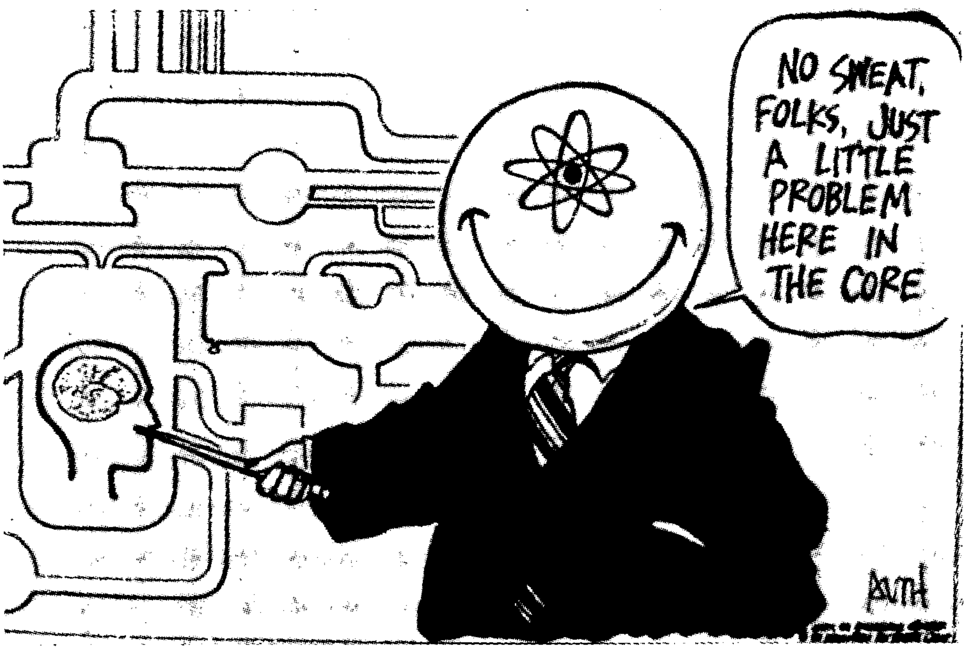
[519] *Id.* at 6-7.

[520] *Id.*

[521] Dennis Berry, Energy Security and Climate Change: Nuclear Energy as a Solution?, Roundtable Discussion at the S. Rajaratanam School of International Studies (July 15, 2008) (on file with author).

[522] *Id.*

Figure 6: Political Cartoon Explaining the 1979 Three Mile Island Accident as a "Core" Malfunction[523]



G. Security

Nuclear plants face at least three types of security risks: they rely on a brittle and inefficient "T&D" network prone to accidents, attack and sabotage; power plants and reactor cores themselves offer tempting targets for terrorists; and the fissile material produced from nuclear reactions can be used to make radioactive weapons of mass destruction, for use by rogue states or terrorists regimes bent on producing the greatest amounts of human carnage.

1. T&D Vulnerability

A comprehensive, three-year Department of Defense ("DOD") study "concluded that relying on centralized nuclear plants to transmit and

[523] Hirsch & Sovacool, *supra* note 12, at 19 (citing John W. Gofman, What About Reviving Nuclear Power?, http://www.ratical.org/radiation/CNR/WARevNP.html (last visited Nov. 12, 2008)).

distribute electric power created unavoidable (and costly) vulnerabilities. The study noted that T&D systems constituted 'brittle infrastructure' that could be easily disrupted, curtailed, or attacked."[524] One of the authors of the DOD study, Amory Lovins, has long advanced the idea that power systems which are inefficient and centralized are, by design, prone to major failures.[525] "In Britain during the coalminer strikes of 1976, a leader of the power engineers famously told Lovins that the miners brought the country to its knees in 8 weeks, we could do it in 8 minutes."[526] Centralized generation power requires an overly complex distribution system, "subject to cascading failures easily induced by severe weather, human error, sabotage, or even the interference of small animals."[527] "Continuous electrical supply," notes Lovins, "now depends on many large and precise machines, rotating in exact synchrony across half a continent, and strung together by an easily severed network of aerial arteries whose failure is instantly disruptive."[528]

The DOD's conclusions complement a similar study undertaken by the IEA, which noted that centralized energy facilities create tempting targets for terrorists because they would need to attack only a few, poorly guarded facilities to cause large, catastrophic power outages.[529] Thomas Homer-Dixon, Chair of Peace and Conflict Studies at the University of Toronto, cautions that it would take merely a few motivated people with minivans, a limited number of mortars and few dozen standard balloons to strafe substations, disrupt transmission lines and cause a "cascade of power failures across the country," costing billions of dollars in direct and indirect damage.[530] A deliberate, aggressive, well coordinated assault on the electric power grid could devastate the electricity sector and leave critical sectors of the economy without reliable sources of energy for a long

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[524] Direct Testimony of Benjamin K. Sovacool on Behalf of Piedmont Environmental Council Before the State Corporation Commission of Virginia, Case Nos. Pue-2007-00031 and Pue-2007-00033 6 (Dec. 4, 2007), *available at* http://www.pecva.org/_downloads/powerlines/documents/statefilings/VA_PEC_BSovacoolTestimony_120407.pdf (citing Lovins & Lovins, *supra* note 515) [hereinafter Sovacool Testimony].

[525] *See* AMORY LOVINS, ET AL., SMALL IS PROFITABLE: THE HIDDEN ECONOMIC BENEFITS OF MAKING ELECTRICAL RESOURCES THE RIGHT SIZE (2002).

[526] Sovacool Testimony, *supra* note 524, at 6 (citing LOVINS & LOVINS, *supra* note 515, at 47) (internal citation omitted).

[527] Sovacool Testimony, *supra* note 524, at 6; *see also* LOVINS, *supra* note 525.

[528] LOVINS & LOVINS, *supra* note 515, at 1.

[529] INTERNATIONAL ENERGY AGENCY, DISTRIBUTED GENERATION IN LIBERALIZED ELECTRICITY MARKETS 16-17 (2002).

[530] Thomas Homer-Dixon, *The Rise of Complex Terrorism*, FOREIGN POL'Y, Jan.-Feb. 2002, at 52, 52-53.

time.[531] Paul Gilman, former Executive Assistant to the Secretary of Energy, has argued that the time needed to replace affected infrastructure would be "on the order of Iraq, not on the order of a lineman putting things up a pole."[532]

The security issues facing the modern electric utility grid are almost as serious as they are invisible. In 1975, the New World Liberation Front bombed assets of the Pacific Gas and Electric Company more than ten times, and members of the Ku Klux Klan and San Joaquin Militia have been convicted of attempting to attack electricity infrastructure.[533] Internationally, organized paramilitaries such as the Farabundo-Marti National Liberation Front were able to interrupt more than ninety percent of electric service in El Salvador and penned manuals for successfully attacking power systems.[534] A natural gas pipeline in Colombia has been shot so many times that operators fondly refer to it as "the flute."[535]

The vulnerabilities of centralized generation systems to accidental or intentional disaster has never been so apparent as in Iraq, where determined insurgents destroy critical infrastructure faster than American contractors can rebuild it. James Robb, a former "black ops" agent and expert in counter-terrorism, warns that a terrorist-criminal symbiosis is developing out of the situation in Iraq.[536] There, terrorists have learned to fight nation-states strategically, without weapons of mass destruction using a new method of "systems disruption," a simple way of attacking electricity and natural gas networks that require centralized coordination.[537] In the last three years of the U.S. occupation of Iraq, relatively simple attacks on oil and electricity networks reduced or held delivery of these services to prewar levels, with a disastrous affect on the country's infant democracy and economy.[538]

Insurgents were not the first to use such tactics. In its initial wave of precision air strikes in January 1991 and March 2003 in Iraq, the U.S.

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[531] *Id.* at 53.

[532] Sovacool, *supra* note 106, at 61.

[533] Alexander E. Farrell, Hisham Zerriffi & Hadi Dowlatabadi, *Energy Infrastructure and Security*, 29 ANN. REV. ENV'T & RESOURCES 421, 422 (2004).

[534] *Id.*

[535] Gal Luft, Institute for the Analysis of Global Security, *Pipeline Security is Terrorist's Weapon of Choice*, ENERGY SECURITY, Mar. 28, 2005, http://www.iags.org/n0328051.htm (last visited Oct. 26, 2008).

[536] John Robb, *Security: Power to the People*, FAST COMPANY, Mar. 2006, at 120-26, *available at* http://www.fastcompany.com/magazine/103/essay-security.html.

[537] *Id.*

[538] *Id.*

military targeted energy infrastructure, including three nuclear plants, both to disrupt military systems and to enhance the overall psychological and economic impact of the attacks.[539] Similarly, under its unilateral and multilateral sanctions regime, the U.S. has barred entry of materials used to build or repair electricity generators, knowing full well how essential such technologies are to a country's economic well-being.[540] "Such disruptions are designed to erode the target state's legitimacy by keeping it from providing the services it must deliver to command the allegiance of its citizens."[541]

Several recent trends in the electric utility industry have increased the vulnerability of T&D infrastructure, and thereby made nuclear generation riskier and less reliable. To improve their operational efficiency, many utilities and system operators have increased their reliance on automation and computerization.[542] "Low margins and various competitive priorities have encouraged industry consolidation, with fewer and bigger facilities and intensive use of assets . . ." centralized in one geographical area.[543] As the National Research Council noted, "[power control systems are] more centralized, spare parts inventories have been reduced, and subsystems are highly integrated across the entire business."[544] Restructuring and consolidation has resulted in lower investment in security in recent years, as cash-strapped utilities seek to minimize costs and maximize revenue available for other areas.[545]

2. Plant and Reactor Insecurity

Stringent security regulations enacted after September 11th have reduced the risk of forcible entry, car or truck bombings, cyber-terrorism, and aerial bombardment of nuclear plants.[546] Yet the NRC found that thirty-seven of eighty-one nuclear plants tested failed their 2002 Operational

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[539] Benjamin Sovacool & Saul Halfon, *Reconstructing Iraq: Merging Discourses of Security and Development*, 33 REV. INT'L STUD. 223, 240 (2007).
[540] *Id.* at 239.
[541] Robb, *supra* note 536.
[542] NATIONAL RESEARCH COUNCIL, MAKING THE NATION SAFER: THE ROLE OF SCIENCE AND TECHNOLOGY IN COUNTERING TERRORISM 178 (2002).
[543] *Id.*
[544] *Id.*
[545] *Id.* at 179.
[546] *See* Paul Gaukler, D. Sean Barnett & Douglas J. Rosinski, *Nuclear Energy and Terrorism*, 16 NAT. RESOURCES & ENV'T 165, 167-68 (2002).

Safeguards Readiness Evaluation.[547] And while the industry purports that plant structures housing reactor fuel can withstand aircraft impact, multiple reports have cautioned that for too many plants the vital control building—the building that, if hit, could lead to a meltdown—is still located outside protective structures and is vulnerable to attack.[548] Furthermore, when the National Research Council surveyed the safety of the country's nuclear storage facilities in 2006, they concluded that terrorist attacks were entirely still possible, and that if an attack induced a zirconium cladding fire, it would result in large releases of hazardous radioactive material.[549] The National Research Council emphasized that these vulnerabilities could not be eliminated by dry cask storage technologies because newly discharged fuel rods must be stored onsite.[550]

3. Fissile Material Availability and Weapons Proliferation

The Nobel Prize winning nuclear physicist Hannes Alfven has been noted as saying that "[a]toms for peace and atoms for war are Siamese twins."[551] Because slightly less than twenty pounds, or 9.07 kilograms, of plutonium is needed to make a nuclear weapon,[552] every ton of separated plutonium waste has enough material for 110 nuclear weapons. The European Union alone produces 2500 tons of spent fuel produced annually, containing about twenty-five tons of separated plutonium, along with 3.5 tons of minor actinides such as neptunium, americium, and curium and three tons of long-lived fission products[553]—enough fissile material for 2750 new nuclear weapons every year. The four countries with the largest

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[547] *A Review of Enhanced Security Requirements at NRC Licensed Facilities: Hearing Before the H. Subcomm. on Oversight and Investigations*, 108th Cong (Apr. 11, 2002) (statement of David N. Orrik, Reactor Security Specialist, Nuclear Regulatory Commission).
[548] Robert F. Kennedy, Jr., *Nuclear Plants Vulnerable to Attack*, SEATTLE POST-INTELLIGENCER, Aug. 5, 2005, *available at* http://seattlepi.nwsource.com/opinion/184879_kennedy05.html.
[549] NATIONAL RESEARCH COUNCIL, SAFETY AND SECURITY OF COMMERCIAL SPENT NUCLEAR FUEL STORAGE: PUBLIC REPORT 3 (2006).
[550] *Id.*
[551] *Quoted in* ALEXANDER SHLYAKHTER, KLAUS STADIE & RICHARD WILSON, CONSTRAINTS LIMITING THE EXPANSION OF NUCLEAR ENERGY (1995) (internal citation omitted), *available at* http://phys4.harvard.edu/~wilson/publications/ppaper617.html.
[552] UNION OF CONCERNED SCIENTISTS, NUCLEAR REPROCESSING: DANGEROUS, DIRTY, AND EXPENSIVE (May 2008), *available at* http://www.ucsusa.org/nuclear_power/nuclear_power_risk/nuclear_proliferation_and_terrorism/nuclear-reprocessing.html.
[553] M. Salvatores, *Nuclear Fuel Cycle Strategies Including Partitioning and Transmutation*, 235 NUCLEAR ENGINEERING AND DESIGN 805, 805-06 (2005).

reprocessing fleets—Belgium, France, Germany, and UK—declared more than 190 tons of separated plutonium in 2007, mostly stored in plutonium dioxide powder at above ground sites and fuel manufacturing complexes[554]— enough for 20,900 nuclear weapons. Put another way, the typical nuclear reactor produces enough plutonium every two months to create a nuclear weapon.[555] Taken as a whole, commercial nuclear reactors already create, every four years, an amount of plutonium equal to the entire global military stockpile.[556] And the manufacturing of nuclear weapons from spent fuel is not the only risk: one kilogram of plutonium is equivalent to about twenty-two million kilowatt hours of heat energy.[557] A dirty bomb laced with a kilogram of plutonium can therefore produce an explosion equal to about 20,000 tons of chemical explosive.[558]

There is no shortage of terrorist groups eager to acquire the nuclear waste or fissile material needed to make a crude nuclear device or a dirty bomb. The risks are not confined to the reactor-site. All stages of the nuclear fuel cycle are vulnerable, including:

- Stealing or otherwise acquiring fissile material at uranium mines;
- Attacking a nuclear power reactor directly;
- Assaulting spent fuel storage facilities;
- Infiltrating plutonium stores or processing facilities;
- Intercepting nuclear materials in transit;
- Creating a dirty bomb from radioactive tailings.[559]

After three decades of searching, Pacific Gas & Electric is still unable to locate segments of one of their fuel rods missing from its Humboldt Bay nuclear power plant.[560] Since 1993, shortly after the collapse of the

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[554] Haas & Hamilton, *supra* note 125, at 576.
[555] FEDERATION OF AMERICAN SCIENTISTS, SPECIAL WEAPONS PRIMER: PLUTONIUM PRODUCTION (2000), http://www.fas.org/nuke/intro/nuke/plutonium.htm (last visited Oct. 26, 2008).
[556] *Summary and Recommendations*, *in* ARJUN MAKHIJANI & SCOTT SALESKA, THE NUCLEAR POWER DECEPTION: U.S. NUCLEAR MYTHOLOGY FROM ELECTRICITY "TOO CHEAP TO METER" TO "INHERENTLY SAFE" REACTORS (1996), *available at* http://www.ieer.org/reports/npdb.html.
[557] FEDERATION OF AMERICAN SCIENTISTS, *supra* note 555.
[558] *Id.*
[559] Frank Barnaby, *The Risk of Nuclear Terrorism*, *in* SECURE ENERGY? CIVIL NUCLEAR POWER, SECURITY AND GLOBAL WARMING 24 (Frank Barnaby & James Kemp eds., 2007), *available at* http://www.stormsmith.nl/publications/secureenergy.pdf.
[560] *PG & E Unable to Locate Missing Nuclear Waste, Says it Will Continue Investigation*, FOSTER ELECTRIC REP., Aug. 25, 2004, at 16.

Soviet Union, authorities have documented 917 incidents of nuclear smuggling in Russia, Germany, France, Turkey, Libya, Jordan, and Iran, and those are only the incidents we know about.[561] A 2004 *Jane's Intelligence Review* report concluded that a substantial increase in the number of new nuclear power plants worldwide would directly increase the risks associated with nuclear weapons proliferation.[562]

Existing safeguards are clearly inadequate. After all, the International Atomic Energy Agency was unable to prevent India, Pakistan, Iran, Libya, and North Korea from using their civilian reactors to launch weapons programs.[563]

In September 2007, Israel bombed a Syrian gas-cooled, graphite-moderated nuclear reactor under construction without grid connections in a deserted canyon east of the Euphrates River that would have produced enough plutonium for two bombs within a year of operation.[564] Syria has also turned to North Korea to realize its nuclear ambitions, using reactor designs based on the North Korean facility at Yongbyon.[565] The disgraced Pakistani nuclear laboratory director Abdul Qadeer Khan admitted to helping Libya, Iran, and Syria with nuclear power plant designs.[566]

Moreover, the Nuclear Non-Proliferation Treaty ("NPT") has been significantly weakened by a recent tentative agreement between the U.S. and India where the U.S. functionally ignored the central tenant of the

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561 GOVERNMENT ACCOUNTABILITY OFFICE, COMBATING NUCLEAR SMUGGLING: CORRUPTION, MAINTENANCE, AND COORDINATION PROBLEMS CHALLENGE U.S. EFFORTS TO PROVIDE RADIATION DETECTION EQUIPMENT TO OTHER COUNTRIES 7 (2006) (481 cases), *available at* http://www.gao.gov/new.items/d06311.pdf; RENSSALAEER LEE, REPORT FOR CONGRESS, NUCLEAR SMUGGLING AND INTERNATIONAL TERRORISM: ISSUES AND OPTIONS FOR U.S. POLICY CR-4 (2002) (426 cases), *available at* http://www.usembassy.it/pdf/other/RL31539.pdf.

562 *Dual Use: Perils of Proliferation*, JANE'S INTELLIGENCE DIGEST, Aug. 12, 2004, *available at* http://www.janes.com/security/international_security/news/jid/jid040812_1_n.shtml.

563 *See* Rob Edwards, *Special Report: A Struggle for Nuclear Power*, NEW SCIENTIST, Mar. 22, 2003, *available at* http://www.newscientist.com/article.ns?id=dn3519; Jonathan Schell, *The Folly of Arms Control*, FOREIGN AFFAIRS, Sept.-Oct. 2000, *available at* http://www.foreignaffairs.org/20000901faessay74/jonathan-schell/the-folly-of-arms-control.html; Robert L. Pfaltzgraff Jr., *The Future of the Nuclear Non-Proliferation Treaty*, FLETCHER FORUM OF WORLD AFFAIRS, Special Edition 2006, at 65, 72.

564 *North Korea and Syria: Oh What a Tangled Web They Weave*, THE ECONOMIST, May 1, 2008, *available at* http://www.economist.com/world/international/displaystory.cfm?story_id=11293979.

565 *Id.*

566 *Id.*

NPT that states that signatory nations refrain from transferring nuclear technology to non-signatory states.[567] "Should a state with a fully developed fuel-cycle capability decide for whatever reason to break away from its non-proliferation commitments," Mohamed Elbaradei, the former director of the IAEA, stated, "most experts believe it could produce a nuclear weapon within a matter of months."[568]

Consequently, in October 2007, leading arms control experts signed a letter urging the Senate Appropriations Committee to eliminate all funding for the GNEP on the grounds that continuing the program would encourage substantial nuclear weapons proliferation.[569] A 2005 study from the Nuclear Transmutation Energy Research Center of Korea also concluded that despite the rhetoric spouted by Generation IV advocates, no nuclear power systems, encompassing "all kinds" of possible reactors and fuel cycles, will ever be completely proliferation proof.[570]

III. ANOTHER ALTERNATIVE—RENEWABLE POWER FOR REAL

As this section of the article shows, however, we need not commit ourselves to a power system characterized by intractable technical, social, economic, and political challenges. Renewable power generators, in contrast to nuclear power plants relying on uranium mining or reprocessing, utilize sunlight, wind, falling water, biomass, waste, and geothermal heat to produce electricity from fuels that are mostly free for the taking. These "fuels" also happen to be in great abundance in the U.S., and thus offer a way to make the U.S. electricity sector less susceptible to supply chain interruptions and shortages. Vikram Budhraja, former President of Edison Technology Solutions, noted that "the beauty of renewable energy" is that "it has no fuel input," and that its competitiveness remains relatively constant no matter how much the market price of oil, gas, coal, and uranium changes.[571]

Operators generally divide renewable power systems into seven types: wind turbines, solar photovoltaic panels, solar thermal systems,

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[567] Rislove, *supra* note 206, at 1069-70.
[568] *Quoted in* THE PEMBINA INSTITUTE, NUCLEAR POWER AND CLIMATE CHANGE 5 (2007).
[569] Richard Weitz, *Global Nuclear Energy Partnership: Progress, Problems, and Prospects*, WMD INSIGHTS, Mar. 2008, *available at* http://www.wmdinsights.com/I23/I23_G2_GlobalNuclearEnergy.htm.
[570] Kang, *supra* note 194, at 682.
[571] Sovacool, *supra* note 106, at 57.

geothermal plants, biomass facilities, hydroelectric stations, and ocean, wave, and tidal technologies. See Table 3.

TABLE 3: RENEWABLE POWER GENERATORS AND ASSOCIATED FUEL CYCLES[572]

Source	**Description**	**Fuel**	**Size of Individual Units**
Onshore Wind	Wind turbines capture the kinetic energy of the air and convert it into electricity via a turbine and generator	Wind	1.5 kW to 2.5MW
Offshore Wind	Offshore wind turbines operate in the same manner as onshore systems but are moored or stabilize to the ocean floor	Wind	750 kW to 5 MW
Solar PV	Solar photovoltaic cells convert sunlight into electrical energy through the use of semiconductor wafers	Sunlight	1 W to 100 MW
Solar Thermal	Solar thermal systems use mirrors and other reflective surfaces to concentrate solar radiation, utilizing the resulting high temperatures to produce steam that directly powers a turbine The three most common generation technologies are parabolic troughs, power towers, and dish-engine systems.	Sunlight	5 kW to 320 MW
Geothermal (conventional)	An electrical-grade geothermal system is one that can generate electricity by means of driving a turbine with geothermal fluids heated by the earth's crust	Hydrothermal fluids heated by the earth's crust	25 MW to 1,400 MW

572 BENJAMIN K. SOVACOOL, THE DIRTY ENERGY DILEMMA: WHAT'S BLOCKING CLEAN POWER IN THE UNITED STATES 75-77 (2008).

Geothermal (advanced)	Deep geothermal generators utilize engineered reservoirs that have been created to extract heat from water while it comes into contact with hot rock, and returns to the surface through production wells	Hydrothermal fluids heated by the earth's crust	10 MW to 1,500 MW
Biomass (combustion)	Biomass generators combust to biological material to produce electricity, sometimes gasifying it prior to combustion to increase efficiency	Agricultural residues, wood chips, forest waste, energy crops	20 to 50 MW
Biomass (landfill gas)	These biomass plants generate electricity from landfill gas and anaerobic digestion	Municipal and industrial wastes & trash	30kW to 10.5 MW
Hydroelectric	Hydroelectric dams impede the flow of water and regulates its flow to generation electricity	Water	200 kW to 6,809 MW
Ocean Power	Ocean, tidal, wave, and thermal power systems utilize the movement of ocean currents and heat of ocean waters to produce electricity	Saline Water	N/A

Wind turbines convert the flow of air into electricity, and are most competitive in areas with stronger and more constant winds, such as locations offshore or in regions of high altitude.[573]

Solar photovoltaic ("PV") cells, also called "flat plate collectors," convert sunlight into electrical energy through the use of semiconductor wafers, and are often used in arrays and integrated into buildings.[574]

[573] *See* JULIE BEAUCHEMIN ET AL., FROM THE SUSTAINABILITY OF WIND ENERGY: A GLOBAL APPROACH TO WIND POWER 58-59 (Centre for Environmental Studies University of Aarhus Denmark 2004), *available at* http://www.environmentalstudies.au.dk/publica/f2004windenergy.pdf.

[574] *See* INT'L ENERGY AGENCY, REPORT IEA-PVPS T1-16:2007, TRENDS IN PHOTOVOLTAIC APPLICATIONS: SURVEY REPORT OF SELECTED IEA COUNTRIES BETWEEN 1992 AND 2006 9, 21 (2007), *available at* http://www.iea-pvps.org/products/download/rep1_16.pdf.

Solar thermal systems, also called "concentrated" or "concentrating" solar power, use mirrors and other reflective surfaces to concentrate solar radiation, utilizing the resulting high temperatures to produce steam to then power a turbine.[575]

An electrical-grade geothermal system is one that can generate electricity by means of driving a turbine with geothermal fluids heated by the earth's crust.[576]

Biomass generators combust agricultural residues, wood chips, forest wastes, energy crops, municipal and industrial wastes, and trash to produce electricity.[577] Biomass generation also includes advanced combustion techniques such as biomass gasification, in which the biomaterial is gasified to increase efficiency prior to its combustion, and co-firing, in which biomass burns with another fuel, such as coal or natural gas, to increase its density,[578] as well as the electrical generation from landfill gas[579] and anaerobic digestion.[580]

Two types of hydroelectric facilities exist: large-scale facilities that consist of a dam or reservoir impeding water and regulating its flow, and run-of-river plants that create a small impoundment to store a day's supply of water.[581] Smaller hydroelectric systems, also referred to as "run-of-the-mill," "micro-hydro," and "run-of-the-river" hydro-power, consist of a water conveyance channel or pressured pipeline to deliver water to a turbine or waterwheel that powers a generator, which in turn transforms the energy of flowing water into electricity.[582] Then the diverted water is

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[575] *See* Charles W. Forsberg, Per F. Peterson, & Haihua Zhao, *High-Temperature Liquid-Fluoride-Salt Closed-Brayton-Cycle Solar Power Towers*, 129 J. SOLAR ENERGY ENGINEERING 141, 141 (2007).

[576] *See* KEVIN RAFFERTY, GEOTHERMAL POWER GENERATION: A PRIMER ON LOW-TEMPERATURE, SMALL-SCALE APPLICATIONS 3-4 (Geo-Heat Center 2000), *available at* http://geoheat.oit.edu/pdf/powergen.pdf.

[577] *See* Behdad Moghtaderi, Changdong Sheng, & Terry F. Wall, *An Overview of the Australian Biomass Resources and Utilization Technologies*, 1 BIORESOURCES 93, 94 (2006), *available at* http://ojs.cnr.ncsu.edu/index.php/BioRes/article/viewFile/BioRes_01_1_093_115_Mohthtaderi_SW_Australian_Biomass_Resources_Utilization/125.

[578] *See* EUROPEAN BIOENERGY NETWORKS, BIOMASS CO-FIRING: AN EFFICIENT WAY TO REDUCE GREENHOUSE GAS EMISSIONS 9, 21 (2003), *available at* http://ec.europa.eu/energy/res/sectors/doc/bioenergy/cofiring_eu_bionet.pdf.

[579] *See* California Energy Commission, Landfill Gas Power Plants, http://www.energy.ca.gov/biomass/landfill_gas.html (last visited Oct. 26, 2008).

[580] *See* California Energy Commission, Anaerobic Digestion, http://www.energy.ca.gov/biomass/anaerobic.html (last visited Oct. 26, 2008).

[581] U.S. Geological Survey, Hydroelectric Power: How It Works, http://ga.water.usgs.gov/edu/hyhowworks.html (last visited Oct. 26, 2008).

[582] Navitron, Water Turbines - Intro, http://navitron.org.uk/page.php?id=58&catId=70

sent almost immediately back into the flow of the original source.[583] Because they operate on a much smaller scale, use smaller turbines and require much less water, run-of-the-mill hydro plants escape many of the challenges raised by their larger counterparts.[584]

The category of electricity known as "ocean power" includes shoreline, near-shore, and offshore "wave extraction" technologies and Ocean Thermal Energy Conversion ("OTEC") systems.[585] Because they are a much newer technology than other renewables, comprehensive cost analyses and product reviews are limited.[586] Because ocean power plants do not currently exist in the commercial sector, we do not discuss them much in this article.

Advances in design, operation, and maintenance now enable these types of power technologies to generate electricity *more* reliably than nuclear plants. Geothermal, bioelectric, and hydroelectric plants have long provided reliable baseload power in the same fashion as nuclear plants.[587] One very recent 2008 assessment of hydroelectric power in the U.S. found that by looking at just four possible resources–constructing new but smaller scale dams, upgrading existing facilities, adding power generators to non-hydroelectric dams, and commercializing hydro-kinetics–58,882 MW to 311,202 MW of installed baseload capacity was available.[588] That amount is equivalent to between 50 and 300 new nuclear reactors, and it already takes into account restrictive environmental standards.

(last visited Oct. 26, 2008).

[583] *Id.*

[584] CanREN, Hydroelectric Energy, Environmental Impacts and Preventable Measures, http://www.canren.gc.ca/tech_appl/index.asp?CaId=4&PgId=43 (last visited Oct. 26, 2008).

[585] *See* Heng Zhang, Ocean Electric Energy Extraction Opportunities (June 27, 2003) (unpublished M.Sc. thesis, Oregon State University) (on file with Oregon State University libraries), *available at* http://ir.library.oregonstate.edu/dspace/bitstream/1957/7121/1/Zhang_Heng.pdf.

[586] *See* Larry West, *Is Ocean Power a Viable Energy Source?*, ABOUT.COM: ENVIRONMENTAL ISSUES, http://environment.about.com/od/offbeatenergysources/a/ocean_power.htm (last visited Nov. 6, 2008) ("Given the difficulty and cost of building tidal arrays at sea and getting the energy back to land, however, ocean technologies are still young and mostly experimental."); *see also* Martin LaMonica, *Seadog Pump Fetches Ocean Power*, GREENTECH, May 28, 2008, http://news.cnet.com/8301-11128_3-9952575-54.html ("Ocean power is, for the most part, experimental technology.").

[587] *See* U.S. CONGRESS, OFFICE OF TECHNOLOGY ASSESSMENT, RENEWING OUR ENERGY FUTURE 147, 151, 166, 186 n.81 (1995), *available at* http://www.princeton.edu/~ota/disk1/1995/9552/955207.PDF. Baseload power plants produce electricity continuously, and are often referred to as the backbone of the electricity industry. *Id.* at 150.

[588] Lea Kosnik, *The Potential of Water Power in the Fight Against Global Warming in the US*, 36 ENERGY POL'Y 3252, 3253, 3258 (2008).

Previously intermittent sources such as wind and solar also are used to displace nuclear resources.[589] No less than nine recent studies have concluded that the variability and intermittency of wind and solar resources becomes *easier* to manage the more they are deployed and interconnected, and not the other way around, as some utilities suggest.[590] This is because wind and solar plants help grid operators handle major outages and contingencies elsewhere in the system, since they generate power in smaller increments that are less damaging than unexpected outages from large plants.[591] Researchers at the Georgia Institute of Technology and the Virginia Polytechnic Institute & State University even found that when coupled with a rigorous energy efficiency and demand management program, solar panels could completely displace the electricity currently coming from the two GW Indian Point nuclear facility in New York.[592]

Energy storage technologies allow wind and solar farms to operate as baseload plants, even when interconnecting the two technologies is infeasible. Wind turbines combined with compressed air energy storage technologies allow the capacity factor to rise above 70%, making them "functionally equivalent to a conventional baseload plant," according to Paul Denholm of the National Renewable Energy Laboratory ("NREL").[593] Combining pumped hydro storage with wind and solar can further offset baseload generation. Sovacool noted that

> Bonneville Power Administration, a large federal utility in the Pacific Northwest, uses its existing 7000 MW hydroelectric and pumped hydro storage network to do just that. Starting in 2005, Bonneville offered a new business service to "soak up" any amount of intermittent renewable

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[589] *See* Plant Power: Energy and the Environment, Biomass Energy Education—The Need for Base Load Renewable Energy Resources, http://www.treepower.org/outreach.html (last visited Oct. 27, 2008).

[590] Benjamin K. Sovacool, *The Intermittency of Wind, Solar, and Renewable Electricity Generators: Technical Barrier or Rhetorical Excuse?*, UTIL. POL'Y (forthcoming 2008) (manuscript at 7, on file with author).

[591] *Id.*

[592] Marilyn A. Brown & Benjamin K. Sovacool, *Promoting a Level Playing Field for Energy Options: Electricity Alternatives and the Case of the Indian Point Energy Center*, 1 ENERGY EFFICIENCY 35, 46-48 (2008).

[593] Paul Denholm, Gerald L. Kulcinski & Tracey Holloway, *Emissions and Energy Efficiency Assessment of Baseload Wind Energy Systems*, 39 ENVTL. SCI. & TECH. 1903, 1903 (2005).

> output, and sell it as firm output from its hydro-power network one week later.[594]

Depending on their locations, these storage technologies can have more than 1000 MW of capacity, readily available at potentially low costs.[595] As evidence of their effectiveness, the U.S. enjoys a combined installed capacity of 22.1 GW from pumped hydro and compressed air storage systems.[596]

A. *Cost*

In contrast to gargantuan nuclear units, most renewable power technologies tend to have quicker construction lead times, taking between a few months to five years to implement. There is no need for mining, milling, or leeching uranium, enriching and reprocessing fuel assemblies, or permanently storing radioactive waste. The quicker lead times for renewables enables a more accurate response to load growth, and minimizes the financial risk associated with borrowing hundreds of millions of dollars to finance plants for ten or more years before they start producing a single kW of electricity. Florida Power & Light ("FPL") claimed that it can take a new wind farm from groundbreaking to commercial operation in as little as three to six months.[597] In 2005, Puget Sound Energy proved that FPL's boast was achievable in practice when it brought eighty-three 1.8 MW wind turbines at its Hopkins Ridge Wind Project from groundbreaking to commercial operation in exactly six months and nine days.[598]

Wind turbines are not the only technology that can achieve these kinds of quick lead times. In Nevada, Ormat Nevada Incorporated commissioned a twenty MW geothermal power plant only eight months after groundbreaking on the facility.[599]

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594 Sovacool, *supra* note 590, at 7.

595 U. OF OREGON, APPENDIX A: ENERGY STORAGE TECHNOLOGIES A-2 (2001), *available at* http://zebu.uoregon.edu/2001/ph162/append_overview.pdf.

596 *Id.* at A-4.

597 WORLDWATCH INSTITUTE & CENTER FOR AMERICAN PROGRESS, AMERICAN ENERGY: THE RENEWABLE PATH TO ENERGY SECURITY 16 (2006).

598 PSE poured the first foundation on May 18, 2005 and the Hopkins Ridge Wind Project began commercial operations on Nov. 27, 2005. Roger Garratt, Director, Resource Acquisition & Emerging Technologies, Puget Sound Energy, Exploring Wind & Solar Resources, Presentation at Harvesting Clean Energy Conference 6 (Jan. 29, 2008) (on file with author).

599 Press Release, Ormat Technologies, Inc., ORMAT's State of the Art Geothermal Power Plant, Commissioned Eight Months After Ground Breaking (Nov. 15, 2005), *available at* http://www.nevadarenewables.org/?section=news&id=419.

Solar panels can be built in various sizes, placed in arrays ranging from watts to megawatts, and used in a wide variety of applications, including centralized plants, distributed sub-station plants, grid connected systems for home and business use, and off-grid systems for remote power use.[600] "PV systems have long been used to power remote data relaying stations critical to the operation of supervisory control and data acquisition systems used by electric and gas utilities and government agencies."[601] Solar installations may require even less construction time than wind or geothermal facilities since the materials are prefabricated and modular. The Partnership for Advancing Technology in Housing recently conducted a case study of one PV powered home, finding it required only a two month lead time for the panels.[602]

Utilities and investors can cancel modular plants more easily, so abandoning a project is not a complete loss, and the portability of most renewable systems means recoverable value exists should the technologies need to be resold as commodities in a secondary market.[603] Smaller units with shorter lead times "reduce the risk of buying a technology that . . .becomes obsolete even before it's installed," and quick installations "can better exploit rapid learning," as "many generations of product development can be compressed into the time it would take simply to build a single giant [power plant]."[604] In addition, outage durations tend to be shorter than those from larger plants and repairs for reciprocating gas and diesel engines take less money, time, and skill. As one study concluded, "[t]echnologies that deploy like cell phones and personal computers are faster than those that build like cathedrals. Options that can be mass-produced and adopted by millions of customers will save more carbon and money sooner than those that need specialized institutions, arcane skills, and suppression of dissent."[605]

Amazingly, the United Nations recently calculated in a study utilizing 2007 data collected from dozens of countries, that renewable power sources can produce incredibly cheap power without subsidies. At

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[600] *See supra* notes 574 & 575 and accompanying text.
[601] Sovacool, *supra* note 590, at 5.
[602] *See* PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING, HARNESSING THE SUN: PASSIVE AND ACTIVE SOLAR SYSTEMS OFFER GROWING NICHE MARKET 4 (2006).
[603] LOVINS, *supra* note 525, at 140-41.
[604] *Id.* at 132.
[605] Lovins, *supra* note 300, at 252.

the low end of the range, hydroelectric, geothermal, wind, and biomass can all generate electricity for 7 ¢/kWh or less.[606] See Table 4.

TABLE 4: LEVELIZED COST OF ELECTRICITY (LCOE) FOR RENEWABLE POWER TECHNOLOGIES, WITHOUT SUBSIDIES[607]

Technology	Nominal LCOE ($2007 U.S. ¢/kWh)
Hydroelectric	3 to 7 ¢/kWh
Geothermal	4 to 7 ¢/kWh
Wind	5 to 12 ¢/kWh
Bioelectric	5 to 12 ¢/kWh
Solar Thermal	12 to 18 ¢/kWh
Solar PV	20 to 80 ¢/kWh

Without additional subsidies, most renewable power sources, with their "intermittent" or "low" capacity factors, are already cost-competitive with conventional systems.[608] Their progress is all the more impressive considering that these technologies reached such a point while receiving only a small fraction of the subsidies set aside for conventional systems.

However, even these estimates fail to compare accurately the price of renewable power sources with nuclear power plants, looking at all of their costs and benefits. For example, Thomas Sundqvist analyzed 132 separate estimates for individual generators to determine the extent to which price estimates failed to reflect true costs and benefits.[609] Aware that one could tweak the numbers by looking at only one or two studies, Sundqvist looked at as many studies of renewable energy price estimates as he could—thirty-eight.[610] He found that true life cycle costs, when averaged across studies, represented an additional 8.63¢/kWh for nuclear plants but only 0.29 to 5.20¢/kWh for renewable power generators.[611]

[606] RENEWABLE ENERGY POLICY NETWORK FOR THE 21ST CENTURY, RENEWABLES 2007: GLOBAL STATUS REPORT 14 (2008), *available at* http://www.ren21.net/pdf/RE2007_Global_Status_Report.pdf.
[607] *Id.*
[608] *See id.* at 14-15.
[609] Thomas Sundqvist, *What Causes the Disparity of Electricity Externality Estimates*, 32 ENERGY POL'Y 1753, 1755 (2004).
[610] *Id.*
[611] *Id.*

Taking the mean values from Sundqvist and adjusting them to $2007, the seven technologies with the lowest true costs (including life-cycle costs) are energy efficiency, offshore wind, onshore wind, geothermal, hydroelectric, biomass, and solar thermal.[612]

By contrast, taking the extra cost associated with nuclear power—12.5¢/kWh in $2007—and multiplying it only by nuclear electricity generation in 2006—787 billion kWh–and the extra cost of nuclear energy is stupefying: $98.38 billion.[613] In other words, nuclear power generation created $98.38 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 had to pay for these additional expenses. Instead, the additional life-cycle costs of nuclear energy were shifted to society at large.[614] When all of these "hidden costs" are considered in estimates of the costs and benefits, nuclear power is the eighth most expensive form of power currently available on the market. See Table 5.

TABLE 5: THE TRUE COST OF POWER GENERATORS, $2007[615]

Technology	True Cost, $2007 (¢/kWh)
Offshore Wind	3.4
Onshore Wind	6.7
Geothermal	8
Hydroelectric	8.7
Biomass (Landfill Gas)	12.1
Parabolic Troughs (Solar Thermal)	12.8
Biomass (Combustion)	15.3
Advanced Nuclear	18
Solar Ponds (Solar Thermal)	22.1
Advanced Gas and Oil Combined Cycle	22.7
Gas Oil Combined Cycle	23
Advanced Gas and Oil Combined Cycle with Carbon Capture	27.8
Integrated Gasification Combined Cycle	29.1
Scrubbed Coal	29.5

[612] Sovacool, *supra* note 290, at 18, 25.
[613] *Id.*, adjusted per *supra* note 105.
[614] *See id.* at 19.
[615] *Id.* at 25, adjusted per *supra* note 105.

IGCC with Carbon Capture	31.3
Advanced Combustion Turbine	43.7
Solar Photovoltaic (panel)	44.8
Combustion Turbine	47.2

B. Fuel Availability

All renewable power sources utilize widely abundant, non-depletable, and domestically available forms of fuel. M. King Hubbert, the famous geophysicist who accurately predicted that American oil production would peak about 1970, often remarked that it would be incredibly difficult for people living now, accustomed to exponential growth in energy consumption, to assess the transitory nature of fossil fuels.[616] Hubbert argued that proper reflection could only happen if one looked at a time scale of ten thousand years. On such a scale, Hubbert thought that the complete cycle of the world's exploitation of fossil and nuclear fuels would encompass perhaps 1100 years, with the principal segment of this cycle covering about 300 years.[617] Indeed, some are already projecting that, at current rates of consumption, the world has less than seventy years of supply left.[618] For this reason, Tim Jackson has referred to conventional fuels as "thermodynamic time-bombs."[619]

Thankfully, the Earth receives radiation from the sun in a quantity far exceeding humanity's needs. By heating the planet, the sun generates wind and creates waves.[620] The sun powers the evapo-transpiration cycle, allowing for the generation of power from hydroelectric sources.[621] Plants photosynthesize, creating a wide range of "biomass" products.[622] These resources, in contrast to fossil fuels, have no foreseeable end. As German Parliamentarian Hermann Scheer put it, "[o]ur

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616 M. King Hubbert, *The Energy Resources of the Earth*, *in* ENERGY AND POWER 31 (1971).
617 *Id.*
618 Toni Johnson, *Global Uranium Supply and Demand*, COUNCIL ON FOREIGN RELATIONS, Nov. 2, 2007, *available at* http://www.cfr.org/publication/14705/global_uranium_supply_and_demand.html.
619 Tim Jackson, *Renewable Energy: Great Hope or False Promise?*, 19 ENERGY POL'Y 2, 7 (1991).
620 Ian Burdon, Chair, North East Renewable Energy Group, Presentation at The Great Debate: Development, Sustainability and Environment Conference (Oct. 2005) (transcript available at http://www.thegreatdebate.org.uk/GDDSE2Energy.html).
621 *Id.*
622 *Id.*

dependence on fossil fuels amounts to global pyromania . . . [a]nd the only fire extinguisher we have at our disposal is renewable energy."[623]

Fortunately, the U.S. has an enormous cache of renewable energy resources. A comprehensive study undertaken by the DOE calculated that 93.3 percent of all domestically available energy in the United States was in the form of wind, geothermal, solar, and biomass.[624] We are literally the Saudi Arabia of renewable resources. The DOE estimated, in fact, that the total amount of renewable resources found within the country amounted to a total resource base equivalent to 657,000 billion barrels of oil, more than 46,800 times the national rate of energy consumption per year.[625] Amazingly, this estimate was validated by researchers at U.S. Geological Survey, Oak Ridge National Laboratory ("ORNL"), Pacific Northwest National Laboratory, Sandia National Laboratory, NREL, the Colorado School of Mines, and The Pennsylvania State University.[626]

According to published, nonpartisan, and peer-reviewed estimates from the DOE, EPA, NREL, ORNL, and the Energy Foundation, and not estimates from manufacturers and trade associations, assuming the utilization of existing, commercially available technologies, the country has 3,730,721 MW of *achievable* renewable energy potential by 2010.[627]

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[623] *Quoted in* Kate Connolly, *Endless Possibility*, GUARDIAN, Apr. 16, 2008, at 9, *available at* http://www.guardian.co.uk/environment/2008/apr/16/renewableenergy.windpower.

[624] *See* U.S. DEP'T OF ENERGY, CHARACTERIZATION OF U.S. ENERGY RESOURCES AND RESERVES 19 (1989) (finding that geothermal, solar, biomass, and wind energy represented 613,311 barrels of oil equivalent out of the domestic total of 657,596).

[625] *Id.* at 1.

[626] *Id.* at IV.

[627] SOVACOOL, *supra* note 572, at 95 (2008). As of 2006, the U.S. generated 385,669 MWh of electricity generation from renewable sources. U.S. ENERGY INFORMATION ADMINISTRATION, TABLE 1.11: ELECTRICITY NET GENERATION FROM RENEWABLE ENERGY BY ENERGY USE SECTOR AND ENERGY SOURCE, 2002-2006 1 (2008), *available at* http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/table1_11.pdf. The expansion of wind would cause the greatest increase in renewable power generation. DOE estimates that onshore wind could supply "more than one and a half times the current electricity consumption of the United States." Energy Efficiency and Renewable Energy Program at the U.S. Department of Energy, Wind Energy Resource Potential, http://www1.eere.energy.gov/windandhydro/wind_potential.html (last visited Oct. 27, 2008). Achievable offshore wind potential assumes water depths from zero to 900 meters. The estimate excludes 266,200 MW of offshore potential for waters currently deeper than 900 meters because such technology is not commercially available. *See* Walt Musial, Senior Engineer, Nat'l Renewable Energy Lab., Presentation at Wind Powering America—Annual State Summit: Offshore Wind Energy Potential for the United States 9 (May 19, 2005), http://www.windpoweringamerica.gov/pdfs/workshops/2005_summit/musial.pdf. Achievable solar photo-

Within this estimate, two numbers become significant: first, renewable resources have the capability to provide 3.7 times the total amount of installed electricity capacity operating in 2008;[628] second, the country has harnessed only a whopping 2.9 percent of the potential energy to be found in the nation's available renewable resources.[629]

C. *Land and Waste Storage*

Renewable power sources also require less land area than conventional generators, and most of the land they occupy is still "dual use." When configured in large centralized plants and farms, wind and solar technologies use around ten to seventy-eight square kilometers of land per installed GW per year, but traditional plants can use more than 100

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voltaic potential assumes prices of $2 to $2.50 per installed watt. *See* MAYA CHAUDHARI, LISA FRANTZIS, & TOM E. HOFF, PV Grid Connected Market Potential under a Cost Breakthrough Scenario 7 (The Energy Foundation ed., 2004), *available at* http://www.ef.org/documents/ EF-Final-Final2.pdf. Achievable solar thermal potential includes parabolic troughs. *See* National Renewable Energy Laboratory, Concentrating Solar Power Resource Maps, http://www.nrel.gov/csp/maps.html (last visited Nov. 13, 2008). NREL states that "[r]ealistically, the potential of concentrating solar power in the Southwest could reach hundreds of gigawatts or greater than 10% of U.S. electric supply. . . ." National Renewable Energy Laboratory, Parabolic Trough FAQs, http://www.nrel.gov/csp/troughnet/ faqs.html (last visited Nov. 13, 2008). Achievable geothermal potential was taken from BRUCE D. GREEN & R. GERALD NIX, GEOTHERMAL—THE ENERGY UNDER OUR FEET, NREL/TP-840-40665 (2006), *available at* http://www1.eere.energy.gov/geothermal/pdfs/40665.pdf. Achievable biomass potential (combustion) was converted from estimates pro-vided in OAK RIDGE NAT'L LAB. & U.S. DEP'T OF ENERGY, BIOMASS AS FEEDSTOCK FOR A BIOENERGY AND BIOPRODUCTS INDUSTRY: THE TECHNICAL FEASIBILITY OF A BILLION-TON ANNUAL SUPPLY, DOE/GO-102995-2135 (2005), *available at* http://feedstockreview.ornl.gov/pdfbillion_ton_vision.pdf. Achievable biomass potential (landfill gas) was taken from U.S. EPA LANDFILL METHANE OUTREACH PROGRAM, AN OVERVIEW OF LANDFILL GAS ENERGY IN THE UNITED STATES (2008), *available at* www.epa.gov/lmop/docs/overview.pdf. Achievable hydroelectric potential excludes all nationally protected lands and areas, and is taken from U.S. DEP'T OF ENERGY, WATER RESOURCES OF THE UNITED STATES WITH EMPHASIS ON LOW HEAD/ LOW POWER RESOURCES, DOE/ID-11111 (2004), *available at* http://hydropower.inel.gov/ resourceassessment/pdfs/03-11111.pdf.

[628] "The U.S. electric power industry's total installed generating capacity was 1,089,807 megawatts . . .as of December 31, 2007." Edison Electric Institute, Industry Statistics, http://www.eei.org/industry_issues/industry_overview_and_statistics/industry_statistics/index.htm (last visited Oct. 27, 2008).

[629] *See* SOVACOOL, *supra* note 572. Specifically, installed capacity in 2007 in the U.S. amounted to 106,950 MW out of the achievable installed capacity of 3,730,721 MW.

square kilometers of land per year to produce the same amount of electricity.[630]

In open and flat terrain, newer large-scale wind plants require about sixty acres per MW of installed capacity, but the amount drops to as little as two acres per MW for hilly terrain.[631] While this may sound like a lot, only 5%, or three acres, of this area is actually occupied by turbines, access roads, and other equipment; 95% remains free for other compatible uses such as farming or ranching.[632] Alan Nogee from Union of Concerned Scientists ("UCS") estimates that only a small fraction of contiguous land in the country, ranging from between 0.11% to 0.26%, would be needed to supply 20% of the nation's electricity from wind energy, and of that land, more than 98% would be available for other uses.[633]

At the High Winds Project in Solano, California, for example, eight different landowners host ninety separate 1.8 MW wind turbines that total 162 MW of electricity capacity, but are still able to use about 96% of farmland around and between the turbines.[634]

When integrated into building structures and facades, solar PV systems would require no new land at all. The California Exposition Center in Sacramento, California, for example, fully integrates 540 kW of PV into a parking lot.[635] Indeed, NREL concluded that, "a world relying on PV would offer a landscape almost indistinguishable from the landscape we know today."[636] The Energy Policy Initiatives Center at the University of San Diego recently estimated that the city could construct 1532 GWh of

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[630] *See* Cooper & Sovacool, *supra* note 411, at 123; MARK DIESENDORF, U. OF NEW S. WALES, REFUTING FALLACIES ABOUT WIND POWER (August 27, 2006), *available at* http://www.ceem.unsw.edu.au/content/userDocs/RefutingWindpowerFallacies.pdf; NATIONAL RENEWABLE ENERGY LABORATORY, PV FAQS: HOW MUCH LAND WILL PV NEED TO SUPPLY OUR ELECTRICITY? 1-2 (Feb. 2004), *available at* http://www.nrel.gov/docs/fy04osti/35097.pdf.

[631] American Wind Energy Association, Wind Web Tutorial: Wind Energy and the Environment, http://www.awea.org/faq/wwt_environment.html (last visited Sept. 29, 2008).

[632] *Id.*

[633] ALAN NOGEE, UNION OF CONCERNED SCIENTISTS, RESPONSES TO SENATE QUESTIONS 15-16 (2005), *available at* http://www.ucsusa.org/assets/documents/clean_energy/nogee-responses-3-25-05.pdf.

[634] TERRAPASS, HIGH WINDS FACILITY PROFILE, *available at* http://www.terrapass.com/investments/highwinds.pdf.

[635] Scott Sklar, *What Does the Future Hold for Solar Energy Farms?*, RENEWABLE ENERGY WORLD, Dec. 20, 2006, http://www.renewableenergyworld.com/rea/news/ate/story?id=46904 (last visited Oct. 31, 2008).

[636] NATIONAL RENEWABLE ENERGY LABORATORY, *supra* note 630, at 1.

solar PV relying only on available roof area downtown.[637] In fact, the Worldwatch Institute noted that "[s]olar power plants that concentrate sunlight in desert areas require 2,540 acres per billion kWh. On a lifecycle basis, this is less land than a comparable coal or hydro-power plant [generating the same amount of electricity] requires . . . ."[638]

High-yield food crops leech nutrients from the soil, but the cultivation of biomass crops on degraded lands can help stabilize soil quality, improve fertility, reduce erosion, and improve ecosystem health.[639] Perennial energy crops improve land cover and enable plants to form an extensive root system, adding to the organic matter content of the soil.[640] Agricultural researchers in Iowa, for instance, discovered that planting grasses or poplar trees in buffers along waterways captured runoff from corn fields, making streams cleaner.[641] "Prairie grasses, with their deep roots, build up topsoil, putting nitrogen and other nutrients into the ground."[642] Twigs and leaves decompose in the field after harvesting, enhancing soil nutrient composition. Biomass crops can also create better wildlife habitats, since they frequently include native plants that attract a greater variety of birds and small animals, and poplar trees, sugar cane, and other crops can be grown on land unsuitable for food production.[643]

D. Water

Renewables such as wind and solar PV do not consume or withdraw water, and hydroelectric, geothermal, and biomass facilities do not risk radioactive contamination of water supplies. The DOE acknowledges that renewables could play a key role in averting a "business-as-usual scenario" where "consumption of water in the electric sector could grow substantially."[644] Another DOE report noted that "[g]reater additions of

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[637] SCOTT ANDERS & TOM BIALEK, TECHNICAL POTENTIAL FOR ROOFTOP PHOTOVOLTAICS IN THE SAN DIEGO REGION 2 (2006), *available at* http://www.sandiego.edu/epic/publications/documents/060309_asespvpotentialpaperfinal.pdf.
[638] WORLDWATCH INSTITUTE & CENTER FOR AMERICAN PROGRESS, *supra* note 597, at 20.
[639] *See* UNION OF CONCERNED SCIENTISTS, HOW BIOMASS ENERGY WORKS 5-6 (2006), *available at* http://www.ucsusa.org/assets/documents/clean_energy/how_biomass_energy_works_factsheet.pdf.
[640] *Id.* at 5.
[641] *Id.*
[642] *Id.*
[643] *Id.* at 1-2.
[644] U.S. DEP'T OF ENERGY, *supra* note 351, at 10.

wind to offset fossil, hydro-power, and nuclear assets in a generation portfolio will result in a technology that uses no water, offsetting water-dependent technologies."[645] Dr. Ed Brown, Director of Environmental Programs at the University of Northern Iowa, estimated that a 100 W solar panel would save approximately 2000 to 3000 gallons of water over the course of its lifetime.[646] Similarly, Dr. Brown concluded that "billions of gallons of water can be saved every day" through the greater use of renewable energy technologies.[647]

The American Wind Energy Association conducted one of the most comprehensive assessments of renewable energy and water consumption. Their study estimated that wind power uses less than 1/600th as much water per unit of electricity produced as does nuclear, 1/500th as much as coal, and 1/250th as much as natural gas-small amounts of water are used to clean wind and solar systems.[648] By displacing centralized fossil fuel and nuclear generation, clean power sources such as energy efficiency and renewables can conserve substantial amounts of water that would otherwise be withdrawn and consumed for the production of electricity.

E. *Lifecycle Emissions of Pollutants*

Every single renewable power technology is less greenhouse-gas-intensive than any sized nuclear power plant. A single, one MW wind turbine running at only 30% of capacity for one year, for example, displaces more than 1500 tons of CO_2, 2.5 tons of sulfur dioxide, 3.2 tons of nitrogen oxides, and sixty pounds of toxic mercury emissions.[649] One study assessing the environmental savings of a 580 MW wind farm located on the Altamont Pass near San Francisco, California, concluded that the turbines displaced hundreds of thousands of tons of air pollutants each year that would have otherwise resulted from fossil fuel com-

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645 U.S. DEP'T OF ENERGY, THE WIND/WATER NEXUS 2 (2006), *available at* http://www.nrel.gov/docs/fy06osti/37790.pdf.

646 Ed Brown, *Renewable Energy Brings Water to the World*, RENEWABLE ENERGY WORLD, Aug. 23, 2005, http://www.renewableenergyworld.com/rea/news/reinsider/story?id=35664 (last visited Oct. 29, 2008).

647 *Id.*

648 American Wind Energy Association, *supra* note 631.

649 ARI REEVES, RENEWABLE ENERGY POLICY PROJECT, WIND ENERGY FOR ELECTRIC POWER: A REPP ISSUE BRIEF 4 (Frederick Beck ed., 2003), *available at* http://www.repp.org/articles/static/1/binaries/wind issue brief_FINAL.pdf.

bustion.[650] The study estimated that the wind farm will displace more than twenty-four billion pounds of nitrogen oxides, sulfur dioxides, particulate matter and CO_2 over the course of its twenty year lifetime—enough to cover the entire city of Oakland in a pile of toxic pollution forty stories high.[651]

Dedicated biomass electrical plants release no net CO_2 emissions into the atmosphere, as long as they avoid combusting fossilized fuel, and produce fewer toxic gases. One study conducted by the Center for Energy Policy and Technology found that combined cycle biomass gasification plants produce one twentieth the amount of pollutants emitted by coal-fired power plants, and one tenth the pollution of equivalent natural gas plants.[652] Landfill capture generators and anaerobic digesters harness methane and other noxious gases from landfills and transform them into electricity.[653] This does not just produce useful energy, but also displaces greenhouse gases that would otherwise escape into the environment.[654]

Geothermal plants also have immense air quality benefits. "A typical geothermal plant using hot water and steam to generate electricity emits about 1 percent of the sulfur dioxide ("SO_2"), less than 1 percent of the nitrous oxide ("NO_x"), and 5 percent of the CO_2 emitted by a coal-fired plant of equal size."[655] Its airborne emissions are "essentially nonexistent" because geothermal gases are not released into the atmosphere during normal operation.[656] Another study calculated that the geothermal plants currently in operation throughout the U.S. avoid

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[650] PowerWorks, Health and Climate Benefits of Altamont Pass Wind Power, http://www.powerworks.com/HealthAndClimate.aspx (last visited Sept. 29, 2008).

[651] *Id.*

[652] AUSILIO BAUEN, JEREMY WOODS & REBECCA HAILES, BIOELECTRCICITY VISION: ACHIEVING 15% OF ELECTRICITY FROM BIOMASS IN OECD COUNTRIES BY 2020 25 (2004), *available at* http://www.wwf.de/fileadmin/fm-wwf/pdf_misc-alt/klima/biomassereport.pdf.

[653] *See* U.S. Dep't of Energy, Guide to Tribal Energy Development: Biomass Energy Resources, http://www1.eere.energy.gov/tribalenergy/guide/biomass.html (last visited Sept. 29, 2008).

[654] *See* California Integrated Waste Management Board, Climate Change and Solid Waste Management: Landfill Methane Capture Strategy, http://www.ciwmb.ca.gov/Climate/Landfills/default.htm (last visited Sept. 29, 2008).

[655] WENDELL A. DUFFIELD, U.S. DEP'T OF THE INTERIOR & JOHN H. SASS, U.S. GEOLOGICAL SURVEY, GEOTHERMAL ENERGY-CLEAN POWER FROM THE EARTH'S HEAT 26 (2003).

[656] *Id.*

32,000 tons of NO_x, 78,000 tons of SO_2, 17,000 tons of particulate matter, and sixteen million tons of CO_2 emissions every single year.[657]

All forms of hydroelectric generation combust no fuel, meaning they produce little to no air pollution in comparison with conventional power plants. Luc Gagnon and Joop F. van de Vate conducted a full lifecycle assessment of hydroelectric facilities, and focused on the activities related to building of dams, dykes, and power stations; decaying biomass from flooded land, where plant decomposition produces methane and CO_2; and the thermal backup power needed when seasonal changes cause hydroelectric plants to run at partial capacity.[658] They found that typical emissions of greenhouse gases for hydro-power were still thirty to sixty times less than those from equally sized fossil-fueled stations.[659]

In terms of climate change, and greenhouse gases, the IAEA estimates that when direct and indirect carbon emissions are included, coal plants are about seven times more carbon intensive than solar and fifty times more carbon intensive than wind technologies.[660] Natural gas fares little better, at two times the carbon intensity of solar and twenty seven times the carbon intensity of wind.[661] In the U.S., the DOE estimates that "every kilowatt-hour (kWh) of renewable power avoids the emission of more than one pound of carbon dioxide."[662] According to data compiled by UCS, achieving twenty percent renewables penetration by 2020 would reduce CO_2 emissions by 434 million metric tons, the equivalent of taking nearly seventy-one million automobiles off the road.[663]

An almost identical study published in *Energy Policy* found that biomass facilities were about ten times cleaner than the best coal technologies and that wind, solar electric, and hydroelectric systems were almost

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657 Alyssa Kagel & Karl Gawell, *Promoting Geothermal Energy: Air Emissions Comparison and Externality Analysis*, ELEC. J., Aug.-Sept. 2005, at 92.
658 Luc Gagon & Joop F. van de Vate, *Greenhouse Gas Emissions from Hydro-power: The State of Research in 1996*, 25 ENERGY POL'Y 7, 8 (1997).
659 *Id.* at 7.
660 *See* Joseph V. Spadaro, Lucille Langlois & Bruce Hamilton, *Greenhouse Gas Emissions of Electricity Generation Chains: Assessing the Difference*, IAEA BULL., Mar. 2000, at 19, 21.
661 *Id.*
662 U.S. DEP'T OF ENERGY ET AL., GUIDE TO PURCHASING GREEN POWER: RENEWABLE ELECTRICITY, RENEWABLE ENERGY CERTIFICATES, AND ON-SITE RENEWABLE GENERATION 2 (2004), *available at* http://www.epa.gov/greenpower/documents/purchasing_guide_for_web.pdf.
663 UNION OF CONCERNED SCIENTISTS, SUCCESSFUL STRATEGIES: RENEWABLE ELECTRICITY STANDARDS 2 (2008), *available at* http://www.ucsusa.org/assets/documents/clean_energy/climate-solutions-res-12-06-update.pdf.

100 times cleaner than the cleanest coal-fueled system.[664] Martin Pehnt from the Institute for Energy and Environmental Research in Heidelberg conducted lifecycle analyses of fifteen separate distributed generation and renewable energy technologies and found that all but one—solar PV—emitted much less carbon dioxide or other greenhouse gases per kilowatt hour than nuclear reactors.[665] In an analysis using updated data, researchers from Brookhaven National Laboratory found that current estimates of the greenhouse gas emissions for a typical solar PV system range from twenty-nine to thirty-five grams of carbon dioxide equivalent/ kWh,[666] significantly less than the equivalent emissions for nuclear power.[667]

Nuclear energy proponents may argue that these estimates compare base-load energy sources, such as nuclear, to intermittent or non-dispatchable sources, such as wind and solar PV. However, if these updated numbers are correct, then renewable energy technologies are two to seven times more effective on a per kWh basis than nuclear power at fighting climate change. Therefore, even the deployment of much more intermittent renewable capacity to generate equivalent amounts of energy would still more effectively address climate change than relying on deployment of base-load nuclear or fossil fueled generators.

F. *Safety*

Unlike the scores of nuclear accidents discussed above, not a single major energy accident in the past century involved small-scale renewable energy systems or energy efficiency, whereas fossil fueled, nuclear, and larger hydroelectric facilities were responsible for 279 accidents totaling forty-one billion dollars in damages and 182,156 deaths.[668] An investigation of energy-related accidents in the European

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[664] *See* Luc Gagnon, Camille Belanger, & Yohji Uchiyama, *Life-Cycle Assessment of Electricity Generation Options: The Status of Research in Year 2001*, 30 ENERGY POL'Y 1267, 1271 (2002).

[665] *See* Martin Pehnt, *Dynamic Life Cycle Assessment of Renewable Energy Technologies*, 31 RENEWABLE ENERGY 55, 60 (2006). Specifically, Pehnt found that all renewable energy sources but solar PV emitted less than sixty-six grams of carbon dioxide per kWh. This is as compared to nuclear plants, which emit an average of sixty-six grams of carbon dioxide per kWh. Sovacool, *supra* note 26, at 2954.

[666] Vasilis M. Fthenakis, Hyung Chul Kim & Erik Alsema, *Emissions from Photovoltaic Life Cycles*, 42 ENVTL. SCI. TECH. 2168, 2170 (2008).

[667] *Id.* at 2170-71.

[668] Sovacool, *supra* note 442, at 1805-06.

Union found that nuclear power was forty-one times more dangerous than equivalently sized coal, oil, natural gas, and hydroelectric projects.[669] Nuclear plants were at risk of killing about forty-six people for every GW-year of power produced.[670] A database of major industrial accidents from 1969 to 1996 compiled by the Paul Scherrer Institute found that 31%, or 4290 out of 13,914, were related to the fossil fuel sector.[671] Another study concluded that about 25% of the fatalities caused by severe accidents worldwide in the period 1970 to 1985 occurred in the conventional energy sector.[672] Even if we were to assume that a massive expansion of renewable energy systems may increase the likelihood of industrial accidents within the sector, any reasonable estimate would find that renewables are a far safer alternative to nuclear or fossil fuels.

G. Security

Deploying renewable power systems in targeted areas provides an effective alternative to constructing new transmission and distribution lines, transformers, local taps, feeders, and switchgears, especially in congested areas or regions where the permitting of new transmission networks is difficult. One study found that up to 10% of total distribution capacity in ten year high growth scenarios could be cost-effectively deferred using distributed generation technologies such as solar PV and solar thermal.[673]

PG&E, the largest investor-owned utility in California, built an entire power plant in 1993 to test the grid benefits of a 500 kW solar PV plant. PG&E found that the generator improved voltage support, minimized power losses, lowered operating temperatures for transformers on the grid, and improved transmission capacity.[674] The benefits were so

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669 Stefan Hirschberg & Andrzej Strupczewski, *How Acceptable?: Comparison of Accident Risks in Different Energy Systems*, IAEA BULL., Mar. 1999, at 25, 27, *available at* http://www.iaea.org/Publications/Magazines/Bulletin/Bull411/article6.pdf.
670 *Id.* at 30.
671 Stefan Hirschberg et al., *Severe Accidents in the Energy Sector: Comparative Perspective*, 111 J. HAZARDOUS MATERIALS 57, 58 (2004).
672 Andrew F. Fritzsche, *Severe Accidents: Can They Occur Only in the Nuclear Production of Electricity?*, 12 RISK ANALYSIS 327, 327 (1992).
673 LOVINS, *supra* note 525, at 234 (*quoting* R.G. Pratt et al., Potential for Feeder Equipment Upgrade Deferrals in a Distributed Utility, Presentation at the American Council for an Energy Efficient Economy 1994 Summer Conference 2.649.12 (Aug. 28, 1994), *available at* http://www.osti.gov/bridge/servlets/purl/10183237-KVUDd2/native/10183237.pdf.
674 Howard J. Wenger, Thomas E. Hoff & Brian K. Farmer, *Measuring the Value of*

large that the small-scale solar PV generator was twice as valuable as the utility had originally estimated, with projected benefits of 14 to 20 ¢/kWh.[675] The experience convinced PG&E to consider the use of solar PV as a *substitute* for greater investments in T&D infrastructure. Using conventional approaches, planners proposed an upgrade of 230-kV and 60-kV lines serving seven substations in the San Francisco area, estimated to cost PG&E $355 million, in 1990 dollars.[676] However, PG&E ultimately discovered that a cheaper alternative was to strategically deploy distributed 500-kW solar PV plants connected to distribution feeders.[677] By investing in such locally sited solar PV projects, PG&E found that it could defer a significant number of its transmission upgrades and ultimately saved $193 million, or more than half the present cost of the expansion plan, by installing solar panels.[678]

Since modern renewable technology enables utilities to remotely dispatch hundreds of scattered units, it also improves the ability of utilities to handle peak load and grid congestion problems. Another PG&E analysis, comparing fifty 1-MW distributed solar PV plants to one .50-MW central plant in Kerman, California, found that the grid advantages, in forms of load savings and congestion, more than offset the disadvantages, in terms of high capital cost and interconnection, of installing the new generation.[679]

The use of renewables also diversifies the "fuels" used to generate electricity, thereby minimizing the risk of fuel interruptions, shortages, and accidents. Together, renewable power technologies can increase security by reducing the number of large and vulnerable targets on the grid, providing insulation for the grid in the event of an attack, and minimizing foreign dependence on uranium. While renewable technologies are constantly derided as intermittent or variable, it is far more certain to rely on the sun shining and the wind blowing than to

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Distributed Photovoltaic Generation: Final Results of the Kerman-Grid Support Project, *in* 1994 IEEE FIRST WORLD CONFERENCE ON PHOTOVOLTAIC ENERGY CONVERSION, VOLUME 1 793 (IEEE ed., 1994).

[675] *Id.* at 795.

[676] Charles D. Feinstein, Ren Orans & Stephen W. Chapel, *The Distributed Utility: A New Electric Utility Planning and Pricing Paradigm*, 22 ANN. REV. ENERGY & ENV'T 155, 159-60 (1997).

[677] *Id.* at 160-62.

[678] *Id.* at 162.

[679] *See* T. Hoff & D.S. Shugar, *The Value of Grid-Support Photovoltaics in Reducing Distribution System Losses*, 10 IEEE TRANSACTIONS ON ENERGY CONVERSION 569-76 (1995).

rely on a system that saboteurs could easily disrupt by blowing up a single power station or snipping a few transmission lines. Renewables are far more resilient and far less attractive a target to possible attackers than the ever-tempting nuclear power plant, spent fuel repository, or uranium mine.

CONCLUSION

Nuclear power generators cannot be mass produced. 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 T&D systems. The nuclear system is thus subject to highly uncertain projections about uranium availability, is centrally administered by a technocratic elite, and is vulnerable to the ebb and flow of international politics, requiring garrison-like security measures at multiple points in the supply chain.

Renewable power technologies, in contrast, reduce dependence on foreign sources of fuel, 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 affects 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 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, leeching, transporting, storing, sequestering, and polluting of land, and in some cases can restore degraded ecosystems.

Our choice of an energy future thus boils down to a simple question: Do we want a nuclear economy, centrally administered by technical specialists, completely reliant on government subsidies, dependent on future breakthroughs in research, sure to promote international proliferation and worsen inequity and vulnerability, which requires draconian security measures, wastefully generates and distributes electricity, remains based on highly uncertain projections about theoretical nuclear designs and available fuel, fouls the nations water and land, and trashes the planet for many future generations?

Or do we want a small to medium scale, decentralized electricity system that is more efficient, independent from government funding, 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 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 to enrich 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 to harness free and clean fuels widely available in the United States and throughout the world. Policymakers should peek beyond the smoke-and-mirrors 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.

APPENDIX TABLE A: ESTIMATED AND ACTUAL COSTS OF 75 NUCLEAR POWER PLANTS IN THE UNITED STATES

Plant	Estimated Costs at Start of Construction (Millions of 1990$)	Realized Cost (Millions of 1990$)	Plant	Estimated Costs at Start of Construction (Millions of 1990$)	Realized Cost (Millions of 1990$)
Arkansas Nuclear 1	$375	$624	McGuire 1	$414	$1,299
Arkansas Nuclear 2	$460	$1,081	McGuire 2	$472	$1,269
Beaver Valley 1	$513	$1,176	Millstone 2	$474	$936
Beaver Valley 2	$913	$4,099	Millstone 3	$1,046	$3,998
Braidwood	$762	$2,723	Nine Mile Point 2	$1,008	$5,281
Browns Ferry 1	$303	$876	North Anna 1	$515	$1,555
Browns Ferry 2	$227	$657	North Anna 2	$445	$932
Browns Ferry 3	$227	$657	Palisades	$294	$422
Brunswick 1	$430	$718	Palo Verde 1	$1,234	$4,185
Brunswick 2	$352	$933	Palo Verde 2	$920	$2,291
Byron 1	$741	$2,518	Peach Bottom 2	$532	$1,418
Byron 2	$552	$2,072	Peach Bottom 3	$423	$560
Callaway	$1,136	$2,999	Perry 1	$981	$3,729
Calvert Cliffs 1	$357	$1,142	Rancho Seco	$389	$876
Calvert Cliffs 2	$287	$765	River Bend 1	$718	$4,091
Catawba 1	$559	$2,074	Salem 1	$462	$1,829
Clinton	$710	$4,058	Salem 2	$378	$1,497
Cooper	$378	$1,053	San Onofre	$1,134	$3,343
Crystal River 3	$362	$948	San Onofre 3	$1,056	$2,078
Davis-Besse 1	$484	$1,359	Sequoyah 1	$524	$1,560
Diablo Canyon 1	$445	$3,750	Sequoyah 2	$429	$1,276
Diablo Canyon 2	$459	$2,333	Shoreham	$300	$4,139
Donald C. Cook 1	$657	$1,303	St. Lucie 1	$365	$1,130
Duane Arnold	$340	$716	St. Lucie 2	$893	$1,876
Edwin I. Hatch 1	$417	$951	Surry 1	$419	$761
Edwin I. Hatch 2	$653	$922	Surry 2	$329	$437
Fermi 2	$596	$3,783	Susquehanna 1	$1,320	$2,654
Fort Calhoun 1	$222	$520	Susquehanna 2	$753	$2,274
Grand Gulf 1	$1,105	$3,473	Three Mile Island 1	$323	$1,008

Plant	Estimated Costs at Start of Construction (Millions of 1990$)	Realized Cost (Millions of 1990$)	Plant	Estimated Costs at Start of Construction (Millions of 1990$)	Realized Cost (Millions of 1990$)
Harris 1	$898	$3,999	Three Mile Island 2	$668	$1,287
Hope Creek	$1,592	$4,598	Trojan	$582	$1,145
Indian Point	$477	$859	Virgil Summer 1	$630	$1,707
Joseph M. Farley 1	$387	$1,463	Waterford 3	$617	$3,303
Joseph M. Farley 2	$406	$1,228	Wolf Creek 1	$1,143	$2,835
Kewaunee	$297	$559	WPSS 2	$786	$4,008
LaSalle 1	$715	$1,918	Zion 1	$593	$768
LaSalle 2	$532	$1,255	Zion 2	$430	$752
Limerick 1	$921	$3,980			
			Total	**$45,247**	**$144,650**

APPENDIX TABLE B: LIST OF 76 MAJOR NUCLEAR POWER ACCIDENTS 1952 TO 2008

Date	Location	Description	Fatalities	Cost (in millions 2006$)
December 12, 1952	Chalk River, Ontario, Canada	Hydrogen explosion damage reactor interior, releasing 30 kilograms of uranium oxide particles	0	$45
October 8, 1957	Windscale, United Kingdom	Fire ignites plutonium piles, destroys surrounding dairy farms	33	$78
May 24, 1958	Chalk River, Ontario, Canada	Fuel rod catches fire and contaminates half of facility	0	$67
July 26, 1959	Simi Valley, California, United States	Partial core meltdown takes place at Santa Susana Field Laboratory's Sodium Reactor Experiment	0	$32
January 3, 1961	Idaho Falls, Idaho, United States	Explosion at National Reactor Testing Station	3	$22
October 5, 1966	Monroe, Michigan, United States	Sodium cooling system malfunctions at Enrico Fermi demonstration breeder reactor causing partial core meltdown	0	$19
May 2, 1967	Dumfries and Galloway, Scotland	Fuel rod catches fire and causes partial meltdown at the Chaplecross Magnox nuclear power station	0	$76
January 21, 1969	Lucens, Canton of Vaud, Switzerland	Coolant system malfunctions at underground experimental reactor	0	$22
May 1, 1969	Stockholm, Sweden	Malfunctioning valve causes flooding in Agesta pressurized heavy water nuclear reactor, short circuiting control functions	0	$14

August 11, 1973	Palisades, Michigan, United States	Steam generator leak causes manual shut-down of pressurized water reactor operated by the Consumers Power Company	0	$10
March 22, 1975	Browns Ferry, Alabama, United States	Fire burns for seven hours and damages more than 1,600 control cables for three nuclear reactors, disabling core cooling systems	0	$240
February 22, 1977	Jaslovske Bohunice, Czechoslovakia	Mechanical failure during fuel loading causes severe corrosion of reactor and release of radioactivity into the plant area, necessitating total decommission	0	$1,700
February 4, 1979	Surry, Virginia, United States	Virginia Electric Power Company manually shuts down Surry Unit 2 in response to replace failed tube bundles in steam generators	0	$12
March 28, 1979	Middletown, Pennsylvania, United States	Equipment failures and operator error contribute to loss of coolant and partial core meltdown at Three Mile Island nuclear reactor	0	$2,400
February 11, 1981	Florida City, Florida, United States	Florida Light & Power manually shut down Turkey Point Unit 3 after steam generator tubes degrade and fail	0	$2
March 8, 1981	Tsuruga, Japan	278 workers exposed to excessive levels of radiation during repairs of Tsuruga nuclear plant	0	$3

February 26, 1982	San Clemente, California, United States	Southern California Company shut down San Onofre Unit 1 out of concerns for earthquake	0	$1
March 20, 1982	Lycoming, New York, United States	Recirculation system piping fails at Nine Mile Point Unit 1, forcing 2 year shutdown	0	$45
March 25, 1982	Buchanan, New York, United States	Multiple water and coolant leaks cause damage to steam generator tubes and main generator, forcing the New York Power Authority to shut down Indian Point Unit 3 for more than one year	0	$56
February 12, 1983	Fork River, New Jersey, United States	Oyster Creek nuclear plant fails safety inspection, forced to shut down for repairs	0	$32
February 26, 1983	Pierce, Florida, United States	Workers discover damaged thermal shield and core barrel support at St. Lucie Unit 1, necessitating 13 month shutdown	0	$54
September 7, 1983	Athens, Alabama, United States	Tennessee Valley Authority discovers extensive damage to recirculation system pipeline, requiring extended shutdown	0	$34
September 23, 1983	Buenos Aires, Argentina	Operator error during fuel plate reconfiguration cause meltdown in an experimental test reactor	1	$65
December 10, 1983	Plymouth, Massachusetts, United States	Recirculation system piping cracks and forces Pilgrim nuclear reactor to shutdown	0	$4
April 18, 1984	Delta, Pennsylvania, United States	Philadelphia Electric Company shuts down Peach Bottom Unit 2 to due to extensive recirculation system and equipment damage	0	$18

June 13, 1984	Platteville, Colorado, United States	Moisture intrusion causes 6 fuel rods to fail at Fort St. Vrain nuclear plant, requiring emergency shutdown from Public Service Company of Colorado	0	$22
September 15, 1984	Athens, Alabama, United States	Safety violations, operator error, and design problems force 6 year outage at Browns Ferry Unit 2	0	$110
March 9, 1985	Athens, Alabama, United States	Instrumentation systems malfunction during startup, convincing the Tennessee Valley Authority to suspend operations at all three Browns Ferry Units	0	$1,830
June 9, 1985	Oak Harbor, Ohio, United States	Loss of feedwater provokes Toledo Edison Company to inspect Davis-Besse facility, where inspectors discover corroded reactor coolant pumps and shafts	0	$23
August 22, 1985	Soddy-Daisy, Tennessee, United States	Tennessee Valley Authority Sequoyah Units 1 and 2 fail NRC inspection due to failed silicon rubber insulation, forcing 3 year shutdown, followed by water circulation problems that expose workers to excessive levels of radiation	0	$35
December 26, 1985	Clay Station, California, United States	Safety and control systems unexpectedly fail at Rancho Seco nuclear reactor, ultimately leading to the premature closure of the plant	0	$672

April 11, 1986	Plymouth, Massachusetts, United States	Recurring equipment problems with instrumentation, vacuum breakers, instrument air system, and main transformer force emergency shutdown of Boston Edison's Pilgrim nuclear facility	0	$1,001
April 26, 1986	Kiev, Ukraine	Mishandled reactor safety test at Chernobyl nuclear reactor causes steam explosion and meltdown, necessitating the evacuation of 300,000 people from Kiev and dispersing radioactive material across Europe	4,056	$6,700
May 4, 1986	Hamm-Uentrop, Germany	Operator actions to dislodge damaged fuel rod at Experimental High Temperature Gas Reactor release excessive radiation to 4 square kilometers surrounding the facility	0	$267
May 22, 1986	Normandy, France	A reprocessing plant at Le Hague malfunctions and exposes workers to unsafe levels of radiation and forces five to be hospitalized	0	$5
March 31, 1987	Delta, Pennsylvania, United States	Philadelphia Electric Company shuts down Peach Bottom units 2 and 3 due to cooling malfunctions and unexplained equipment problems	0	$400
April 12, 1987	Tricastin, France	Areva's Tricastin fast breeder reactor leaks coolant, sodium, and uranium hexachloride, injuring seven workers and contaminated water supplies	0	$50

December 17, 1987	Hesse, Germany	Stop valve fails at Biblis Nuclear Power plant and contaminates local area	0	$13
December 19, 1987	Lycoming, New York, United States	Fuel rod, waste storage, and water pumping malfunctions force Niagara Mohawk Power Corporation to shut down Nine Mile Point Unit 1	0	$150
September 10, 1988	Surry, Virginia, United States	Refueling cavity seal fails and destroys internal pipe system at Virginia Electric Power Company's Surry Unit 2, forcing 12 month outage	0	$9
March 5, 1989	Tonopah, Arizona, United States	Atmospheric dump valves fail at Arizona Public Service Company's Palo Verde Unit 1, leading to main transformer fire and emergency shut down	0	$14
March 17, 1989	Lusby, Maryland, United States	Inspections at Baltimore Gas & Electric's Calvert Cliff Units 1 and 2 reveal cracks at pressurized heater sleeves, forcing extended shutdowns	0	$120
September 10, 1989	Tarapur, Maharashtra, India	Operators at the Tarapur nuclear power plant discover that the reactor had been leaking radioactive iodine through its cooling structures and discover radiation levels of iodine—129 more than 700 times normal levels. Repairs to the reactor take more than one year.	0	$78

November 24, 1989	Greifswald, East Germany	Electrical error causes fire in the main trough that destroys control lines and 5 main coolant pumps and almost induces meltdown	0	$443
November 17, 1991	Scriba, New York, United States	Safety and fire problems force New York Power Authority to shut down the FitzPatrick nuclear reactor for 13 months	0	$5
April 21, 1992	Southport, North Carolina, United States	NRC forces Carolina Power & Light Company to shut down Brunswick Units 1 and 2 after emergency diesel generators fail	0	$2
May 13, 1992	Tarapur, Maharashtra, India	A malfunctioning tube causes the Tarapur nuclear reactor to release 12 curies of radioactivity	0	$2
February 3, 1993	Bay City, Texas, United States	Auxiliary feedwater pumps fail at South Texas Project Units 1 and 2, prompting rapid shutdown of both reactors	0	$3
February 27, 1993	Buchanan, New York, United States	New York Power Authority shut down Indian Point Unit 3 after AMSAC system fails	0	$2
March 2, 1993	Soddy-Daisy, Tennessee, United States	Equipment failures and broken pipes cause Tennessee Valley Authority to shut down Sequoyah Unit 1	0	$3
March 31, 1993	Bulandshahr, Uttar Pradesh, India	The Narora Atomic Power Station suffers a fire at two of its steam turbine blades, damaging the heavy water reactor and almost leading to a meltdown	0	$220

December 25, 1993	Newport, Michigan, United States	Detroit Edison Company prompted to shut down Fermi Unit 2 after main turbine experienced catastrophic failure due to improper maintenance	0	$67
April 6, 1994	Tomsk, Russia	Pressure buildup causes mechanical failure at Tomsk-7 Siberian Chemical Enterprise plutonium reprocessing facility, exploding a concrete bunker and exposing 160 onsite workers to excessive radiation	0	$44
January 14, 1995	Wiscasset, Maine, United States	Steam generator tubes unexpectedly crack at Maine Yankee nuclear reactor, forcing Maine Yankee Atomic Power Company to shutdown the facility for 1 year	0	$62
February 2, 1995	Kota, Rajasthan, India	The Rajasthan Atomic Power Station leaks radioactive helium and heavy water into the Rana Pratap Sagar River, necessitating a two year shutdown for repairs		$280
May 16, 1995	Salem, New Jersey, United States	Ventilation systems fail at Public Service Electric & Gas Company's Salem Units 1 and 2	0	$34
February 20, 1996	Waterford, Connecticut, United States	Leaking valve forces Northeast Utilities Company to shut down Millstone Units 1 and 2, further inspection reveals multiple equipment failures	0	$254

September 2, 1996	Crystal River, Florida, United States	Balance-of-plant equipment malfunction forces Florida Power Corporation to shut down Crystal River Unit 3 and make extensive repairs	0	$384
September 5, 1996	Clinton, Illinois, United States	Reactor recirculation pump fails, prompting Illinois Power Company to shut down Clinton boiling water reactor	0	$38
September 20, 1996	Senaca, Illinois, United States	Service water system fails and prompts Commonwealth Edison to close LaSalle Units 1 and 2 for more than 2 years	0	$71
September 9, 1997	Bridgman, Michigan, United States	Ice condenser containment systems fail at Indiana Michigan Power Company's D.C. Cook Units 1 and 2	0	$11
June 18, 1999	Prefecture, Japan	Control rod malfunction set off uncontrolled nuclear reaction	0	$34
September 30, 1999	Ibaraki Prefecture, Japan	Workers at the Tokaimura uranium processing facility try to save time by mixing uranium in buckets, killing two and injuring 1,200	2	$54
February 16, 2002	Oak Harbor, Ohio, United States	Severe corrosion of control rod forces 24 month outage of Davis-Besse reactor	0	$143
April 10, 2003	Paks, Hungary	Damaged fuel rods hemorrhage spent fuel pellets, corroding heavy water reactor	0	$37
August 9, 2004	Fukui Prefecture, Japan	Steam explosion at Mihama Nuclear Power Plant kills 5 workers and injures dozens more	5	$9

April 19, 2005	Sellafield, United Kingdom	20 metric tons of uranium and 160 kilograms of plutonium leak from a cracked pipe at the Thorp nuclear fuel reprocessing plant	0	$65
June 16, 2005	Braidwood, Illinois, United States	Exelon's Braidwood nuclear station leaks tritium and contaminates local water supplies	0	$41
August 4, 2005	Indian Point, New York, United States	Entergy's Indian Point Nuclear Plant, located on the Hudson River, leaks tritium and strontium into underground lakes from 1974 to 2005		$30
March 6, 2006	Erwin, Tennessee, United States	Nuclear fuel services plant spills 35 liters of highly enriched uranium, necessitating 7 month shutdown	0	$98
December 24, 2006	Jadugoda, India	One of the pipes carrying radioactive waste from the Jadugoda uranium mill ruptures and distributes radioactive materials more than 100 square kilometers	0	$25
July 18, 2007	Kashiwazaki, Japan	The Tokyo Electric Power Company announces that their Kariwa nuclear plant leaks 315 gallons of radioactive water into the Sea of Japan after being damaged by a 6.8 magnitude earthquake	0	$2

June 4, 2008	Ljubljana, Slovenia	Slovenian regulators shut down the Krsko nuclear power plant after the primary cooling system malfunctions and coolant spills into the reactor core	0	$1
June 14, 2008	Fukushima Province, Japan	A 7.2 magnitude earthquake cracks reactor cooling towers and spent fuel storage facilities, spilling 19 liters of radioactive wastewater and damaging the Tokyo Electric Power Company's No. 2 Kurihara Power Plant	0	$45
July 4, 2008	Ayrshire and Suffolk, United Kingdom	Two British Energy nuclear reactors (the Largs and the Sizewell B facilities) shutdown unexpectedly after their cooling units simultaneously malfunction, damaging emergency systems and triggering blackouts	0	$10
July 13, 2008	Tricastin, France	The nuclear power operator Areva reports that dozens of liters of wastewater contaminated with uranium are accidentally poured on the ground and runoff into a nearby river	0	$7
Total			**4,100**	**$19,076**