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The Nuclear Fuel Cycle, Global Security, and Climate Change: Weighing the Costs and Benefits of Nuclear Power Expansion

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THE NUCLEAR FUEL CYCLE, GLOBAL SECURITY, AND CLIMATE CHANGE: WEIGHING THE COSTS AND BENEFITS OF NUCLEAR POWER EXPANSION

Christopher E. Paine *

I. INTRODUCTION: A VALUES FRAMEWORK FOR ANALYSIS

Those who call themselves environmentalists and political progressives have long sought the emergence of an environmentally sustainable global economy and the continuing reduction and eventual elimination of inconceivably destructive nuclear arsenals, which, like climate change, pose an existential threat to human civilization and the natural world on which human life depends. Finding compatible paths to sustainability for both human populations and natural systems, while averting and ultimately eliminating the threat of nuclear war, remain the critical challenges for human survival in the twenty-first century.

An explicit corollary of longstanding efforts to reduce and eventually eliminate the threat posed by nuclear arsenals has been an equally strong commitment to preventing the proliferation of nuclear weapons or improvised nuclear explosive devices to additional states, sub-national groups, or international terrorists. Looking back, it is interesting to note that the first Earth Day, which marked the beginning of the modern environmental movement, and the entry into force of the Nuclear Non-Proliferation Treaty ("NPT") occurred within a few weeks of each other in the spring of 1970.[1] While certainly distinct from each other, the environmental and nuclear disarmament movements in the United

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1. *See* U.S. Envtl. Prot. Agency, EPA Environmental Progress, http://www.epa.gov/earthday/history.htm (last visited Feb. 24, 2010); *see also* Treaty on the Non-Proliferation of Nuclear Weapons, *opened for signature* July 1, 1968, 21 U.S.T. 483, 729 U.N.T.S. 161 (entered into force Mar. 5, 1970) [hereinafter Nuclear Non-Proliferation Treaty].

States have grown up together, culminating in the recent election of a president that strongly supports both a global clean energy transformation and more rapid and tangible progress toward the global elimination of nuclear weapons.[2]

Some organizations, political parties, and prominent individuals around the world have taken the position that nuclear power generation is inherently so dangerous—either in its own right or in connection with nuclear weapons—that it should be stricken from the menu of eligible global energy options as soon as possible.[3] This view is not, as nuclear power supporters would have us believe, to be automatically disparaged as intellectually disreputable or simply dismissed as a knee-jerk, tree-hugger response to a complex issue. If the twin imperatives of nuclear nonproliferation and nuclear disarmament are to be taken seriously, then there are fundamental political, historical, and technical arguments that can be mustered to support the view that nuclear power should be phased out, particularly in the context of a longer-term strategy for ensuring global sustainability and international security. But this remains a minority view in the United States and probably in most other countries, which continue to voice their support for the "peaceful atom" and for vindication of their rights under the NPT to share in the peaceful uses of nuclear technology.[4]

2. *See, e.g.*, Press Release, Office of the Press Secretary, The White House, Joint Statement Between Prime Minister Dr. Singh and President Obama (Nov. 24, 2009), http://www.whitehouse.gov/the-press-office/joint-statement-between-prime-minister-dr-singh-and-president-obama (describing President Obama's support for global clean energy and nuclear disarmament).

3. *E.g.*, Greenpeace International, End the Nuclear Age, http://www.greenpeace.org/international/campaigns/nuclear (last visited Feb. 24, 2010).

4. Article IV of the NPT states, in pertinent part:

> 1. Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with articles I and II of this Treaty.
> 2. All the Parties . . . have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy.

Nuclear Non-Proliferation Treaty, *supra* note 1, art. IV. Unfortunately, the dual military-civil potential of nuclear fuel cycle facilities creates an inherent tension between the exercise of this inalienable right and the non-proliferation of nuclear weapons. For this reason, Article IV requires that peaceful cooperation be undertaken *in conformity with* the basic obligation of the nuclear-weapon States in Article I "not in any way to assist, encourage, or induce any non-nuclear-weapon State to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices," and with the basic obligation of the non-

If a U.S. consensus on responsible utilization of nuclear power can be said to have evolved over the last fifty years, it might be summarized as follows: Where nuclear energy activities do not obviously threaten international security or the health and safety of the public or pose an unacceptable risk of environmental contamination to future generations, these activities should be allowed under careful regulation, provided that the industry, its government promoters, and its nominally independent regulators continue to act responsibly in fulfilling their mandates to protect workers and the public from routine radiation hazards while maintaining an operational discipline and nuclear safety culture that reduces the risk of serious nuclear accidents to the lowest possible level consistent with continued practical reliance on nuclear technology.

But when governments and industry have sought to commercialize inherently sensitive dual-use nuclear activities—such as the separating and recycling of weapons-usable plutonium from spent fuel or developing and demonstrating costly and erratic liquid-metal-cooled fast reactors for breeding additional weapons-usable plutonium, which would convey bomb-making capabilities and materials into the global marketplace or into the hands of states with obvious nuclear weapons ambitions[5]—the policy consensus over nuclear energy has fractured, leading to hard fought battles over export policies and development budgets for nuclear technology and materials.[6] Given the negligible potential for cost-effective nuclear power generation represented by plutonium fuel cycle technologies,[7] critics have long pointed out that there is no economic benefit to be foregone by giving precedence to nuclear weapons proliferation concerns,[8] and the case for nuclear restraint has more often than not prevailed over narrow bureaucratic and nuclear industrial interests.[9] In other words, it has not

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nuclear-weapons States in Article II "not to seek or receive any assistance in the manufacture of nuclear weapons or other nuclear explosive devices." *Id.* arts. I, II, IV. The Parties are thus also obligated not to engage in peaceful nuclear cooperation when this cooperation would assist a non-nuclear-weapon State in acquiring nuclear weapons.

5. Benjamin K. Sovacool & Christopher Cooper, *Nuclear Nonsense: Why Nuclear Power Is No Answer to Climate Change and the World's Post-Kyoto Energy Challenges*, 33 WM. & MARY ENVTL. L. & POL'Y REV. 1, 31–32 (2008).

6. *See* William C. Sailor, *The Case Against Reprocessing*, 14 F. FOR APPLIED RES. & PUB. POL'Y, 108, 108 (1999).

7. *See id.*

8. *See id.* at 111–12.

9. *See id.* at 108.

yet been necessary for the United States to compromise core international security objectives in order to continue reaping the benefits of commercial nuclear power.

The question for today, however, is whether the dire threat of climate change should cause us to re-evaluate this stance. Should the progressive community mute its immediate nuclear nonproliferation concerns or compromise its longer-term nuclear disarmament and clean energy goals by acceding to a large decarbonizing global deployment of nuclear power?

Before tackling this question from a factual and analytical perspective, it is important to specify the values that one is seeking to maximize by choosing one energy path over another. More often than not it is these unstated *value choices*—rather than divergent views on strictly factual issues—that determine the salience of some facts rather than others, thereby prompting divergent perceptions of the risks and benefits based on the same body of factual information. This is frequently the case with debates about nuclear power, which can make the public dialogue particularly non-productive and frustrating.

This analysis brings the following set of values to bear on its evaluation of the risks and benefits of a major nuclear power expansion to combat climate change:

1. We inhabit and share a "global commons": local, regional, and national energy choices have global implications and impacts—e.g., China's decision to allow construction of a new coal-fired power plant at the rate of one per week does not affect China alone and is not strictly an internal Chinese matter.

2. While environmental tradeoffs are inevitable in our increasingly crowded world, environmental progress in one area should not, if possible, be pursued at the expense of environmental degradation somewhere else—e.g., we should not clean the air over Atlanta or Richmond by substituting low-carbon uranium fuels for coal if these fuels are extracted in a way that despoils the land and groundwater resources of the Rocky Mountain West, or anywhere else, for that matter.

3. All forms of energy production—even the "green" ones—have harmful environmental impacts that must be identified, comprehensively assessed, compared, and either mitigated or re-

jected as unacceptable based on a full life-cycle, complete supply-chain analysis.

4. Priority should be given to deployment of affordable energy resources that are low-carbon and environmentally sustainable–i.e., that do not result in permanent depletion of natural resources or irreparable harm to the natural systems on which all life depends.

5. Priority should likewise be given to energy alternatives that are socially and geopolitically sustainable, i.e., that can be implemented and replicated without displacing human populations, destroying communities and cultural resources, triggering harmful macroeconomic effects on vulnerable populations, aggravating regional security concerns, or invoking invidious political distinctions between nations. Many of the problems surrounding creation of large dams, global markets for biofuels, and the spread of nuclear power implicate this criterion.

6. When possible, wholesale and retail energy prices should reflect the relative environmental harms and other social costs that are imposed by extraction and use of each available resource, thereby harnessing the power of markets rather than bureaucrats to redirect capital investment and consumption in an environmentally sustainable direction.

7. Costs, harms, and risks that are not fully reflected in relative prices should be minimized directly through tax and financial policy innovations, legislative mandates, or more stringent regulatory regimes, and clearly abusive practices—e.g., mountaintop removal mining of coal, aquifer contamination from coal-bed methane and uranium mining—should be banned outright.

8. The climate crisis is an urgent one, and therefore decarbonization of the global energy system must be pursued swiftly and efficiently by prioritizing low-carbon resources for deployment in order of (1) their current and reasonably foreseeable cost-effectiveness for carbon displacement—as measured in dollars per ton of carbon dioxide ("CO_2") averted—and (2) their performance in a balance-of-harms test against the other critical environmental and social values noted above.

In other words, cost-effective and timely carbon displacement is an enormously significant criterion, but it is not the only criterion. Regrettably, there are many possible paths to environmental degradation and geopolitical chaos on a planetary scale. Carbon loading of the atmosphere is only one of them, so the task is inherently broader and more demanding than mapping decarbonization pathways alone.

Before assessing how nuclear power expansion stacks up against these fundamental values, some background on the current distribution and plausible scalability of the current global nuclear power resource is essential, so that individuals may form their own judgment about whether the practical potential of this resource is worthy of all the attention that has recently been lavished upon it. There is currently something of a mismatch between the expectations of some prominent U.S. politicians and what the United States and global nuclear power industry can plausibly deliver over the next several decades. Closing this gap likely will prove important to achieving a political compromise on climate and energy legislation that can fundamentally alter pricing signals in the energy marketplace and launch the U.S. economy on the long march away from fossil fuels.

II. THE GLOBAL NUCLEAR POWER RESOURCE

Nuclear power already plays a significant role in avoiding greenhouse gas emission and is a major energy resource in some advanced industrial countries. In 2008 nuclear power supplied 2,601 terawatt-hours of electricity globally,[10] providing approximately 15% of global grid-connected electricity production, 19.7% in the United States, 24.9% in Japan, 35.6% in South Korea, and 76.2% in France.[11]

At the end of 2009, there were 437 operational nuclear units worldwide with a nameplate-generating capacity of about 370 gigawatts ("GWe").[12] Since 1988, the average annual increase in the total number of reactor units operating worldwide has been 1.4% per year.[13] During this period, much of the approximately 44 GWe

10. World Nuclear Ass'n, World Nuclear Power Reactors & Uranium Requirements, http://www.world-nuclear.org/info/reactors.html (last visited Feb. 24, 2010).

11. *Id.*

12. Int'l Atomic Energy Agency, Nuclear Power Plants Information: Operational Reactors by Age, http://www.iaea.org/cgi-bin/db.page.pl/pris.reaopag.htm (last visited Feb. 24, 2010).

13. Int'l Atomic Energy Agency, Nuclear Power Plants Information: Number of Oper-

growth in capacity has come from the de- ployment of larger individual units relative to those retired and the uprating or modification of existing units to produce more power.[14]

A. *Setting the Stage for a "Nuclear Renaissance"*

The commercial nuclear power industry has existed for about fifty years but still remains concentrated in thirty of the world's 195 countries,[15] and 81% of reactors are located in just ten countries: the United States (121 reactors), France (68), Japan (57), Russia (31), South Korea (20), India (17), Canada (25), the United Kingdom (29), Germany (30), and Ukraine (17).[16] The steep capital costs and demanding technical requirements for safe and secure operation of nuclear reactors and their supporting fuel cycle have constituted formidable barriers to entry and have kept nuclear power out of reach for most countries.[17]

Most forays by developing countries into nuclear power generation have been either inconsequential relative to their overall electricity requirements, economically disastrous, or both. For example, from 2006 to 2008, Pakistan's two civil reactors achieved only an average capacity factor of 64.9%, while India's seventeen reactors achieved 74.2%.[18] Lifetime capacity utilization factors for these two countries are even lower: 44.3% and 66.7%, respectively.[19] Notable exceptions have been Taiwan, whose six

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ating Reactors by Age (Feb. 24, 2010), http://www.iaea.org/cgi-bin/db.page.pl/pris.agereac.htm (including data for years 1966 through 2009).

14. *See* WORLD NUCLEAR ASS'N, NUCLEAR POWER IN THE WORLD TODAY 3 (2009), http://www.world-nuclear.org/info/inf01.html (stating that world capacity rose by 44 GWe between 1990 and 2006).

15. *See* Int'l Atomic Energy Agency, Nuclear Power Plants Information: Nuclear Share in Electricity Generation in 2008, http://www.iaea.org/cgi-bin/db.page.pl/pris.nucshare.html (last visited Feb. 24, 2010).

16. Int'l Atomic Energy Agency, Nuclear Power Plants Information: Lifetime Energy Availability Factor, http://www.iaea.org/programmes/a2 (follow "World Summary" hyperlink; then follow the "Energy Availability Factor" hyperlink under "Lifetime factors by Country up to 2008") (last visited Feb. 24, 2010).

17. *See* Todd R. La Porte & Craig W. Thomas, *Regulatory Compliance and the Ethos of Quality Enhancement: Surprises in Nuclear Power Plant Operations*, 5 J. OF PUB. ADMIN. RES. & THEORY 109, 109–12 (1995).

18. Int'l Atomic Energy Agency, Nuclear Power Plants Information: Last Three Years Unit Capability Factor, http://www.iaea.org/programmes/a2 (follow "World Summary" hyperlink; then follow "Unit Capability Factor" hyperlink under "Last three years factors by Country up to 2008") (last visited Feb. 24, 2010).

19. Int'l Atomic Energy Agency, Nuclear Power Plants Information: Last Three Years Unit Capability Factor, http://www.iaea.org/programmes/a2 (follow "World Summary"

reactors operated at 90.5% capacity over this same three-year period, South Korea, which operated at 92.1%, and Mexico, which operated its two nuclear units at 89.1%.[20]

Perhaps even more notable, however, has been the poor average performance of some of the leading nuclear power countries. From 2006 to 2008, nuclear-leader Japan operated its reactors at 65% of their rated capacity, while the United Kingdom operated at 62.1% and Canada at 82.3%.[21] Even the ostensible global leader in nuclear power technology, France, managed only 81%, less than the world average of 82.4%.[22] A possible explanation is France's overbuilding of nuclear baseload capacity, allowing nuclear units to cover the maintenance and refueling outages of other nuclear units.[23] The performance of the 104 U.S. nuclear units over the same period was significantly better, averaging 91.4% of rated capacity.[24] Given this mixed operating record and the prolonged plateau in the nuclear share of global electricity production, there is ample cause for skepticism regarding the claim that a major expansion of nuclear power must be a key component of any global strategy to combat global warming.

What is a realistic estimate of the nuclear industry's potential to displace carbon emissions globally and in the United States over the next twenty years, which we assume to be the period during which reactors currently under construction, planned and proposed would come online? Using the Natural Resources Defense Council ("NRDC") Nuclear Power Database of world nuclear power plants in operation, under construction, planned, proposed, and anticipated for replacement, and by making reasonable assumptions about probable unit lifetimes and license extensions for the current fleet of operating reactors, the NRDC Nuclear

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hyperlink; then follow "Unit Capability Factor" hyperlink under "Lifetime factors by country up to 2008") (last visited Feb. 24, 2010).

20. *Id.*

21. *Id.*

22. *See id.*

23. *See* C. PIERRE ZALESKI: THE FUTURE OF NUCLEAR POWER IN FRANCE, THE EU AND THE WORLD FOR THE NEXT QUARTER-CENTURY 2 (Feb. 2005), *available at* http://www.dauphine.fr/cgemp.Publications/Articles/zaleskifutureo%20nuclearpower.pdf. The downside of this French strategy is the country's obvious deficit in low-carbon peaking power assets, leading to costly imports of fossil generation from the rest of Europe during periods of peak demand. *See* Robin Pagnamenta, *France Imports UK Electricity As Plants Shut*, TIMES ONLINE, July 3, 2009, at http://business.timesonline.co.uk/tol/business/industry_sectors/utilities/article6626811.ece.

24. Int'l Atomic Energy Agency, *supra* note 18.

Program has prepared a set of estimates that can serve to guide our thinking on this matter.[25]

If one assumes that all the nuclear capacity included within the twenty-year planning horizon of all nuclear power programs worldwide is actually achieved, including twenty-year license extensions for the entire existing fleet of operating U.S. reactors, then nuclear power worldwide could grow at an average annual rate of 3.9%,[26] increasing by approximately 22 GWe/year on average.[27] But this growth rate includes offsetting planned retirements, averaging 4.1 GWe/year, that will occur mainly in Europe, such as those in Sweden, Germany, and Spain.[28] Policy reversals in some if not all of these countries may occur as they confront the need for carbon reductions. Removing retirements from the calculation, the average annual growth rate in new nuclear capacity is 26 GWe/year over the twenty-year span.[29] This rate is comparable to the first wave of global nuclear power expansion, occurring during the mid-1970s and 1980s. For example, the average number of reactors connected to the grid between 1974 and 1989 was about 21 GWe/year.[30] The maximum annual growth in nuclear capacity occurred in 1984 when 31 GWe was connected to the grid.[31] The average annual growth in nuclear capacity between 1975 and 1985 was about 18 GWe/year.[32]

In sum, the growth rates projected for a nuclear renaissance appear feasible from an historical perspective, but, as investors in the stock market well know, a record of past growth is no guarantee of future performance. There are many differences between

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25. *See* Natural Res. Def. Council, NRDC Nuclear Power Database (2010) (on file with author) [hereinafter NRDC Nuclear Power Database]. The NRDC data are derived primarily from three sources: the World Nuclear Association Reactors Database; The International Atomic Energy Agency ("IAEA") Power Reactor Information System ("PRIS"); and Nuclear Engineering International's World Nuclear Industry Handbook.

26. *See* INT'L ATOMIC ENERGY AGENCY, ENERGY, ELECTRICITY AND NUCLEAR POWER ESTIMATES FOR THE PERIOD UP TO 2030, at 17 tbl.3 (2009), *available at* http://www-pub.iaea.org/MTCD/publications/PDF/RDS1-29_web.pdf [hereinafter ENERGY, ELECTRICITY AND NUCLEAR POWER] (estimating that worldwide nuclear energy output could rise from 376 GWe in 2010 to as high as 807 GWe annually in 2030).

27. *See id.*

28. *See* NRDC Nuclear Power Database, *supra* note 25.

29. *See supra* notes 27–28 and accompanying text.

30. *See* INT'L ATOMIC ENERGY AGENCY, NUCLEAR POWER REACTORS IN THE WORLD 21 tbl.7 (2009), *available at* http://www-pub.iaea.org/MTCD/publications/PDF/RDS2-29_web.pdf [hereinafter NUCLEAR POWER REACTORS].

31. *Id.*

32. *See id.*

current conditions and the last nuclear build-out that could affect future build rates, including (1) many of the best nuclear plant sites have already been taken and there is greater competition for the remaining sites;[33] (2) there is vastly increased competition for the inland freshwater resources needed for reactor cooling;[34] (3) today, nuclear power must compete with clean technologies not present during the first build-out;[35] and (4) nuclear safety regulations and environmental standards have increased significantly in the majority of countries that are realistic candidates for nuclear deployments.[36]

Between 1995 and 2005, there was an average of 3.1 new reactor construction starts per year.[37] From 2005 to 2008, the number of reactor construction starts per year increased from three to ten reactors.[38] Concerns have been raised about whether worldwide capacity for heavy forging of reactor vessels would substantially constrain the rate of new constructions going forward.[39] Currently, there are forty-four reactors under construction worldwide, totaling 39 GWe of nameplate capacity.[40] Given that nuclear expansion plans by their very nature take a long time to fulfill and can be adjusted to avert supply bottlenecks before concrete is poured, strong demand for nuclear plants likely will elicit the required level of investment in heavy forging capacity such that, when measured over a twenty year span, this factor will not be a significant restraint on the growth of nuclear power.

33. *Cf.* Green America, Ten Strikes Against Nuclear Power, http://www.greenamericatoday.org/programs/climate/dirtyenergy/nuclear.cfm (last visited Feb. 24, 2010) (explaining that few sites are suitable for nuclear plants and many communities resist placement of such plants nearby).

34. *See* JEFFREY HOFFMAN ET AL., ESTIMATING FRESHWATER NEEDS TO MEET 2025 ELECTRICITY GENERATING CAPACITY FORECASTS 1 (2004), *available at* http://www.netl.doe.gov/technologies/coalpower/ewr/pubs/Estimating%20Freshwater%20Needs%20to%202025.pdf.

35. Natural Res. Def. Council, Nuclear Facts 3 (2007) *available at* http://www.nrdc.org/nuclear/plants/plants.pdf (stating that wind and solar power are emerging as formidable competitors to nuclear energy).

36. *See* Toni Johnson, Council on Foreign Relations, *Challenges for Nuclear Power Expansion*, Aug. 11, 2008, http://www.cfr.org/publication/16886/ (stating that environmental and safety concerns during the 1970s and 1980s spurred regulation in the United States and Europe).

37. *See* NUCLEAR POWER REACTORS, *supra* note 30, at 21 tbl.7.

38. *Id.*

39. *See, e.g.*, Peter Alpem, *U.S. Cedes Capability for Largest Nuclear Forgings*, INDUSTRY WEEK, June 24, 2009, http://www.industryweek.com/articles/u-s-_cedes_capability_for_largest_nuclear_forgings_19453.aspx?ShowAll=1.

40. ENERGY, ELECTRICITY AND NUCLEAR POWER, *supra* note 26, at 13 tbl.1.

From the end of 2009 until the end of 2059, the NRDC model calculates the carbon offset for reactors in the following categories: currently operational, 16.7 gigaton ("Gt"); under construction, 4.1 Gt; planned, 9.9 Gt; proposed, 18.9 Gt; and replacement reactors (in Canada, France and Switzerland only), 2.3 Gt.[41] Taken together, these amount to a total carbon offset of 51.8 Gt during the fifty-year period.[42] Were nuclear capacity maintained at its current level for fifty years, the carbon offset would be 29.5 Gt.[43] Thus, the net carbon offset is calculated to be 22.3 Gt,[44] or 0.9 Pacala-Socolow climate wedges, for those who are acquainted with this mode of thinking about carbon displacement.[45]

In reality, over the next fifty years, global nuclear power's contribution to carbon reductions could be substantially different from 0.9 wedges due to a number of uncertainties. Foremost, we have assumed a reactor planning horizon of only twenty years,

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41. NRDC Nuclear Power Database, *supra* note 25.

42. *Id.*

43. *Id.*

44. *Id.* The net carbon offset is calculated by subtracting the offset resulting from maintaining current nuclear capacity, 29.5 Gt, from the offset that would result if plants that are under construction, planned, proposed, or that will serve as replacements are factored in, 51.8 Gt.

45. S. Pacala & R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies*, SCIENCE, Aug. 13, 2004, at 968. To demonstrate the breadth and scope of any effort required to stabilize world carbon emissions over a fifty-year period, Princeton professors Stephen Pacala and Robert Socolow developed a handy concept they called "stabilization wedges." *Id.* Each wedge represents a capacity for displacing one Gt of carbon per year at the end of fifty years, or a total of 25 Gts over the fifty-year period. *Id.* Pacala and Socolow presented fifteen possible technology wedges, not all completely independent of each other, and argued that at least seven of these wedges, or a larger number of partial wedges, would be necessary to stabilize global atmospheric CO_2 concentrations where stabilization is defined as a reduction of atmospheric concentrations of carbon dioxide at twice the pre-industrial level. *Id.* at 968, 970. One of their wedges represented global expansion of nuclear capacity. *Id.* at 971. Approximately 700 GWe of new net nuclear capacity would be needed globally by the mid-2050s to achieve a wedge, assuming that this capacity would displace new, highly efficient coal generation. *Id.* Since the Pacala-Socolow wedges are triangular, this translates into [½ x 700 GWe x 50 year =] 17,500 GWe-years (GWe-y) of nuclear capacity. *See id.* This added nuclear capacity can be expressed mathematically as a linear net addition of 700 GWe over fifty years, or a constant 350 GWe sustained over fifty years. *See id.* While the Pacala-Socolow analysis assumes that nuclear energy displaces highly efficient coal plants (50% thermal efficiency), actual carbon displacement is a function of other resource options, growth rates, relative operating costs, and the current generating mix. *See id.* at 969. To the extent that nuclear energy replaces less thermally efficient coal capacity or other high-emitting resources, the amount of nuclear energy generation needed to displace a wedge of carbon would be less; if nuclear displaces natural gas, hydro, or other lower carbon emitting resources, the amount of nuclear energy capacity needed to displace a wedge of carbon would be greater.

and it is not possible to predict the net number of new reactors that could be built beyond this time horizon. In addition, reactor licenses could be extended beyond what we have assumed—from sixty to eighty years for most pressurized water reactors increasing the carbon offsets from currently operational reactors. Also, many of the "proposed" reactors may never be built and some could be deferred beyond 2030, which would substantially reduce the carbon offset contribution from the proposed reactors. The contribution from planned reactors similarly could be reduced as schedules slip because the extent of carbon displacement varies with the time of its inception. Specifically, early arriving carbon reductions are worth more than later arriving ones due to the tendency of CO_2 to accumulate in the atmosphere.[46] As noted above, the most favorable carbon offset scenario assumes no erosion—i.e., 100% replacement—of the current installed base of reactors as these reach the end of their licensed lifetimes of typically forty to sixty years. However, this assumption may not hold in some or even many cases. What types and mix of low-carbon generating capacities will ultimately replace the current installed base of reactors is an open question at this point.

If one assumes that all of the reactors currently planned or are built, but that none of the less certain proposed reactors are built, then the estimate of the likely contribution of nuclear power to climate change mitigation is only on the order of a tenth of a wedge.[47] However, if all of the currently proposed reactors are built in addition to those now under construction and planned, and the existing capacity is replaced as it wears out so that global reactor capacity plateaus and is sustained at the higher 2030 level in a manner analogous to what occurred after the first wave of nuclear power expansion, then contribution of nuclear power to climate change mitigation would be approximately one Pacala-Socolow wedge, or about 14% of the target level for global carbon displacement.[48] While it is always hazardous to venture a prediction in such matters, based on the non-carbon factors discussed in this paper that bear on the future of nuclear power, a qualitative net assessment today would place the most likely outcome some-

46. *See* Gary W. Harding, How Much of Atmospheric Carbon Dioxide Accumulation Is Anthropogenic? (1998), http://www.strom.clemson.edu/becker/prtm320/commons/carbon3.html.

47. *See* NRDC Nuclear Power Database, *supra* note 25.

48. *Id.*

where closer to 1/10 of a climate wedge, as opposed to 9/10 of one.[49]

B. *Whither the U.S. "Nuclear Renaissance?"*

After two decades of stagnant to slow growth in the U.S. nuclear power sector, consisting of power uprates to existing units and completion of a few long-delayed units that began construction in the 1980s,[50] the looming prospect of federal regulation to reduce carbon emissions from fossil-fueled power plants and the availability of taxpayer-guaranteed financing and other subsidies for construction of new nuclear reactors have raised the prospect of a second coming for U.S. nuclear power.[51] The first coming, some readers may remember, ended in what *Forbes* magazine called "the largest managerial disaster in business history," with losses running into the hundreds of billions of dollars.[52]

A recent retrospective estimate of these losses performed for the Union of Concerned Scientists calculated the losses at $50 billion (in 2006 dollars) for the 117 plants that were cancelled or abandoned during construction during the period 1972–1985, and estimated $200–$300 billion for the cost overruns built into the population of plants that were ultimately completed and put into the rate base.[53] When electricity markets were restructured in some parts of the country during the 1990s to separate power generation and distribution functions, and thereby provide for some price competition in the supply of electricity, many of the nuclear plants turned out to have stranded costs that impeded their sale by their integrated utility owners.[54] In the new market environment, these capital costs could not be recovered within the time horizon of those willing to invest in, or finance, long-

49. *Id.*

50. *See* WORLD NUCLEAR ASS'N, NUCLEAR POWER IN THE USA 1 (2010), *available at* http://www.world-nuclear.org/info/inf41.html.

51. Andrew Paterson, Conditions Shift in Favor of Nuclear Power (July 3, 2006), http://www.america.gov/st/energy-english/2008/May/2006/July/20080520183442WRybakcuH0.4799463.html.

52. James Cook, *Nuclear Follies*, FORBES, Feb. 11, 1985, at 82.

53. DAVID SCHLISSEL ET AL., UNION OF CONCERNED SCIENTISTS, NUCLEAR LOAN GUARANTEES: ANOTHER TAXPAYER BAILOUT AHEAD? 11 (2009), *available at* http://www.ucsusa.org/assets/documents/nuclear_power/nuclear-loan-guarantees.pdf

54. *See id.* at 11–13.

term energy assests.[55] States securitized some $40 billion of these stranded costs and secured the bonds with charges to ratepayers, who ultimately bore the financial burden of this second nuclear bailout.[56]

The current second coming of nuclear power appears to be on a similar trajectory, except the potential recourse to a taxpayer bailout is being arranged in advance through a massive federal loan guarantee program.[57] This supposed "nuclear renaissance" began modestly enough in 2002 with a Department of Energy ("DOE") program, Nuclear Power 2010,[58] to share half the cost of licensing two new standard reactor designs using the United States Nuclear Regulatory Commission's ("NRC") reformed, but unproven, licensing process, with the intention of operating them "in the 2010 time frame."[59] It is an article of faith—albeit a false one—among many nuclear power proponents that public participation in the original adjudicatory licensing process created under the Atomic Energy Act was the primary cause of the industry's travails during the implosion of the first nuclear build-out.[60] The new licensing process—reshaped to the nuclear industry's specifications in 1989 when nuclear power's growth prospects looked dim—promised a greatly streamlined path to reactor deployment.[61]

At the option of the applicant, environmental impact issues involved in siting a new reactor could be addressed in an Early Site Permit ("ESP") process and resolved apart from the consideration of nuclear design safety or other contentious issues, such as the availability of other objectively reasonable electricity supply op-

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55. *See id.* at 19.

56. *Id.* at 13.

57. *See id.* at 19–20.

58. U.S. Dep't of Energy, Nuclear Power 2010, http://nuclear.gov/np2010/overview.html (last visited Feb. 24, 2010).

59. Peter A. Bradford, *The Nuclear Renaissance Meets Economic Reality*, BULL. ATOMIC SCIENTISTS, Nov./Dec. 2009, at 60, 60.

60. Anthony Z. Roisman et al., *Regulating Nuclear Power in the New Millennium (The Role of the Public)*, 26 PACE ENVTL. L. REV. 317, 318–21 (2009), (explaining the constructive historical role played by public interveners in the nuclear licensing process).

61. LARRY PARKER & MARK HOLT, CONG. RESEARCH SERV., NUCLEAR POWER: OUTLOOK FOR NEW U.S. REACTORS 3, 6 (2009), *available at* http://www.fas.org/sgp/crs/misc/RL33442.pdf. The NRC regulations governing reactor licensing can be found at 10 C.F.R. §§ 52.0–.303 (2009), *available at* http://www.nrc.gov/reading-rm/doc-collections/cfr/part052/.

tions.[62] This banking of a qualified reactor site can be done years ahead of the applicant settling on a specific reactor design for deployment, and future environmental challenges would be foreclosed so long as the range of nominal environmental impacts approved in the ESP bounded those of the design ultimately chosen.[63]

Reactor safety and other design issues, such as blast and fire resistance, would also be resolved early in the licensing process—not through the previous adjudicatory public hearing process, with intervener rights of discovery and cross-examination—by settling them in a separate agency notice-and-comment rulemaking process dominated by reactor vendors and NRC staff, with distinctly limited opportunities for public intervention.[64] This process would presumably result in the early adoption of individual rules certifying the safety of a limited number of standardized, and presumably more cost-effective, paper designs, which could later be cross-referenced by any combined license applicant using that design.[65] If all went well, any potential "show stopper" safety issues would be identified early and resolved in a final rule for each reactor design, making it very difficult, if not impossible, for interveners to contest these issues at the subsequent construction and operating license stage.[66]

The former two-step licensing requirements—(1) approving construction of a specific safe reactor design at an environmentally suitable site, and (2) attesting to the readiness of the reactor as built to operate safely—were merged into a single combined Construction and Operating License ("COL").[67] The intent was to

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62. *See* U.S. Nuclear Regulatory Comm'n, Early Site Permit Applications for New Reactors, http://www.nrc.gov/reactors/new-reactors/esp.html (last visited Feb. 24, 2010).

63. *See id.*

64. *See* U.S. Nuclear Regulatory Comm'n, Design Certification Applications for New Reactors, http://www.nrc.gov/reactors/new-reactors/design-cert.html (last visited Feb. 24, 2010) [hereinafter Design Certification Applications].

65. See U.S. NUCLEAR REGULATORY COMM'N, NEW NUCLEAR PLANT DESIGNS 1–2 (2008) *available at* http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/new-nuc-plant-des-bg.pdf [hereinafter NEW NUCLEAR PLANT DESIGNS]. It is important to recognize that the NRC's paper-based design certification process does not require real world data from prior operation of a prototype or demonstration plant reflecting the specific design under review. *See* Design Certification Applications, *supra* note 64.

66. *See* Design Certification Applications, *supra* note 64.

67. U.S. NUCLEAR REGULATORY COMM'N, NUCLEAR PLANT LICENSING PROCESS 1, 3 (2005), *available at* http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/licensing-process-bg.pdf [hereinafter NUCLEAR POWER PLANT LICENSING FACT SHEET].

greatly reduce the applicant's risk of exposure to intervener contentions that could lead to costly delays in starting up or completing a plant.[68] Both the NRC staff and the licensee are now supposed to agree in advance on the specific acceptance criteria for critical items that will later be verified by NRC inspectors as having been completed correctly as construction proceeds.[69] Opportunities for the public to raise concerns at this stage are extremely limited. According to the NRC, at unspecified periodic intervals during construction, it will publish

> notices of these completions in the *Federal Register*. Then, not less than 180 days before the date scheduled for initial loading of fuel, the NRC will publish a notice of intended operation of the facility in the *Federal Register*. There is an opportunity for a hearing at this time, but the NRC will consider petitions for a hearing only if the petitioner demonstrates that the licensee has not met or will not meet the acceptance criteria.[70]

In any event, this orderly progression is not how the second coming of nuclear power has developed. Instead of one or two standardized designs receiving early generic design certification, five new or significantly amended designs are now moving simultaneously through the generic rulemaking process, with more likely to be submitted in the coming years.[71] Parallel to this generic design review process, the NRC continues to docket and review COL applications to construct and operate multiple reac-

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68. *See* U.S. NUCLEAR REGULATORY COMM'N, NUCLEAR POWER PLANT LICENSING PROCESS 4 (2009), *available* at http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0298/br0298r2.pdf. An application for a combined license under 10 CFR Part 52 (2009) can incorporate by reference a design certification and/or an early site permit. The advantage of this approach is that the issues resolved during the design certification rulemaking and the early site permit hearing processes are precluded from reconsideration later at the combined license stage. NUCLEAR POWER PLANT LICENSING FACT SHEET, *supra* note 67, at 5.

69. NUCLEAR POWER PLANT LICENSING FACT SHEET, *supra* note 67, at 3.

70. *Id.*

71. Design Certification Applications, *supra* note 64. The NRC staff is currently reviewing the following design certification applications: an AP1000 Amendment submitted by Westinghouse Electric Company; an Advanced Boiling Water Reactor (ABWR) Design Certification Rule Amendment submitted by the South Texas Project Nuclear Operating Company (Toshiba is a partner); the Economic Simplified Boiling-Water Reactor (ESBWR) submitted by GE-Hitachi Nuclear Energy; the U.S. Evolutionary Power Reactor (U.S. EPR) submitted by AREVA Nuclear Power; and the U.S. Advanced Pressurized-Water Reactor (US-APWR) submitted by Mitsubishi Heavy Industries, Ltd. *Id.* Note the dominance of Japanese- and French-owned firms and joint ventures in the applicant pool.

tors that reference these incomplete, evolving, not yet certified designs.[72]

The modest government-industry goal near the end of 2001 was to advance two "first mover" standard plant designs into the construction phase before 2010.[73] One of these designs was a modular high-temperature gas-cooled reactor, which remains under development by DOE, offering the prospect of higher thermal-to-electric conversion efficiencies than the typical light-water reactor ("LWR") power plant.[74] The other was a new LWR design offering both improved, passive safety features and reduced capital cost.[75] An influential Massachusetts Institute of Technology ("MIT") study in 2003 argued that additional government support for deploying such improved reactor designs was justified to gauge whether nuclear power had practical near term potential for decarbonizing the electricity supply, under a future scenario in which nuclear capital cost reductions and a tax on greenhouse gas emissions might converge to make future nuclear power generation economically competitive.[76] But the MIT study recommended that this additional support take the form of production tax credits "to assure that taxpayer monies paid for kilowatt-hours generated rather than cancelled plants or cost overruns."[77]

Had the nuclear industry and its boosters in Congress heeded this advice and focused intensively on design certification and cross-ownership arrangements for sharing the financial risk of building just these lead units for two standardized designs, they might well be under construction today. Instead, the nuclear power community became overzealous when it perceived what seemed to be a golden opportunity during the Bush administra-

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72. *See* NEW NUCLEAR PLANT DESIGNS, *supra* note 65, at 2.

73. 1 NEAR TERM DEPLOYMENT GROUP ET AL., A ROADMAP TO DEPLOY NEW NUCLEAR POWER PLANTS IN THE UNITED STATES BY 2010 vii (2001), *available at* http://nuclear.gov/np2010/reports/ntdroadmapvolume1.pdf.

74. 2 *id.* at 5–11, *available at* http://nuclear.gov/np2010/reports/ntdroadmapVolII.pdf.

75. *Id.* at 6–9, D-1.

76. *See* MASS. INST. OF TECH., THE FUTURE OF NUCLEAR POWER 8 (2003), *available at* http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf ("The government should provide a modest subsidy for a small set of 'first mover' commercial nuclear plants to demonstrate cost and regulatory feasibility in the form of a production tax credit. . . . We prefer the production tax credit mechanism because it offers the greatest incentive for projects to be completed and because it can be extended to other carbon free electricity technologies, for example renewables, (wind currently enjoys a $0.17 per kWe-hr tax credit for ten years) and coal with carbon capture and sequestration.").

77. Bradford, *supra* note 59, at 61.

tion to privatize the potential upside gains from a much larger nuclear power deployment while socializing the downside economic risks.[78]

The Energy Policy Act of 2005 was larded with new taxpayer giveaways to the nuclear industry, including a production tax credit for the first 6,000 megawatts ("MWe") of licensed new nuclear capacity;[79] a "Standby Support Program" insuring new reactor applicants against schedule delays caused by NRC licensing requirements or intervener litigation—worth $500 million per project for the first two reactors and $250 million each for the next four;[80] and potentially unlimited authority for the Secretary of Energy to grant federal taxpayer loan guarantees covering up to 80% of the cost of constructing a new reactor.[81] The availability of these incentives was linked to first-come, first-served filing deadlines before the end of 2008, which triggered an avalanche of hastily prepared and incomplete COL applications.[82] Not surprisingly, having rightly harbored a low level of conviction that deployment of a new generation of reactors would prove economically feasible without massive government help and/or aggressive carbon taxation, the reactor vendors had grossly under-invested in preparing their Generation III+ designs for the NRC's generic design certification process.[83] When the coffers suddenly opened up on Capitol Hill, the reactor design packages available for submission were not ready for prime time, and the NRC was not staffed to respond to the new reactor licensing workload.[84]

Meanwhile, a confluence of factors was leading to a meteoric rise in the projected cost of nuclear plants in the United States. While all the causes of this cost surge are not fully understood, the main culprits seem to have been (1) unrealistically low initial cost estimates from pro-nuclear power academics and companies seeking to fan interest in a "nuclear renaissance";[85] (2) a sudden

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78. *See id.* at 60–61.

79. 26 U.S.C. § 45J(a), (b)(2) (2006).

80. 42 U.S.C. § 16014(e)(1), (d)(2)–(3).

81. *Id.* § 16512(c).

82. Bradford, *supra* note 59, at 61; *see* Energy Policy Act of 2005, Pub. L. No. 109-58, 119 Stat. 594.

83. *See Nuclear Energy Development: Hearing Before the S. Comm. on Energy and Natural Res.*, 111th Cong. 5 (2009) (statement of Dale E. Klein, Chairman of the Nuclear Regulatory Commission).

84. *See id.* at 5.

85. Peter D'Ambrosio & Kevin O'Brien, *On Nuclear Power Projects, New Risks Re-*

rush of new plant proposals in a domestic labor market and manufacturing base with almost no extant capacity to build nuclear plants;[86] (3) a sharp global run-up in prices for the commodities, like cement and steel, that go into a nuclear plant;[87] (4) the decline of the dollar relative to the currencies of European and East Asian countries where many nuclear plant components are now manufactured;[88] (5) strong Asian demand for nuclear plants, driving up prices for specialized nuclear components;[89] and (6) large construction project contingencies to cover the execution risk inherent in building unproven new designs.[90] The nuclear new-build capital cost component alone—i.e., not including land acquisition, finance, fuel, operation and maintenance, and other owners' costs—which had been estimated at $1200 to $1500 per kilowatt ("kW") in 2002, soared to estimates of $4000 to $9000 per kW by 2009.[91]

As of January 4, 2010, the NRC reported on its website that it had accepted eighteen COLs to construct and operate twenty-eight new reactors—eight applications involve the construction of two units at a given site.[92] However, the chart notes that reviews of four of these applications, covering four units, have already been indefinitely suspended at the request of the applicants.[93] This leaves fourteen applications to construct and operate twenty-four new reactors still nominally under review, with almost all of them located in the Southeast and Texas.[94]

Fully half of the remaining applications involve construction of two-unit plants at sites located in the regulated utility markets of the Southeast—Florida, Alabama, Georgia, South Carolina, and

quire New Approaches, CONSTRUCTION LAW, Fall 2009, at 5, 9–10.

86. *See id.* at 7.

87. *See id.* at 11.

88. *Id.* at 10–11.

89. *See id.* at 10.

90. *See id.* at 7.

91. UNION OF CONCERNED SCIENTISTS, NUCLEAR LOAN GUARANTEES: ANOTHER TAXPAYER BAILOUT? (2009), *available at* http://www.ucsusa.org/assets/documents/nuclear_power/nuclear-loan-guarantees-_fact-sheet_.pdf.

92. U.S. Nuclear Regulatory Comm'n, Combined License Applications for New Reactors (Jan. 4, 2010), http://www.nrc.gov/reactors/new-reactors/col.html [hereinafter Combined License Applications].

93. Nuclear Regulatory Comm'n, New Reactor Licensing Applications: Schedules by Calendar Year (Jan. 29, 2010), http://www.nrc.gov/reactors/new-reactors/new-licensing-files/new-rx-licensing-app-legend.pdf [hereinafter New Reactor Licensing Applications].

94. *See* Combined License Applications, *supra* note 92.

North Carolina[95]—where usually compliant public utility commissions ("PUCs") are able to compel ratepayers to bear the high costs of these new plants while protecting them from competition from smaller, cheaper, faster, and cleaner sources of electricity.[96] Recently, though, there have been signs of PUC resistance in the South to committing to the construction of new nuclear plants by in which the financing plan consists of including the costs in the rate-base. Four previously approved AP1000 units in Florida are on hold following a decision by the Florida Public Service Commission in January 2009 to reject rate hike requests from Florida Power and Light and Progress Energy needed to finance the plants.[97] While these decisions may be largely tied to the political unpopularity of raising rates in the depths of a severe economic downturn, and therefore temporary, the current recession has also postponed demand growth projections by several years,[98] affording regulators and legislators some breathing room to consider other options.

According to the NRC's published license review schedules—which one should not assume reflect the actual state of affairs—only a handful of new reactor projects are slated to obtain COL approvals before the end of 2011.[99] One of the two new designs that was supposed to lead the U.S. nuclear renaissance, GE-Hitachi's Economic Simplified Boiling Water Reactor ("ESBWR"), has been dropped by three of its four prospective U.S. customers.[100] The remaining customer, Detroit Edison, is still showing an

95. *See id.*

96. *See* LISA JANAIRO, COUNCIL OF STATE GOVERNMENTS, NUCLEAR POWER MAY MAKE COMEBACK 4 (2009), *available at* http://trendsinamerica.com/knowledgecenter/docs/TIA_nuclear_final_3.pdf.

97. *See Turkey Point Nuclear Suspension*, WORLD NUCLEAR NEWS, Jan. 14, 2010, http://www.world-nuclear-news.org/NN_Turkey_Point_nuclear_suspension_1410102.html.

98. *See* NATALIE MIMS ET AL., ROCKY MOUNTAIN INST., ASSESSING THE ELECTRIC PRODUCTIVITY GAP AND THE U.S. EFFICIENCY OPPORTUNITY 7 (2009), *available at* http://ert.rmi.org/files/ documents/CGU.RMI.pdf. It is also interesting to note that two of the pro-nuclear states, South Carolina and Alabama, are also characterized by some of the lowest levels of electric productivity—dollars of gross domestic product per kWh consumed—in the nation, while Georgia and North Carolina by this measure use electricity only about half as efficiently as the average for the top ten states in electric productivity. *Id.* app. A.

99. New Reactor Licensing Applications, *supra* note 93.

100. Dominion Power and Entergy both announced separately in January 2009 that they could not come to terms with GE-Hitachi on a financial risk-sharing mechanism for constructing the ESBWR at North Anna, Virginia (Dominion), Grand Gulf, Mississippi, and River Bend, Louisiana (Entergy). Jeff Beattie, *Dominion Picking New Nuke Through Competitive Bidding*, ENERGY DAILY, Dec. 24, 2009, at 1, 2. In November 2008 the nation's

active COL application pending for construction of a single ESBWR unit at its Fermi nuclear plants in Monroe County, Michigan,[101] but the review schedule stretches into the first quarter of 2011,[102] and getting a COL license in no way obligates a company to build a plant. The ESBWR design has received low rankings for loan guarantee eligibility from DOE, reportedly because of problems it is experiencing in the NRC's design certification process.[103]

Some companies have fallen back to considering an older General Electric ("GE") Advanced Boiling Water Reactor ("ABWR") design that was certified by the NRC in May 1997, based on design documentation that was submitted piecemeal between September 1987 and March 1989.[104] Four units of a licensed version of this design have been constructed over the last fifteen years in Japan, and another three units are under construction in Japan and Taiwan.[105] A joint venture led by merchant energy provider NRG—with Toshiba as the prospective nuclear technology provider and project manager—has proposed using federal loan guarantees to construct two ABWR units in the competitive Texas power market, but these units are also in trouble.[106] Soaring project costs have given the third joint venture partner, San Antonio's public power company CPS Energy, a severe case of cold feet.[107] CPS Energy owns 45% of the South Texas ABWR project,

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largest nuclear utility, Exelon, dropped plans to build two ESBWR units at a site near Victoria, Texas, and the NRC suspended work on the COL permit. *See* U.S. Nuclear Regulatory Comm'n, Victoria County Station, Units 1 and 2 Application (Jan. 20, 2010), http://www.nrc.gov/reactors/new-reactors/col/victoria.html. In October 2009, Exelon told the NRC it would apply for an Early Site Permit for the Victoria site beginning in March 2010 but left the choice of reactor technology unspecified, suggesting that any decision to pursue a COL license was at least two years away. *See id.*

101. U.S. Nuclear Regulatory Comm'n, Fermi, Unit 3 Application, (Jan. 20, 2010), http://www.nrc.gov/reactors/new-reactors/col/fermi.html.

102. U.S. Nuclear Regulatory Comm'n, Application Review Schedule for the Combined License Application for Fermi, Unit 3 (Sept. 30, 2009), http://www.nrc.gov/reactors/new-reactors/col/fermi/review-schedule.html.

103. Rebecca Smith, *Nuclear Project Hits Obstacle As Exelon Balks*, WALL ST. J., Nov. 28, 2008, at B2.

104. *See* U.S. Nuclear Regulatory Comm'n, Issued Design Certification-Advanced Boiling-Water Reactor (ABWR) (June 3, 2009), http://www.nrc.gov/reactors/new-reactors/design-cert/abwr.html.

105. GE Hitachi, Advanced Boiling Water Reactor (ABWR) Fact Sheet (2008), http://www.gepower.com/prod_serv/products/nuclear_energy/en/downloads/gea14576e_abwr.pdf.

106. *See* Jeff Beattie, *CPS Accuses NRG, Toshiba of Fraud in Reactor Fight*, ENERGY DAILY, Jan. 6, 2010, at 1, 3.

107. *Id.*

ironically called Nuclear Innovation North America LLC,[108] despite its reliance on an older nuclear plant design.[109] CPS and its partners are now embroiled in a court fight over who misled whom and who will be compensated if CPS Energy walks away from the project.[110] The GE ABWR design that NRC certified in the 1990s must be modified to meet the requirements of NRC's new aircraft impact rule and thus requires a near-term NRC design certification amendment.[111]

Meanwhile, none of the five candidate reactor types have completely cleared the NRC's standard design certification process,[112] which was originally intended to precede, inform, and simplify the site-specific COL licensing process.[113] These logically sequential processes are instead proceeding on parallel but connected tracks. Such regulatory improvisation is sowing mounting confusion and consternation among intervenors and local governments, who are demanding to know the real world licensing basis on which to gauge the safety, environmental, and rate impacts of the plants already involved in the individual COL proceedings.[114] To clear this logjam, the NRC has initiated yet a fourth licensing board proceeding, which would aggregate and resolve outstand-

108. *Id.*

109. That a twenty-one-year-old APWR design already deployed in multiple units overseas can somehow qualify for federal loan guarantee support as an "innovative energy technology" suggests either the glacial pace of technological change in the nuclear power sector or that someone is opportunistically pushing the envelope of what Congress intended.

110. *See* Beattie, *supra* note 106, at 3.

111. *See* U.S. Nuclear Regulatory Comm'n, Design Certification Application Review-ABWR Amendment (Jan. 20, 2010), http://www.nrc.gov/reactors/new-reactors/design-cert/amended-abwr.html. The underlying certification for the ABWR, granted in May 1997 and good for fifteen years is due for review before May 2012. *See id.*; Design Certification Applications, *supra* note 64.

112. Design Certification Applications, *supra* note 64.

113. Texans for a Sound Energy Policy's Petition to Hold Docketing Decision and/or Hearing Notice for Victoria Combined License Application in Abeyance Pending Completion of Rulemaking on Design Certification Application for Economically Simplified Boiling Water Reactor at 8, *In re* Exelon Nuclear Holdings, LLC (Victoria County Station, Units 1 and 2), Nos. 52-031-COL, 52-032-COL (Nuclear Regulatory Comm'n dismissed Dec. 30, 2008) ("As described in the Final Rule that was promulgated the following year, the 'key procedural device' . . . for 'bringing about enhanced safety and early resolution of licensing issues' was the provision for certification of standard designs in advance of consideration of COLAs.").

114. *See* 10 C.F.R. § 52 (2009).

ing issues deemed common to all COLs that reference the same reactor design.[115]

Think about what this full employment program for nuclear licensing attorneys means for cash-strapped state officials and public interveners who lack the resources to hire the specialized legal help needed to navigate the dense thicket of NRC regulations and documentation. It means that to effectively present contentions involving a reactor proposed for construction in their own vicinity, local interveners may be compelled to track up to four separate NRC proceedings, involving four distinct chains of cross-referencing documents and document revisions totaling many tens of thousands of pages: (1) an ESP process, (2) a generic Design Certification Rulemaking process, (3) a COL process for resolving admitted contentions deemed unique to a particular COL proposal, and (4) a lead-unit COL process for resolving admitted contentions that are deemed to be common to all reactors of that type.[116]

On top of this onerous regulatory maze, the NRC has layered revised regulations that drastically curtail the longstanding right under the Atomic Energy Act of state and local governments and members of the public to challenge a licensing decision in an adjudicatory hearing.[117] When Congress legalized the domestic production of nuclear energy in 1954, it exempted the new industry from state and local regulation, vesting sole regulatory authority in the federal Atomic Energy Commission ("AEC"); authority passed to the NRC when the AEC was dissolved in 1975.[118] As a safeguard against the potential abuse of this new federal monopoly, Congress gave state and local governments and the general public the right to challenge every federal nuclear licensing decision in an adjudicatory hearing.[119]

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115. *See id.* § 52 app. N.

116. *See id.* § 52.0; *see also* MICHAEL MARIOTTE, NUCLEAR INFO. AND RESOURCE SERV., THE NRC'S REACTOR LICENSING PROCESS: AN OVERVIEW 3–6 (Sept. 2006), http://www.nirs.org/reactorwatch/licensing/licensingprocess.pdf; Letter from Ronald L. Simard, Senior Director of New Plant Deployment, Nuclear Energy Inst., to James E. Lyons, Director of New Reactor Licensing Project Office, U.S. Nuclear Regulatory Comm'n (May 1, 2003), *available at* http://www.nrc.gov/reactors/new-reactors/new-licensing-files/ml031270366.pdf.

117. *See* Roisman et al., *supra* note 60, at 336; *see also* Richard Goldsmith, *Regulatory Reform and the Revival of Nuclear Power*, 20 HOFSTRA L. REV. 159, 161 (1991).

118. *See* Goldsmith, *supra* note 117, at 163–64.

119. *See* 42 U.S.C. § 2239(a)(1)(A) (2006).

For decades these hearings have employed the full suite of trial-type procedures designed to probe the evidence of opposing parties, including pre-hearing depositions and interrogatories taken under oath and the opportunity to cross examine adverse witnesses during the hearing.[120] In 2004, however, the NRC issued new regulations eliminating the use of trial-type procedures in virtually every kind of NRC licensing decision, no matter how significant or complex.[121] The only possible exception is if the presiding officer, an NRC administrative law judge, finds that the credibility of an eyewitness is at issue or "issues of motive or intent of the party or eyewitness [are] material to the resolution of [the] contested factual matter."[122]

In place of all the previous discovery tools and the right to cross-examine adverse witnesses in the hearing, state and local governments and members of the public may exchange documents with the other parties to the proceeding and submit written questions in advance of the hearing to be asked by the presiding officer who has complete discretion over the process.[123] The NRC calls this mangy vestige of an adjudicatory process an oral hearing.[124] This is as good as it gets in the new streamlined world of NRC regulation. One thing is certain: if there is some hidden defect in the siting, safety design, construction, or operational readiness of one of these new reactors, these new COL proceedings are exceedingly unlikely to uncover it.

III. NUCLEAR POWER: A BALANCE SHEET FOR NET ASSESSMENT OF RISKS AND BENEFITS

Despite its record of occasionally serious accidents,[125] poor financial performance,[126] and never-ending battles over storage and

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120. *See* Roisman et al., *supra* note 60, at 344.

121. *See* Changes to Adjudicatory Process, 69 Fed. Reg. 2182, 2182 (Jan. 14, 2004); *see also* Roisman et al., *supra* note 60, at 344–45.

122. Changes to Adjudicatory Process, 69 Fed. Reg. at 2191.

123. *See* 10 C.F.R. § 2.1207(a)(3) (2009).

124. *Id.* § 2.1207.

125. *See, e.g.*, U.S. NUCLEAR REGULATORY COMM'N, THREE MILE ISLAND ACCIDENT 1 (2009), *available at* http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.pdf.

126. John W. Schoen, *Does Nuclear Power Make Financial Sense?*, MSNBC.COM, Jan. 26, 2007, http://www.msnbc.msn.com/id/16286304/from/ET/.

ultimate disposal of spent fuel,[127] nuclear power technology has a number of positive attributes that deserve to be recognized:

1. It is an energy-dense source of low-carbon electricity (but not zero-emissions when its complete cradle-to-grave life cycle is considered).[128]

2. A reliable and plentiful supply of uranium fuel is normally available at predictable cost under long-term commercial contracts, and this situation is expected to persist for many decades.[129]

3. Fuel is a small fraction of total cost, and fuel costs are low and relatively stable in comparison to fossil alternatives.[130]

4. In recent years, numerous U.S. and foreign nuclear units have attained very high rates of capacity utilization, averaging around 89%.[131]

5. Nuclear power plants can have a long operating life—forty to sixty years—if properly built and maintained, including costly but necessary capital additions such as steam generator replacements.[132]

6. Nuclear power plants have low public health impacts from routine plant emissions.[133]

7. Nuclear plants are hardened facilities built to withstand severe events such as tornadoes, hurricanes, and various types of design basis earthquakes—but necessary external support and

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127. Peter Behr, *Yucca Mountain Is Dead, Says Domenici*, EENEWS.NET, Feb. 2, 2009, http://www.eenews.net/public/climatewire/print/2009/12/02/2.

128. Fred Bosselman, *The Ecological Advantages of Nuclear Power*, 15 N.Y.U. ENVTL. L.J. 1, 41 (2007).

129. *See* Press Release, Nuclear Energy Agency, Uranium Resources Sufficient to Meet Projected Nuclear Energy Requirements Long into the Future (June 2008), http://www.nea.fr/html.general/press/2008/2008-02.html; WORLD NUCLEAR ASS'N, URANIUM MARKETS 1, 3 (Sept. 2008), http://www.world-nuclear.org/info/default.aspx?id=442&terms=uranium+markets (click on "download this page as PDF").

130. ROGER DUNSTAN, BENEFITS AND RISKS OF NUCLEAR POWER IN CALIFORNIA 13 (2002), *available at* http://www.library.ca.gov/crb/02/08/02-008.pdf; WORLD NUCLEAR ASS'N, THE ECONOMICS OF NUCLEAR POWER (Nov. 2008), http://world-nuclear.org/uploadedFiles/org/info/pdf/EconomicsNP.pdf.

131. DUNSTAN, *supra* note 130.

132. Bruno Comby, The Benefits of Nuclear Energy, http://www.ecolo.org/documents/documents_in_english/BENEFITS-of-NUCLEAR.pdf (last visited Feb. 24, 2010); Nucleartourist.com, Steam Generator Replacement, http://nucleartourist.com/operation/sg-mod1.htm (last visited Feb. 24, 2010).

133. *See* DUNSTAN, *supra* note 130, at 21–23.

transmission links may not be as well-protected[134]—and the next generation of plants will supposedly be hardened against explosive aircraft impacts as well.[135]

On the other side of the ledger lies a long list of concerns. Nuclear power entails major economic, geopolitical, safety, security, and environmental burdens that must be borne or mitigated if it is to play a significant carbon abatement role. On a global scale, and in no particular order, these nuclear power burdens include:

1. Very large up-front capital investment costs on both a per-project and per-kilowatt-of-new-capacity basis. The projection execution and financial risks, including both the absolute amount of capital at risk in each project and the competitive levelized cost of the resulting electricity, strongly discourage private financing.

2. Nuclear plants require large and persistent public subsidies—for financing, safety and environmental regulation, security, peaceful-use safeguards, nuclear waste management and disposal—and related budget opportunity costs on more benign types of public investment.

3. Fifty years on, nuclear power everywhere remains a ward of the state, with no discernible secular cost reduction trend.

4. Potentially competitive low-carbon nuclear power, relative to heavily carbon-taxed coal-fired generation, is currently offered only in very large, inflexible increments—typically 1000–1600 MWe—requiring costly transmission upgrades for grid integration in many deployment settings.

5. Nuclear power deployed in such large increments requires significant and potentially very costly additional reserve capacity to be available in the regional or national grid to provide replacement power in the event that such a large generating source is temporarily lost to the grid via a refueling shutdown or an unplanned outage, which can last months, or even years,

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134. David A. Garbin & John F. Shortle, *Measuring Resilience in Network-Based Infrastructures*, *in* CRITICAL THINKING: MOVING FROM INFRASTRUCTURE PROTECTION TO INFRASTRUCTURE RESILIENCE 73, 78 (2007), *available at* http://cip.gmu.edu/archive/CIPP_Resilience_Series_Monograph.pdf; MARK HOLT & ANTHONY ANDREWS, CONGRESSIONAL RESEARCH SERVICE, NUCLEAR POWER PLANT SECURITY AND VULNERABILITIES 4 (2009), *available at* http://www.fas.org/sgp/crs/homesec/RL34331.pdf.

135. HOLT & ANDREWS, *supra* note 134, at 4–5.

depending on the nature of the problem. Similarly, nuclear power plants can greatly amplify the effects of local grid disturbances when such disturbances prompt them to automatically disconnect from the grid, thereby contributing to a cascading blackout.

6. Even when things go right, nuclear projects have a lengthy project-development, construction, and startup timeframe of seven to fifteen years[136] compared to two to five years for wind and solar projects, months to a few years for waste heat cogeneration projects, and days to months for energy efficiency improvements. When things go wrong, of course, completing the construction and startup phase can take a lot longer. The risk presented by a long and potentially protracted construction and startup phase, tying up billions of dollars of capital investment with no revenue stream associated with it, explains why nuclear plants are mainly proposed by regulated public utilities or public companies that can arrange for a revenue stream before and during construction.

7. Nuclear plants pose a continuing risk of nuclear accidents, including a small probability of a very high-consequence event, which should nonetheless be weighed against the benefit of reducing the ongoing known harmful health and climate effects of burning fossil fuels.

8. Environmental harms and risks from the nuclear fuel cycle that offset its low-carbon attributes include radionuclide and heavy metals contamination from uranium mining and processing activities, massive freshwater withdrawals and evaporative losses for reactor cooling, excessive thermal discharges to aquatic environments, massive entrainment and destruction of young fish stocks by reactor condenser cooling systems, and the leakage of radionuclides from storage and processing of spent nuclear fuels.

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136. Author's estimate is based on three to eight years required for nuclear site identification, project planning, nuclear licensing, environmental permitting, and state regulatory approvals—it is difficult to imagine that this phase could be compressed to less than three years—in addition to four to seven years for construction, initial core-loading, and plant start-up operations prior to the initiation of commercial operations. Four years for construction and startup seem to be the minimum achievable with current nuclear technology.

9. Nuclear plants bear potentially catastrophic vulnerability to earthquakes, requiring seismic limitations on siting and co-locating nuclear plants and/or increased costs for improved seismic resistance.
10. A lack of sufficient technical competence, official transparency, government accountability, and "safety culture" in countries that may acquire or develop nuclear facilities increases the risk of an accident that, harmful in its own right, could also prompt the shutdown of similar reactors worldwide.
11. A convoluted and biased U.S. nuclear regulatory process treats the public as an adversary, fosters gratuitous procedural and legal complexity, prolongs questionable practices rather than ensuring that they are identified early and remedied expeditiously, and deprives members of the public of due process rights to which they are entitled under law.
12. The prevailing weak status quo for international control of nuclear fuel cycle technology expands the horizon for nuclear weapons proliferation.
13. One form of foreign energy dependence—foreign-supplied reactors and fuel—replaces another—petroleum-based fuels.
14. Nuclear plants can be a magnet for attacks in regions of tension and conflict and a target for terrorist assault or sabotage.
15. A final roadblock to nuclear disarmament—a big nuclear build-out supported by autonomous national fuel cycle facilities—would create regional and global insecurity and place a floor under the process of eliminating existing nuclear arsenals.

The balance of this paper discusses each of these liabilities in turn and concludes with a brief discussion of their policy implications.

A. *Very High Capital Costs*

When talk of a U.S. "nuclear renaissance" began eight years ago, the nuclear industry was predicting overnight capital costs for the new generation of reactors as low as $1,500 to $2,000 per kW (in 2001 dollars).[137] "Overnight cost" is an industry convention for estimating and comparing direct construction costs that assumes the plant is built overnight—i.e., with no finance costs, price level inflation, real cost escalation, grid integration costs, or other owners' costs included in the calculation.[138] Overnight costs represent the starting point for cost models that include the other elements of capital costs, specify the capital structure and finance terms for the project, and incorporate other cost assumptions for operations and maintenance, capital additions, plant availability, fuel, taxes, and so forth.[139]

The empirical bases for these early predictions were always suspect, given that the only overnight costs for new reactors completed within the previous decade came from Japan and South Korea, where they had supposedly ranged from $1800 to $2800 per kW (in 2002 dollars).[140]

Since these early projections, the overnight capital cost projections for new nuclear reactors have more than doubled in real terms. Here are some recent estimates for reactor overnight costs by U.S. utilities, the financial community, the Congressional Research Service, California and Georgia state regulators, and an independent electricity cost expert:

137. MASS. INST. OF TECH., *supra* note 76, app. 5.B at 137.

138. *See* STAN KAPLAN, CONGRESSIONAL RESEARCH SERVICE, POWER PLANTS: CHARACTERISTICS AND COSTS 71 app. B (2008), *available at* http://www.fas.org/sgp/crs/misc/RL34746.pdf.

139. *See* NUCLEAR ENERGY INST., THE COST OF NEW GENERATING CAPACITY IN PERSPECTIVE 4 (2010), *available at* http://www.nei.org/filefolder/The_Cost_of_New_Generating_Capacity_in_Perspective.pdf.

140. *See* MASS. INST. OF TECH., *supra* note 76, app. 5.A at 140–42.

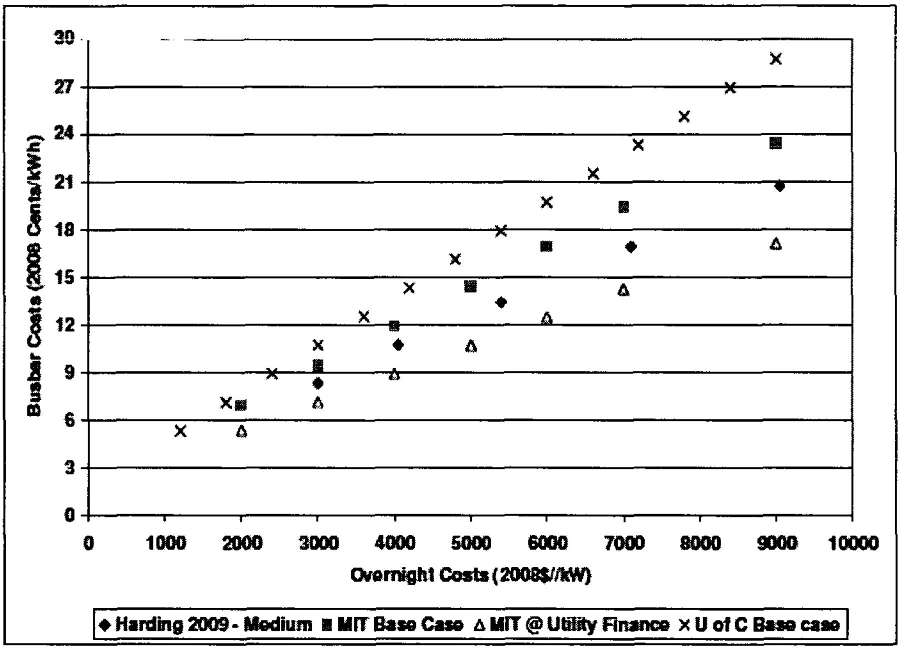
Table 1: Recent Estimates of Nuclear Overnight Construction Costs[141]

Source of Estimate	Plant	Reactor Type	Date of Estimate	Overnight Cost 2008 dollars per kW
CRS	Calvert Cliffs Unit 3	Areva EPR	2007	5778
FPL	Turkey Point Units 6 & 7	GE ABWR	2007	3760
CRS	Summer Units 2 & 3	AP1000	2008	4387
Georgia PUC	Vogtle (2 units)	AP1000	2008	4381
Moody's	unspecified	Large LWR	2008	6250
Standard & Poors	unspecified	Large LWR	2008	4100
PPL	Bell Bend, PA	Areva EPR	2009	9375
CEC	unspecified	AP1000	2009	3950
MIT II	unspecified	Large LWR	2009	4092
James Harding	unspecified	Large LWR	2009	8184

141. Cost estimates compiled in MARK COOPER, THE ECONOMICS OF NUCLEAR REACTORS: RENAISSANCE OR RELAPSE? 23 tbl.III-1 (2009), *available at* http://www.vermontlaw.edu/Documents/Cooper%20Report%20on%20Nuclear%20Economics%20FINAL%5B1%5D.pdf. CEC overnight cost estimate from CALIFORNIA ENERGY COMM'N, COMPARATIVE COSTS OF CALIFORNIA CENTRAL STATION ELECTRICITY GENERATION 46 tbl.14 (2009), *available at* http://www.energy.ca.gov/2009publications/CEC-200-2009-017/CEC-200-2009-017-SD.PDF. Florida Power and Light ("FPL") overnight cost estimate is the average of high-, medium-, and low-case estimates presented by FPL in 2007, inflation adjusted to 2008 at 2.5%. These estimates are cited in ARJUN MAKHIJANI, INST. FOR ENERGY & ENVTL. RESEARCH, ASSESSING NUCLEAR PLANT CAPITAL COSTS FOR THE TWO PROPOSED NRG REACTORS AT THE SOUTH TEXAS PROJECT SITE 8 tbl.2 (2008), *available at* http://www.nukefreetexas.org/downloads/makhijani_cost_report.pdf. In this report prepared for the San Antonio City Council, Dr. Makhijani warned that NRG's then current cost estimate of $6 to $7 billion dollars for two GE-Toshiba ABWR reactors was off by a "a factor of two or more." *Id.* at 1. A year and a half later he was proven right when the city council belatedly discovered, just before it was to vote on a bond issue to finance the plant in October 2009, that Toshiba had disclosed to the city's public power company and partner in the project, CPS Energy, that the cost had jumped to $12.5 billion. *See* Anton Caputo & Tracy Idell Hamilton, *CPS Knew of Higher STP Cost Year Ago*, SAN ANTONIO EXPRESS-NEWS, Nov. 22, 2009, at 1A.

Applying a value of overnight cost from Table 1, above, on the horizontal axis of Figure 1 below, one can readily determine the corresponding range of average levelized electricity costs at the point of entry into the transmission grid that will pay for the plant, pay interest expense, and earn a fair or expected return on invested capital typically over a fifteen- to thirty-year-period, depending on the type of plant—merchant, regulated investor-owned utility, or publicly owned utility—and the debt term.

Figure 1: The Relationship Between Overnight Capital Cost and Levelized Busbar Electricity Costs in Three Different Cost Models for New Nuclear Power Plants.[142]



For example, using an overnight cost value near the mid-point range in Table 1—$6000 per kW—then the financial modeling results plotted in Figure 1 reveal that a reactor with this overnight cost, built in a traditional regulated utility environment (the "MIT @ utility finance model" in Figure 1), would generate electricity at an average cost of $0.125 per kilowatt-hour [("kWh")] (in 2008 dollars) over thirty years. But if the same plant were built

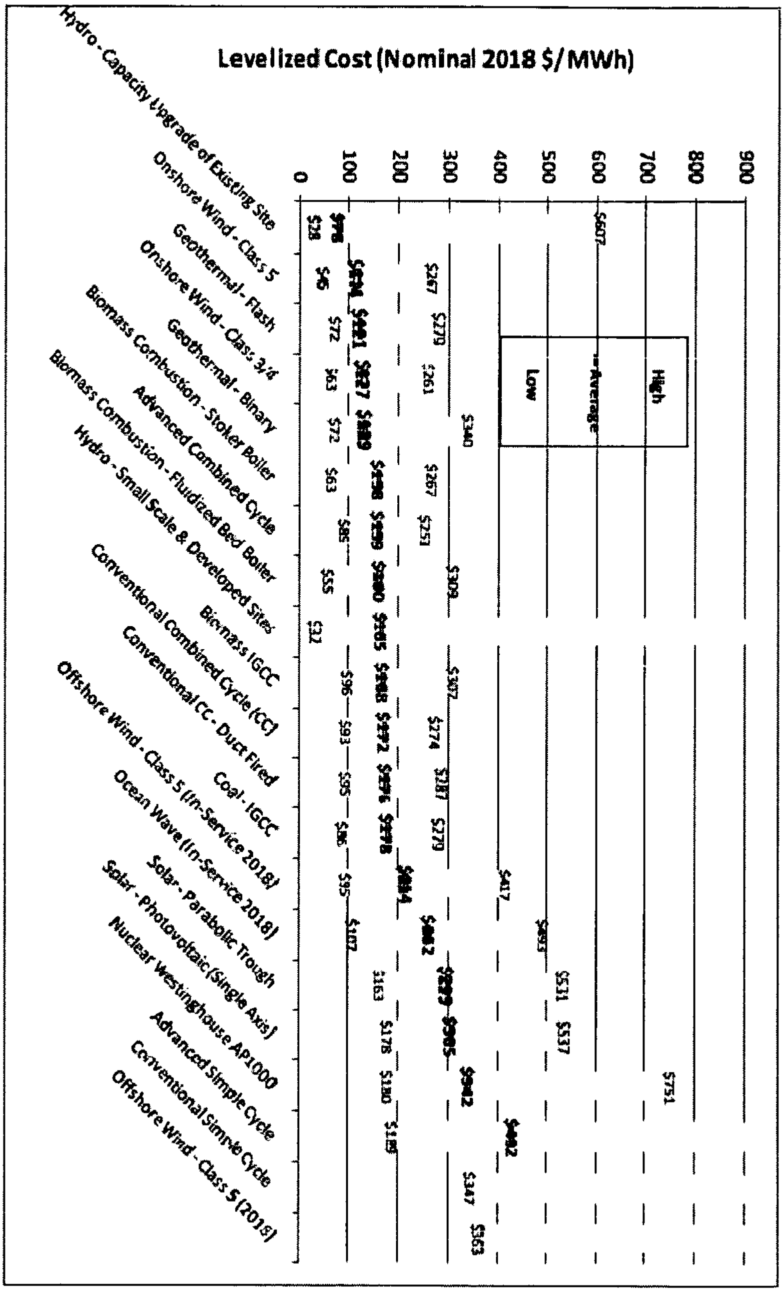
142. COOPER, *supra* note 141, at 27 fig.III-3.

in a competitive merchant plant environment, with a less debt-laden capital structure, a higher expected return on invested capital, and—without the security of a captive rate base—a higher cost for borrowed funds (the "U of C (University of Chicago) Base case"), then the electricity would cost on the order of $0.195 per kWh.

If one adds a typical transmission and distribution charge of $0.035–$0.07 per kWh to these busbar cost estimates, the range of likely consumer costs for this nuclear-generated electricity today would be $0.16–$0.265 per kWh—1.5 to 3 times what consumers are currently paying for electricity in most areas of the country.[143] The more relevant question, however, is what will be the low-carbon electricity cost landscape in 2018, when this new reactor would come on line and supply electricity to the grid. Figure 2 shows how a merchant nuclear plant stacks up against the other low-carbon and conventional technologies in the most recent staff analysis from the California Energy Commission ("CEC"):

143. According to the Department of Energy's Energy Information Administration, the average retail price of electricity to U.S. residential customers in 2009 was $0.1168 per kWh. U.S. ENERGY INFO. ADMIN., AVERAGE RETAIL PRICE OF ELECTRICITY TO ULTIMATE CUSTOMERS BY END-USE SECTOR, BY STATE tbl.5.6.B (Jan. 15, 2010), http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html. For commercial customers, it was $0.1031 per kWh. *Id.* For industrial customers, it was $0.695 per kWh. *Id.*

Figure 2: Forecast Average Levelized Cost of Generation in California in 2018.[144]



144. CALIFORNIA ENERGY COMM'N, *supra* note 141, at 34 fig.18.

In 2018, according to Figure 2, an AP1000 merchant nuclear plant in California is expected to generate electricity within a range of eighteen to seventy-five cents per kWh, in nominal 2018 dollars with the average cost (middle number in bold) expected to be $0.342 per kWh. This expected cost is higher than every other low-carbon technology in Figure 2, higher than even the cost of advanced solar photovoltaic and solar thermal power plants. Granted, a competitive merchant environment, as opposed to a traditional regulated utility one, is not the optimal basis for comparing nuclear power to other low-carbon energy technologies. Nuclear power costs can benefit substantially from the reduced nuclear risk premium available to borrowers in regulated utility markets with captive ratepayers and from the willingness of public utility commissions to allow nuclear projects to employ construction work in progress charges to recover borrowing costs and sometimes even project engineering and site preparation costs in the rate base as they are incurred, long before the plant is placed into operation.[145] The recent CEC analysis also looked at the cases of an AP1000 deployed by both a publicly regulated investor-owned utility and a publicly owned utility, such as the previously-mentioned CPS Energy in San Antonio, Texas. In the investor-owned utility case (see Table 2 below), nuclear at $0.273 per kWh is still a very high-cost resource but does become marginally competitive with utility scale solar photovoltaic and solar thermal (parabolic trough) plants.[146] However, it is still vastly more costly than all the remaining low-carbon energy alternatives. In the not very prevalent publicly-owned power company case, nuclear power at $0.167 per kWh is competitive with large solar and ocean wave power plants but still more costly than geothermal, wind, hydro, and various approaches to small scale biomass combustion.[147] Moreover, this relatively competitive cost for nuclear power is predicated on the overnight capital cost of the AP1000 remaining at $3950 per kWh, i.e., not undergoing any further real cost escalation between now and 2018.

145. *See* Peter Navarro, *Financing U.S. Energy Development: An Economist's Perspective*, 2 ENERGY L.J. 9, 14 (1981).

146. CALIFORNIA ENERGY COMM'N, *supra* note 141, at 18 tbl.5.

147. *Id.*

Table 2: Summary of Average Levelized Costs—In-Service in 2018.[148]

In-Service Year = 2018 (Nominal 2018 $)	Size	Merchant			IOU			POU		
	MW	$/kW-Yr	$/MWh	¢/kWh	$/kW-Yr	$/MWh	¢/kWh	$/kW-Yr	$/MWh	¢/kWh
Small Simple Cycle	49.9	422.48	1028.23	102.82	330.89	805.60	80.56	323.59	394.09	39.41
Conventional Simple Cycle	100	398.71	970.39	97.04	311.27	757.86	75.79	307.31	374.26	37.43
Advanced Simple Cycle	200	354.72	431.66	43.17	294.42	358.41	35.84	308.73	250.66	25.07
Conventional Combined Cycle (CC)	500	1052.85	171.58	17.16	980.42	160.01	16.00	920.08	150.42	15.04
Conventional CC - Duct Fired	550	1009.36	176.24	17.62	937.12	163.87	16.39	878.57	153.55	15.35
Advanced Combined Cycle	800	975.62	158.99	15.90	910.16	148.54	14.85	855.45	139.86	13.99
Coal - IGCC	300	2422.09	178.14	17.81	911.10	142.48	14.25	723.39	113.17	11.32
Nuclear Westinghouse AP1000 (2018)	960	1139.56	342.41	34.24	1929.55	273.07	27.31	1171.66	166.85	16.68
Biomass IGCC	30	1008.20	168.48	16.85	966.60	161.86	16.19	841.43	140.97	14.10
Biomass Combustion - Fluidized Bed Boiler	28	1054.11	160.43	16.04	974.35	148.32	14.83	837.46	127.60	12.76
Biomass Combustion - Stoker Boiler	38	1061.71	158.22	15.82	998.40	148.82	14.88	890.68	132.88	13.29
Geothermal - Binary	15	666.46	129.42	12.94	695.05	136.73	13.67	591.29	124.98	12.50
Geothermal - Flash	30	646.49	120.72	12.07	674.90	127.66	12.77	580.53	117.99	11.80
Hydro - Small Scale & Developed Sites	15	315.28	164.59	16.46	304.10	159.84	15.98	220.33	120.27	12.03
Hydro - Capacity Upgrade of Existing Site	80	157.31	77.80	7.78	152.81	76.09	7.61	115.80	59.88	5.99
Ocean Wave (2018)	40	511.74	261.71	26.17	485.22	249.02	24.90	361.85	189.33	18.93
Solar - Parabolic Trough	250	500.65	298.64	29.86	483.85	288.92	28.89	427.05	256.13	25.61
Solar - Photovoltaic (Single Axis)	25	512.14	305.50	30.55	494.76	295.43	29.54	436.12	261.57	26.16
Onshore Wind - Class 3/4	50	357.14	127.19	12.72	337.44	120.59	12.06	248.91	90.69	9.07
Onshore Wind - Class 5	100	363.57	114.06	11.41	343.90	108.27	10.83	255.53	82.02	8.20
Offshore Wind - Class 5 (2018)	350	731.39	214.16	21.42	690.08	202.78	20.28	504.75	151.21	15.12

Source: Energy Commission

148. CALIFORNIA ENERGY COMM'N, *supra* note 141, at 18 tbl.5.

Given these runaway costs, it appears that nuclear power will only become viable in competitive energy markets under the constraint of a sharp run-up in the CO_2 allowance price—or carbon taxation equivalent—into the range of $50 to $100 per ton. Such high carbon prices are not anticipated, under most government agency and independent economic models of proposed cap and trade climate legislation, until some time in the 2028–2045 timeframe.[149] So at least for the next few decades, the nuclear industry appears to be counting on federal subsidies, currently worth on the order of $0.43 per kWh, to buy down its exorbitant costs and make them acceptable to state regulators and ratepayers.

Constellation Energy, for example, values the current level of federal loan guarantees and production tax credits at $575 million per year for each subsidized 1600 MWe Evolutionary Power Reactor ("EPR") it deploys.[150] But as the above table makes clear, even under a high-carbon price scenario, nuclear power will have a host of cleaner energy competitors in areas of the country that are well endowed with renewable energy resources, and most areas are well endowed. An obvious concern is that a big federally subsidized rollout of nuclear power generation in traditional regulated markets, such as in the southeastern United States, will squeeze out electricity that could have been supplied from smaller, cheaper, cleaner sources that were not allowed to connect to the grid.

B. *The Large Public Subsidy and Opportunity Costs of Nuclear Power*

Historically, the federal government's robust commitment to nuclear power has imposed immense direct and indirect costs on taxpayers, and these expenditures continue to impose significant

149. This range from current economic modeling results was provided to the author in an e-mail from David Hawkins. E-mail from David Hawkins, Dir. of Climate Programs, Natural Res. Def. Council Climate Ctr., to Christopher E. Paine, Nuclear Program Dir., Natural Res. Def. Council (Jan. 21, 2010) (on file with author). Hawkins adds, "The allowance price trajectory (and thus the projected date when any particular price may be hit) is obviously very sensitive to the substance of the bill (targets; offsets; complementary policies) and to the assumptions about cost/performance of energy technologies that go into the models." *Id.*

150. DOUG KOPLOW, ENERGY SUBSIDIES: HOW MUCH DOES NUCLEAR POWER HAVE IN COMMON WITH ETHANOL? (2008), *available at* http://www.earthtrack.net/files/NPEC_DC Present_Jan 08.pdf.

opportunity costs on the development of more sustainable energy strategies. According to the Congressional Research Service, direct federal research and development ("R&D") expenditures on nuclear power development totaled $74 billion through 2003, more than half of all DOE R&D expenditures and far more than any other individual energy technology.[151]

Were it not for the U.S. government's willingness, beginning in the 1950s, to cap private liability in the event of a serious nuclear accident and assume the remaining financial risk,[152] it is probably fair to say that there would not be a commercial nuclear industry in the United States today. So in this narrow sense, commercial nuclear power in the United States has always depended on the standby support of the federal treasury for its very existence. There are numerous longstanding and significant forms of federal support for the nuclear industry, both past and present, which are at times difficult to quantify precisely in dollar terms, but have been of critical importance to the industry's development:

1. The government assumed the burden of managing the permanent disposal of the industry's highly radioactive spent nuclear fuel.[153]

2. The nuclear navy's continuing requirement for reactor operators provided the commercial nuclear industry with a steady stream of highly qualified and already vetted personnel, trained at public expense, who walked in the door with much of the technical background and safety culture needed to operate civilian plants.[154] This close relationship continues to this day.

3. For fifty years, enriched uranium has been produced in three huge government-owned enterprises and provided to the nuclear industry at prices that were effectively subsidized by the federal government's prior investment in these facilities for

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151. FRED SISSINE, CONG. RESEARCH SERV., RENEWABLE ENERGY: TAX CREDIT, BUDGET, AND ELECTRICITY PRODUCTION ISSUES 3 (2006), *available at* http://ncseon-line.org/NCE/CLSreports/06jun/IB10041.pdf.

152. David M. Rocchio, *The Price-Anderson Act: Allocation of the Extraordinary Risk of Nuclear Generated Electricity: A Model Punitive Damage Provision*, 14 B.C. ENVTL. AFF. L. REV. 521, 522, 535–36 (1987); Greenpeace Canada, Don't Nuke Green Energy, http://www.greenpeace.org/canada/en/campaigns/end-the-nuclear-threat/what-we-do/nuclear_liability_compensation_act (last visited Feb. 24, 2010).

153. *See* 42 U.S.C. § 10131(a)(4) (2006).

154. *See* Roland M. Frye, Jr., *The Current "Nuclear Renaissance" in the United States, Its Underlying Reasons, and Its Potential Pitfalls*, 29 ENERGY L.J. 279, 361 (2008).

nuclear weapons production.[155] But production of highly-enriched uranium for weapons ceased in 1964,[156] and for naval fuel in 1991.[157] Since 1964, DOE's uranium enrichment complex has been increasingly used for making civil fuel, for the last twelve years operating as a private enterprise, USEC, Inc.[158] Decontamination and decommissioning of this now 'defunct government industry is expected to continue through 2044.[159] A January 2009 DOE report to Congress pegged the remaining costs for cleaning up these facilities at $16.9 to $30.8 billion.[160] Assuming restoration of the one-third cost share with nuclear utilities that expired in 2007, the federal taxpayer's share of the cleanup cost remaining at both these facilities would be $11.3 to $20.5 billion. Setting aside the issue of whether the industry's one-third share of this nuclear environmental liability fully reflects the historical division of enrichment services between civil and military purposes, the implied future taxpayer subsidy to the nuclear utility industry if it continues to duck these costs is $5.6 to $10.3 billion.

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155. *See* ARJUN MAKHIJANI ET AL., INST. FOR ENERGY & ENVTL. RESEARCH, URANIUM ENRICHMENT: JUST PLAIN FACTS TO FUEL AN INFORMED DEBATE ON NUCLEAR PROLIFERATION AND NUCLEAR POWER 20 (2004), *available at* http://www.ieer.org/reports/uranium/enrichment.pdf.

156. 2 THOMAS B. COCHRAN ET AL., NATURAL RES. DEF. COUNCIL, NUCLEAR WEAPONS DATABOOK: U.S. NUCLEAR WARHEAD PRODUCTION app. D n.1 (1987) ("There has been no production of HEU for weapons since 1964.").

157. Chunyun Ma & Frank von Hippel, *Ending the Production of Highly Enriched Uranium for Naval Reactors*, NON-PROLIFERATION REV., Spring 2001, at 86, 88, *available at* http://cns.miis.edu/npr/pdfs/81mahip.pdf.

158. USEC, About the Corporation, Nov. 4, 2009, http://www.usec.com/downloads/newsroom/corpkit.pdf.

159. U.S. GEN. ACCOUNTING OFFICE, URANIUM ENRICHMENT: DECONTAMINATION AND DECOMMISSION FUND IS INSUFFICIENT TO COVER CLEANUP COSTS 18 (2004), *available at* http://www.gao.gov/new.items/d04692.pdf. The GAO estimated in 2004 that "by 2044, the most likely time frame for completion of cleanup at the three plants, cleanup costs will have exceeded [decontamination and decommissioning fund] revenues by $3.5 billion to $5.7 billion (in 2004 dollars)." *Id.* Converting this cost range to 2010 dollars ($4.17–$6.79 billion) and even assuming the utility assessed contribution for one-third of the cost is restored, the taxpayers share will easily exceed $10 billion (in 2010 dollars). However, more recent data suggests the costs to taxpayers may go even higher.

160. This estimate includes $9.5 to $16.4 billion for the Paducah, Kentucky gaseous diffusion enrichment plant—the primary facility for civil nuclear fuel enrichment—and $7.4 to $14.4 billion for the Portsmouth, Ohio gaseous diffusion plant. OFFICE OF ENVTL. MGMT., U.S. DEP'T OF ENERGY, STATUS OF ENVIRONMENTAL MANAGEMENT INITIATIVES TO ACCELERATE THE REDUCTION OF ENVIRONMENTAL RISKS AND CHALLENGES POSED BY THE LEGACY OF THE COLD WAR 79 tbl.3.2 (2009), *available at* http://www.em.doe.gov/pdfs/NDAA%20Report-(01-15-09)a.pdf.

4. Mining and concentration of the natural uranium feedstock needed for both military and civil purposes left a huge environmental legacy of radioactive and heavy metals pollution in the western United States, Canada, and other nations. Much of this pollution still remains to be cleaned up at public expense, again requiring billions in public expenditures over several decades.[161] Remediation of the uranium mill tailings site near Moab, Utah alone is likely to cost almost $1 billion, although some of these costs may be assignable to uranium production for military purposes.[162] The cost of remediating scores of smaller abandoned uranium mine sites has never even been estimated, and no agency of the U.S. government has stepped forward to take responsibility for them. With its flawed and ineffective framework for regulating the uranium mining and recovery industry, the U.S. government appears poised to repeat this disastrous experience.

5. DOE continues to subsidize the industry by such practices as giving away tens of tons of valuable Highly Enriched Uranium ("HEU") from the military stockpile to USEC, the Tennessee Valley Authority ("TVA"), and Toshiba-Westinghouse, who down-blend it at government expense to Low-Enriched Uranium ("LEU") and use it as low-cost fuel for reactors or as cheap working inventory in a fuel-fabrication plant.[163]

161. *See id.*

162. *See id. See generally* Congress Daily, Obama Budget to Seek $7 Billion for Nuclear Stockpile, Jan. 29, 2010, http://www.govexec.com/dailyfed/0110/012910cdpm1.htm; Global Security.org, Military: Depleted Uranium [DU], http://www.globalsecurity.org/military/systems/munitions/du.htm (last visited Feb. 24, 2010) (describing the many uses of uranium by the military).

163. *See* Press Release, Nat'l Nuclear Sec. Admin., NNSA Announces Contract to Downblend 12 Metric Tons of Surplus Highly Enriched Uranium (June 23, 2009), *available* at http://nnsa.energy.gov/2403.htm.

> In December 1994, the Department [of Energy] signed a memorandum of agreement with USEC for the [free] transfer and down-blending of [fifty] metric tons of surplus HEU to USEC for use as commercial reactor fuel. . . .
> The 174 MT declared surplus includes some "off-specification" HEU . . . useable in commercial reactors with special processing. On April 5, 2001, DOE and TVA signed an Interagency Agreement to implement a program to down-blend approximately 33 MT of DOE off-specification surplus HEU to LEU for use as fuel in TVA reactors. Lifecycle costs [to the government] of the off-specification HEU blend-down project require approximately $350,000,000, and a portion of this may be repaid by the end of the project [in 2016] from DOE/TVA-shared fuel savings (depending on future market prices for uranium). Most importantly, this arrangement avoids the alternate disposition option of down-blending all off-specification HEU to LEU and disposing of it

6. The U.S. and multinational nuclear power industry could not have come into being without—and continues to be sustained by—a massive U.S. governmental and multilateral undertaking to ensure the non-proliferation of sensitive nuclear materials and technology.[164] Over the decades, this effort, combining diplomacy, intelligence, export control, international safeguards, and physical security, has cost many tens of billions of taxpayer dollars.[165] A recent independent budget analysis pegged annual expenditures across the entire U.S. government on nuclear non-proliferation activities at $997 million per year (in 2008 dollars) out of a total of $5.2 billion spent annually on the broader category of foreign "Nuclear Threat Reduction," which likewise includes preventing and securing activities that reduce security threats stemming from the civilian nuclear fuel cycle.[166] These figures exclude classified budgets in the major intelligence agencies that are directed toward monitoring and disrupting foreign nuclear proliferation activities.[167] Without these continuing public expenditures, a global nuclear power industry would have posed too great a weapons proliferation threat and would never have been allowed to prosper.[168]

> as waste. . . . Planning for the disposition of additional quantities of surplus HEU is on-going.

U.S. DEP'T OF ENERGY, FY 2004 CONGRESSIONAL BUDGET: DEFENSE NUCLEAR NON-PROLIFERATION PROPOSED APPROPRIATION LANGUAGE 756 (2004), *available at* http://www.mbe.doe.gov/budget/04budget/content/defnn/n.pdf.

164. *See* STEPHEN I. SCHWARTZ & DEEPTI CHOUBEY, NUCLEAR SECURITY SPENDING: ASSESSING COSTS, EXAMINING PRIORITIES, CARNEGIE ENDOWMENT FOR INT'L PEACE 30–31 (2009), *available at* http://www.carnegieendowment.org/files/nuclear_security_spending_complete_high.pdf.

165. *See id.* at 30 (explaining that this effort has cost taxpayers $5.2 billion in 2008 alone).

166. *Id.* at 30 fig.13, 31 tbl.4.

167. *See id.* at 16.

168. Given the historical reluctance of the United States and other nuclear weapon states to invest heavily in the improvement of international safeguards—the IAEA struggles every year to meet its budget even in the face of known flaws and gaps in its safeguards system—whether U.S. policy actually relies on the supposed effectiveness of the IAEA safeguards regime, or is merely using it as window dressing to mask a real policy of reliance on its own nuclear weapons—not safeguards—to protect its own security against nuclear proliferation. *See* Mark Heinrich, *Tight-Fisted Donors "Bastardizing" IAEA*, REUTERS, June 16, 2009, http://www.reuters.com/article/idUSTRE55F5Q320090616. If the latter case, one could argue that a global nuclear power industry would never have been tolerated by the United States and its allies were it not for the fact that they had *already acquired* nuclear weapons—indeed a vast nuclear deterrent arsenal—and thus had less to fear from the prospect of additional nuclear arsenals springing from the spread of the "peaceful atom." This may explain what at first glance seems rash and irresponsible conduct—the U.S. enthusiasm in the 1950s and 1960s for spreading nuclear materials and

7. New sources of federal support emerged in the Energy Policy Act of 2005: a $0.018 per hour production tax credit for the first 6000 MWe of new generation, worth about $6 billion;[169] regulatory risk insurance worth $2 billion—$500 million apiece for the first two reactors and $250 million apiece for the next four;[170] licensing cost-sharing with DOE worth $727 million from 2003 to 2011;[171] and most recently, access to federal loan guarantees insuring debt financing of up to $18.5 billion for reactors and $2 billion for new enrichment technology.[172] The nuclear industry and its supporters in Congress continue to press for much higher levels of support, on the order of at least $100 billion or more, in the form of manufacturing tax credits and loan guarantees, to support deployment of forty-five new reactors by 2030.[173] In its FY 2011 budget proposal, the Obama administration requested an additional $36 billion in nuclear loan guarantee authority for the Secretary of Energy, bringing the total to $54.5 billion, sufficient to support on the order of seven to ten new reactors.[174]

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technology around the world under the Atoms for Peace program. *Asian Nuclear Waste Arrives at Idaho Storage Dump*, REUTERS, July 23, 1998.

169. PUBLIC CITIZEN, NUCLEAR GIVEAWAYS IN THE ENERGY POLICY ACT OF 2005 (2006), *available at* http://www.citizen.org/documents/NuclearEnergyBillFinal.pdf; *see* 26 U.S.C. § 455 (2006).

170. PUBLIC CITIZEN, *supra* note 169; *see* 42 U.S.C. § 16014(d)(2)–(3).

171. NUCLEAR ENERGY INST., NUCLEAR POWER 2010: A KEY BUILDING BLOCK FOR NEW NUCLEAR POWER PLANTS 2 (2009), *available at* http://www.nei.org/resourcesandstats/documentlibrary/newplants/policybrief/nuclearpower 2010 (follow "Download this File" hyperlink).

172. *See* 22 U.S.C. §§ 16512–16513; Rebecca Smith, *U.S. Chooses Four Utilities to Revive Nuclear Industry*, WALL ST. J., June 17, 2009, at A1.

173. Sue Sturgis, Inst. for S. Studies, Nuclear Companies Face Reactor Design Problems, Ethics Questions (Nov. 16, 2009), http://southernstudies.org/2009/11/nuclear-companies-face-reactor-design-problems-ethics-questions.html; *see* NUCLEAR ENERGY INST., LEGISLATIVE PROPOSAL TO HELP MEET CLIMATE CHANGE GOALS BY EXPANDING U.S. NUCLEAR ENERGY PRODUCTION 3 (2009), *available at* http://www.nei.org/filefolder/ 2009_Nuclear_Policy_Initiatives_2.pdf. NEI is not unique in its quest for taxpayer handouts, but the inherently costly nature of its product does lead to some eye-popping support requests compared to other low-carbon energy technologies. Federal taxpayers may rightly question what happened to the idea of letting a rising market price for emissions allowances under a declining national cap become the engine of energy market transformation, rather than legislators and bureaucrats handing out favors to the industry groups who can wield the most influence and donate the most cash to legislators' reelection campaigns.

174. *See* U.S. DEP'T OF ENERGY, FY 2011 BUDGET Overview 7 (2010), *available at* http://www.energy.gov/media/Secretary_Chu_2011_Budget_rollout_presentation.pdf; Michael D. Shear & Steven Mufson, *Obama Offers Loan to Help Fund Two Nuclear* Reactors, WASH. POST, Feb. 17, 2010, at A1.

8. While the sum total of direct and indirect financial support provided by the U.S. government to the nuclear power industry over many decades is probably not known with any degree of precision, it likely exceeds at least $100 billion,[175] and when all the myriad government costs are included for monitoring and safeguarding the civil nuclear fuel cycle against weapons proliferation—countering it when it nonetheless occurs—the total public costs of nuclear power surely exceed $200 billion (most likely $500 billion in current dollars).
9. Despite such major public expenditures designed to sever the links between the civil and military applications of nuclear energy, at some basic level these connections are irreducible, creating an enduring and legitimate concern in the minds of citizens and security experts alike about the wisdom of promoting nuclear power as a global solution to climate change.

C. *The Continuing Risk of Nuclear Weapons Proliferation*

While there is always some inherent proliferation risk involved in spreading the nuclear knowledge, materials, and equipment required to operate safeguarded civilian power reactors, these risks become much more severe if nuclear fuel cycle technology is involved. A nominal national commitment to peaceful nuclear power generation often serves to justify a nation's interest in acquiring inherently dual-use technologies and facilities that are on the critical path to the acquisition of nuclear bomb-making capability. Iran's construction of two initially secret uranium enrichment plants and a heavy water reactor to produce medical isotopes—but also weapons-usable plutonium—is a case in point.[176] This episode is only the latest in a long chain of proliferation stemming from the peaceful uses of the atom.

Since Iran and North Korea are discussed frequently these days in the press and have a proliferation trajectory more linked with the former Soviet Union than with the commercial nuclear industry, the nature of the nuclear proliferation problem is perhaps better appreciated by reviewing the earlier cases of India and Pakistan as well as the current situations of Brazil and South Korea.

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175. James Cook, *Nuclear Follies*, FORBES, Feb. 11, 1985, at 82.

176. *See An Iranian Nuclear Bomb, or the Bombing of Iran?*, ECONOMIST, Dec. 3, 2009, http://www.economist.com/displaystory.cfm?story_id=15016192.

1. India

India used a research reactor supplied by Canada and heavy water supplied by the United States—both transferred under bilateral peaceful use commitments—to make the plutonium for its first nuclear bomb detonated in 1974.[177] India separated the plutonium using a plutonium-uranium extraction ("Purex") reprocessing technique developed by the U.S. nuclear weapons program and made available to India and other nations through the Eisenhower administration's Atoms for Peace program.[178] Indian engineers employed this process in the Phoenix reprocessing plant, designed by Vitro International, an American firm.[179]

2. Pakistan

Munir Khan, the first director of Pakistan's Atomic Energy Commission, was trained in reactor engineering at the Illinois Institute of Technology and Argonne National Laboratory, the center of the U.S. fast breeder reactor development effort, and then served for over a decade as head of the reactor engineering department at the International Atomic Energy Agency ("IAEA") before returning to Pakistan in 1972 to head Pakistan's secret plutonium weapon development effort.[180]

Pakistan's Canadian-supplied natural uranium power reactor, the 137 MWe Karachi Nuclear Power Plant ("KANUPP"), went critical in 1971, and Prime Minister Bhutto's government promptly ordered a spent-fuel reprocessing plant from the San Gobain firm in France to separate the plutonium produced by the reactor.[181] In May 1974 India conducted its first peaceful nuclear explosion, ending the era of mindless civil nuclear power boosterism that was abetting nuclear weapons proliferation far and wide.[182] The Canadians responded to the new international concern about proliferation by withdrawing fuel and heavy water

177. JOSEPH CIRINCIONE ET AL., DEADLY ARSENALS: NUCLEAR, BIOLOGICAL AND CHEMICAL THREATS 225 (2d ed. 2005).

178. GEORGE PERKOVICH, INDIA'S NUCLEAR BOMB: THE IMPACT OF GLOBAL PROLIFERATION 28 (1999).

179. *Id.*

180. THOMAS C. REED & DANNY B. STILLMAN, THE NUCLEAR EXPRESS: A POLITICAL HISTORY OF THE BOMB AND ITS PROLIFERATION 246 (2009).

181. *Id.* at 246–47.

182. *See id.* at 236.

moderator support for the KANUPP reactor, while the French first redesigned the reprocessing plant at Chasma to move it a step away from the Purex process most suited for extracting weapons-grade plutonium, and then under U.S. pressure finally abandoned the sale.[183] But the critical technology transfer had already taken place. Munir Khan's team quietly completed a lab-scale reprocessing facility at the Pakistan Institute of Nuclear Science and Technology and a small reprocessing plant, the New Labs, at Rawalpindi.[184] Some proliferation experts and former government insiders believe the material for the weapon Pakistan exploded on May 30, 1998, came from fuel rods withdrawn from the Canadian-supplied KANUPP power reactor during the extended period from 1976 to 1982, when it was not under international safeguards.[185]

By the time of the 1974 Indian test and the international clamp down on the reprocessing route to the bomb, Pakistan already had in place a "track two" approach to acquiring suitable weapons-usable fissile material in the person of the now notorious A.Q. Khan—no relation to Munir Khan—who was then embedded in a civil nuclear facility in Holland linked to the URENCO European enrichment consortium.[186] In December 1975 A.Q. Khan returned to Pakistan, bringing stolen URENCO centrifuge technology with him and extensive knowledge of the industrial component companies in Europe who could supply key components to Pakistan's secret program for building an unsafeguarded centrifuge enrichment plant.[187]

Following General Zia's coup and declaration of martial law in July 1977 and the Soviet invasion of Afghanistan in 1979, China assumed a large clandestine role in deliberately assisting Pakistan's nuclear weapons design and engineering effort, while the Reagan administration turned a blind eye to all this unsafeguarded nuclear activity in order to enlist Pakistan's cooperation in creating a bloody quagmire for Soviet military power in Afghanistan.[188] By 1985 the A.Q. Khan Research Laboratory had a

183. *See id.* at 247.
184. *See id.* at 251.
185. *Id.* at 258.
186. *See id.* at 247.
187. *See id.*
188. *See id.* at 248–49.

working centrifuge cascade that could produce highly enriched uranium, and, by 1986, enough HEU for a nuclear weapon.[189]

It is widely believed within the U.S. national security community that in 1990 China hosted the first test of a Pakistani nuclear weapon, built to a Chinese HEU design, at the Lop Nur test site in Sinkiang province.[190] An unsafeguarded forty MWe thermal heavy water research reactor at Khushab, built with Chinese assistance during the 1990s in violation of their obligations under the NPT, is believed to be the primary current source of weapons-grade plutonium for Pakistan's nuclear stockpile.[191] A Khushab II plutonium production reactor is under construction.[192] An unsafeguarded Belgian-supplied heavy water plant at Multan provides heavy water to the plutonium production effort.[193]

3. Brazil

Under the military governments that ruled Brazil in the 1970s and 1980s, Brazil's military services ran multiple secret programs related to the development of nuclear weapons.[194] The most technically successful of these was run by the Brazilian Navy's Special Projects Commission, which sought to acquire and further develop centrifuge technology for uranium enrichment.[195] Brazil's primary foreign nuclear technology partner during this period was West Germany.[196] By 1989 the Commission announced that the first module of a pilot enrichment plant at the Navy's Aramar Experimental Center in Ipero, Sao Paolo, Brazil, had produced small amounts of uranium enriched to 20% U-235.[197] At the time, Brazil was not a member of the NPT, so the pilot plant was not under any kind of safeguards.[198] With the return of civilian gov-

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189. *Id.* at 251.

190. *See id.* at 252.

191. *See id.* at 258.

192. *Id.* (citing Joby Warrick, *Pakistan Expanding Nuclear Program*, WASH. POST, July 24, 2006, at A1).

193. CIRINCIONE ET AL., *supra* note 177, at 256–58 tbl.12.1.

194. *See* Sharon Squassoni & David Fite, *Brazil as Litmus Test: Resende and Restrictions on Uranium Enrichment*, ARMS CONTROL TODAY, Oct. 2005, at 13, 16.

195. *See id.*

196. *See id.*

197. *Id.*

198. *See* Daphne Morrison, Nuclear Threat Initiative, Brazil's Nuclear Ambitions, Past and Present (Sept. 26, 2006), http://www.nti.org/e_research/e3_79.html (stating Brazil did not ratify the NPT until 1998).

ernments in the late 1980s, the Air Force's secret laser enrichment program and the Army's graphite reactor program for producing weapons-grade plutonium were cancelled, but the Navy centrifuge enrichment effort survived the transition to democratic rule, and the public rationale became the need to ensure both energy security and national security, in the form of the Navy's effort to develop a nuclear-powered submarine.[199]

Beginning in 1991, Brazil and Argentina pursued a bilateral nuclear transparency regime that eventually brought both countries into the IAEA safeguards regime.[200] Brazil finally ratified the NPT in 1998, but it continues to develop its centrifuge capability and to enrich uranium up to 20%, which, in terms of separative work, is only a short distance away from weapons-grade uranium.[201]

The technology developed at Aramar became the basis for a larger commercial-scale enrichment plant at Resendenear Rio de Janeiro, which has been the object of international concern.[202] In April 2004 Brazil denied full visual access by IAEA inspectors to the cascade hall on the ostensible grounds that it would compromise trade secrets involved in the design of Brazilian machines.[203] The impasse appears to have lasted nine months.[204] Those who are skeptical of the Brazilian trade secrets justification suspect that Brazil may have been guarding against disclosure of details that might reveal a foreign and potentially illicit origin for the technology Brazil is using.[205] More important than getting to the bottom of this controversy, however, is recognizing the sobering fact that Brazil was able to fend off the duly constituted guardians of the global non-proliferation regime for so long on a matter of such critical importance.

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199. *See* Squassoni & Fite, *supra* note 194, at 16.

200. *Id.* at 17.

201. *See* Morrison, *supra* note 198 (stating Brazil ratified the NPT in 1998); *see also* Carey Sublette, Nuclear Weapons Frequently Asked Questions (Aug. 9, 2001), http://nuclearweaponarchive.org/Nwfaq/Nfaq6.html (follow "6.0 Nuclear Materials" hyperlink) (discussing weapons-grade uranium).

202. *See* Squassoni & Fite, *supra* note 194, at 13; *see also* Larry Rohter, *If Brazil Wants to Scare the World, It's Succeeding*, N.Y. TIMES, Oct. 31, 2004, at 3.

203. *See* Squassoni & Fite, *supra* note 194, at 14.

204. Morrison, *supra* note 198 (stating IAEA inspectors were denied visual access to centrifuges in February and March 2004, but in October 2004 both sides agreed to allow IAEA officials to visit the facilities).

205. Mark Hibbs & Daniel Horner, *Bearing Design Prompted Brazil to Withhold Centrifuge Data from IAEA*, NUCLEAR FUEL, Dec. 6, 2004, at 1.

Fortunately, the Resende plant was still in a testing and tuning phase prior to the introduction of uranium hexafluoride and thus not in a position to produce a significant quantity of highly-enriched product during the period of the impass.[206] But the episode puts into sharp relief the weakness of the current nonproliferation regime in dealing with sensitive nuclear fuel cycle facilities.[207] No state should be able to stiff arm a legitimate international inspection authority in such a manner without facing the certain prospect of some kind of meaningful sanction by the international community.

Shortly after the Resende episode concluded with a compromise allowing Brazil to shroud the IAEA's access to the magnetic bearings in the four cascades of the first module—but not future ones[208]—and in the midst of seemingly fruitless and dilatory negotiations with Iran over its illegal pursuit of uranium enrichment capability, IAEA Director-General El Baradei candidly remarked,

> We just cannot continue business as usual that every country can build its own factories for separating plutonium or enriching uranium. Then we are really talking about 30, 40 countries sitting on the fence with a nuclear weapons capability that could be converted into a nuclear weapon in a matter of months.[209]

4. Japan

One of the countries that could readily convert its capabilities to nuclear weapons is Japan. Japan continues to amass a huge stockpile of separated civil plutonium currently declared to be 46.6 metric tons, of which 8.7 metric tons are held within Japan and 37.9 metric tons are stored overseas in France and the United Kingdom.[210] As a purely technical matter, Japan could become a de facto nuclear weapon state in a matter of days, weeks, or

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206. *See Sources: Brazil Blocks Nuclear Inspectors*, CNN.COM, Apr. 4, 2004, http://www.cnn.com/2004/WORLD/americas/04/04/brazil.nuclear/index.html.

207. *See* Squassoni & Fite, *supra* note 194, at 14.

208. M.D. LAUGHTER, OAK RIDGE NAT'L LAB., PROFILE OF WORLD URANIUM ENRICHMENT PROGRAMS-2007, at 17 (2007), http://apps.ornl.gov/~pts/prod/pubs/ldoc8538_final_tm_profile_of_world_uranium_enrichment_programs_2007.pdf.

209. *Multilateral Groups Should Control Nuclear Fuel: IAEA*, TAIPEI TIMES, Feb. 24, 2005, at 6, *available at* http://www.taipeitimes.com/News/world/archives/2005/02/24/2003224385.

210. *See* INT'L PANEL ON FISSILE MATERIALS, GLOBAL FISSILE MATERIAL REPORT 2009: A PATH TO NUCLEAR DISARMAMENT ch. 1 app. 1C (2009), http://www.fissilematerials.org/ipfm/site_down/gfmr09.pdf.

months, depending on the level of secret preparations it is willing to undertake to advance toward this goal.

5. North Korea

Under the guise of a peaceful civil program assisted by Russia, China, and Pakistan, North Korea obtained the plans for a small Belgian reprocessing plant and built its own version, which it used to obtain enough plutonium for several nuclear weapons after it became a party to the NPT in 1985.[211]

6. South Korea

While little known, it is significant and worrisome that South Korea engaged in a series of systematic and protracted violations of its IAEA safeguards agreement from the early 1980s through 2000 in a manner that roughly parallels Iran's much more widely noted violations over a similar time period.[212] Yet South Korea has faced no sanctions, threat of sanctions, or even a mild public rebuke from the international community, despite its record of clandestine nuclear weapons development under the military governments of the 1970s.[213] These violations included:

(1) Secret chemical ion exchange enrichment experiments with uranium conducted from 1979–1981.[214]

(2) Secret construction and operation in the early 1980s, and subsequent destruction, of three laboratories for converting natural or depleted uranium to metallic form.[215] According to the IAEA, these activities "were revealed only as a result of the Agency's verification activities,"[216] and not as a result of the Republic of Korea's ("ROK") voluntary declarations. Two of these se-

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211. *See* LEONARD SPECTOR ET AL., TRACKING NUCLEAR PROLIFERATION: A GUIDE IN MAPS AND CHARTS 103 (1995).

212. Gareth Porter, *South Korea Let Off for Nuclear Deceptions*, ASIA TIMES, Dec. 22, 2009, http://www.atimes.com/atimes/Middle_East/KL22Ak02.html.

213. *See id.*

214. INT'L ATOMIC ENERGY AGENCY, IMPLEMENTATION OF THE NPT SAFEGUARDS AGREEMENT IN THE REPUBLIC OF KOREA 7 (2004), http://www.iaea.org/Publications/Documents/Board/2004/gov2004-84.pdf.

215. *See id.* at 4–5.

216. *Id.* at 4.

cret conversion labs produced 154 kilograms ("kg") of natural uranium metal, which was never declared to the IAEA.[217]

(3) Secret experiments from July to December 1981 using the TRIGA Mark III research reactor supplied by the United States at the Korea Atomic Energy Research Institute ("KAERI") to irradiate a mini-fuel assembly containing about 2.5 kg of depleted uranium for eighty-two days.[218] This irradiation was followed by transfer "to a hot cell for heavy metal separation based on the PUREX process.... [A] basic solvent extraction procedure was performed on a portion of the dissolved solution, and ion exchange used in an attempt to recover a purified plutonium product."[219] This "plutonium separation experiment was carried out by the ROK in a safeguarded facility and was not declared to the Agency.... Moreover, the ROK incorrectly reported the mini-assembly as a measured discard of an unirradiated fuel assembly,"[220] which implies the ROK lied to the IAEA.

(4) "[I]t appears that at least ten [Atomic Vapor Laser Isotope Separation ("AVLIS")] related experiments involving exempted [depleted uranium] and undeclared [natural uranium] were carried out at KAERI facilities between 1993 and 2000" by "some 14 KAERI scientists."[221] In the two years leading up to this disclosure, which was precipitated by entry into force of the ROK's Additional Protocol granting the IAEA broader inspection and sampling rights that threatened to reveal the existence of the program, the ROK had "continued to affirm that its laser enrichment... program[ ] did not involve the use of any nuclear material."[222] This implies that the ROK lied to the IAEA. Finally, in August 2004 the ROK disclosed that it had actually enriched uranium in three separate AVLIS experiments.[223] This disclosure stated the ROK had "achieved an average enrichment level of 10.2% U-235," a maximum of 77% U-235, and "produced 200 [milligrams] of enriched uranium."[224]

217. *Id.*
218. *See id.* at 5.
219. *Id.* at 6.
220. *Id.*
221. *Id.* at 3.
222. *Id.* at 2–3.
223. *Id.* at 3.
224. *Id.*

The IAEA noted that "the ROK's laser technology development involved foreign assistance," but was not more explicit on that subject.[225] From other sources, we know that U.S. institutions, such as the University of New Mexico, the University of Rochester, and DOE's own Lawrence Livermore National Laboratory, provided support for KAERI laser researchers in technical areas identical to those involved in the secret AVLIS program.[226]

Even with the ROK's record of nuclear misconduct and deception, the Bush administration rewarded the ROK with membership in its Global Nuclear Energy Partnership ("GNEP") in December 2007.[227] The GNEP sought to promote the creation of a new global hierarchy, comprised of nuclear fuel cycle states that would possess the full suite of capabilities for reprocessing spent fuel and fabricating plutonium into fresh fuel[228] and a much larger population of customer states that would purchase the fuel and subsequently return it to the nuclear fuel cycle states for processing.[229] This nuclear colonialist vision was transparently unachievable on several levels: Why would the citizens of just a few countries consent to storing and processing the nuclear wastes of scores of customer countries? Further, why would those customer countries resign themselves to a state of permanent exclusion from advanced fuel cycle technology? This neo-colonialist vision mainly served to stimulate the interest of countries like South Korea and Brazil in advancing their own autonomous national nuclear fuel cycle capabilities.[230]

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225. *Id.*

226. Mark Gorwitz, Institute for Science and International Security, The South Korean Laser Isotope Separation Experience (Oct. 5, 2004), http://isis-online.org/isis-reports/detail/the-south-korean-laser-isotope-separation-experience-1/10.

227. *See* Press Release, Dep't of Energy, Department of Energy Welcomes the Republic of Korea to the Global Nuclear Energy Partnership (Dec. 11, 2007), *available at* http://www.ne.doe.gov/newsroom/2007PRs/nePR121107.html.

228. Miles A. Pomper, *GNEP Membership Grows, Future Uncertain*, ARMS CONTROL TODAY, Nov. 2008, at 50, 50.

229. Edwin Lyman & Frank N. von Hippel, *Reprocessing Revisited: The International Dimensions of the Global Nuclear Energy Partnership*, ARMS CONTROL TODAY, Apr. 2008, at 6, 6.

230. South Korea, in particular, is pursuing a form of spent fuel reprocessing it calls the Advanced Spent Fuel Conditioning Process ("ACP"), which uses spent fuel in metallic form, dissolves it in molten salt, and uses electrolysis to separate the longest lived fission products so it can be reformed into a plutonium-uranium fuel with an admixture of other fissile isotopes and put back in plutonium burner/breeder reactors. *See* Miles A. Pomper, *Concerns Raised as South Korea Joins GNEP*, ARMS CONTROL TODAY, Jan. 2008, at 44, 44–45. More compact than Purex wet chemistry technology, this pyro-processing tech-

Consider the stark conclusions of the Keystone Center's 2007 *Joint Nuclear Fact Finding* study.[231] This study included nuclear industry representatives analyzing the GNEP. The study stated that although it is not its aim, "[t]he GNEP program could encourage the development of hot cells and reprocessing R&D centers in non-weapon states, as well as the training of cadres of experts in plutonium chemistry and metallurgy, all of which pose a grave proliferation risk."[232]

As the preceding cases illustrate, proliferation risks often emanate directly from the civil nuclear promotional activities of nuclear weapons states. As Pogo reminded the world in Walt Kelly's memorable poster for Earth Day 1990: "We Have Met the Enemy and He Is Us."[233]

D. *The Lack of Technical Competence, Transparency, Accountability, and Safety Culture in Countries That May Acquire Nuclear Reactors*

Overall, the nuclear power industry in advanced industrial countries has compiled a fairly good safety record, with the most notable exceptions being the Chernobyl and Three-Mile Island accidents.[234] Moderately severe incidents and near-accidents continue to occur, even in advanced nuclear states such as Germany,[235] Japan,[236] and the United States.[237] As the current population

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nique, as it is known in the United States, affords easy access to technical mastery of both the plutonium metallurgy and chemistry needed to make nuclear weapons. The fact that the plutonium is not extracted in pure form during the process does not alter its proliferation implications, especially for a country that is already very conversant with laser isotope separation techniques that could clean-up material for weapons use. *See id.* Moreover, the pyro-processing techniques themselves can be adjusted to yield weapons-usable plutonium product. *See id.*

231. THE KEYSTONE CTR., NUCLEAR POWER JOINT FACT-FINDING (2007), *available at* http://keystone.org/files/file/SPP/energy/NJFF-Final-Report-6_2007.pdf

232. *Id.* at 91.

233. *See* IGoPogo.com, "We Have Met the Enemy . . . and He Is Us," http://www.igopogo.com/we_have_met.htm (last visited Feb. 24, 2010) (showing Walt Kelly's poster and explaining its origin).

234. *See* WORLD NUCLEAR ASS'N, SAFETY OF NUCLEAR POWER REACTORS 1 (2008), http://www.world-nuclear.org/info/inf06.html (stating that Three-Mile Island and Chernobyl "are the only major accidents to have occurred in more than 12,700 cumulative reactor-years of commercial operation in 32 countries").

235. *See Incident Fuels German Nuclear Debate*, UPI.COM, July 6, 2009, http://www.upi.com/Science_News/Resource-Wars/2009/07/06/Incident-fuels-German-nuclear-debate/UPI-29821246922190/.

236. *See Asia-Pacific Nuclear Accident Shakes Japan*, BBC NEWS, Sept. 30, 1999,

of reactors ages but remains in use beyond their originally contemplated lifetimes, the problem of ensuring nuclear safety is likely to be of mounting concern.[238] The same is true of nuclear programs, like China's, that seek to build reactors as fast as they can, leading to concerns about quality assurance in new plants that match the concerns about hidden deterioration in the older plants.[239]

The safety records of Chinese civil nuclear facilities are not transparent, and the world knows little about what has occurred at these facilities other than they have thus far avoided a catastrophic accident.[240] Part of the inherent bargain with nuclear power is a continuing small probability of a very high-consequence nuclear accident.[241] One of the reasons the technology justifiably remains so costly is the building of redundant safety systems that can keep the probability of a severe accident as low as possible.

If ensuring nuclear safety remains a challenge even for advanced industrial states with highly-developed safety cultures, these demanding safety requirements become a significant concern when one considers that some of the countries interested in producing nuclear power, such as Vietnam, Egypt, and Indonesia, have very high indices of both industrial accidents and official corruption.[242] The credibility and effectiveness of the rigorous regulation required for nuclear safety is certainly open to question in these countries. While China already has eleven nuclear plants and is building dozens more, it has an appalling industrial

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http://news.bbc.co.k/2/hi/asia-pacific/461446.stm.

237. Brian Krebs, *Cyber Incident Blamed for Nuclear Power Plant Shutdown*, WASHINGTONPOST.COM, June 5, 2008, http://www.washingtonpost.com/wp-dyn/content/article/2008/06/ 05/AR2008060501958.html.

238. *See, e.g.*, Nuclear Regulatory Comm'n, Nuclear Reactor Safety Research: Plant Aging (July 23, 2009), *available at* http://www.nrc.gov/about-nrc/regulatory/research/reactor-rsch.html ("A better understanding of the effect of age-related degradation on structures, systems, and components is being developed to ensure that adequate margins are maintained under all design conditions for the current and any extended operating life of nuclear power plants.").

239. *See* Keith Bradsher, *China, Rushing into Reactors, Stirs Concerns*, N.Y. TIMES, Dec. 16, 2009, at A1.

240. *See id.*

241. WORLD NUCLEAR ASS'N, *supra* note 234, at 4.

242. *See* George Jahn, *New Energy Behind Nuclear Power*, L.A. TIMES, Jan. 21, 2008, at C4; TRANSPARENCY INT'L, CORRUPTION PERCEPTIONS INDEX 2009, http://www.transparency.org/policy_research/surveys_indices/cpi/2009 (last visited Feb. 24, 2010).

safety record—thousands die annually in "fires, explosions and other accidents often blamed on insufficient safety equipment and ignored safety rules."[243] Also, consider the implications of this recent news summary from China Daily:

> Kang Rixin, former Party chief and general manager of the China National Nuclear Corporation (CNNC), has been stripped of his post and his membership in the Communist Party of China (CPC) for "serious violations of the law and breaches of discipline," the Party's discipline watchdog announced Friday.
>
> Kang was found to have abused his authority, enabled profits for others, and taken huge bribes, according to the findings of investigations conducted by the CPC Central Commission for Discipline Inspection.[244]

Kang reportedly took "$260 million that was earmarked for the construction of three nuclear plants and allegedly used the funds for the stock market sustaining heavy losses."[245] He is also accused of "accepting bribes from a foreign company that intended to build nuclear power stations in China."[246]

We know from the U.S. experience how hard it is to sustain independent and effective regulation in our own country, much less in often chaotic developing nations marked by high degrees of corruption, lack of official and corporate transparency, and an opaque fusion of military and private interests at the top that can subvert all efforts of public accountability and independent oversight. Out of the 163 nations listed in Transparency International's 2009 Corruption Perceptions Index, Vietnam ranked 120th

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243. Jahn, *supra* note 242.

244. *Across China: Beijing*, CHINA DAILY, Jan. 16, 2010, http://www.chinadaily.com.cn/cndy/2010-02/02/content-9411096.htm.

245. Nuclear Threat Initiative, China Nuclear Corporation ("CNNC"), http://www.nti.org/db/china/cnnc.htm (last visited Feb. 24, 2010).

246. *Id.* "According to the CNNC, it 'combines military production with civilian production, taking nuclear industry as the basis while developing nuclear power and promoting a diversified economy.'" *Id.* The profile of CNNC includes the following observation from Chinese scholar Weixing Hu:

> "When it shifted its focus to nuclear energy programs, the [CNNC] began to diversify its products and to chase foreign customers in the international market. . . . The CNNC's long-term goal is to achieve self-reliance in the design, manufacture, construction, and running of nuclear power plants, and to possess the full-cycle nuclear fuel technology. To achieve this objective, it needs, on the one hand, to introduce advanced Western technology and know-how into its program and, on the other hand, to export what it produces to the world market to support its foreign purchases."

Id. (citing Weixing Hu, *China's Nuclear Export Controls: Policy and Regulations*, 1 NONPROLIFERATION REV., Winter 1994, at 3, 4).

and Indonesia and Egypt were tied at 111th.[247] Former members of the Soviet Union, Russia and Ukraine, have a troubling history of nuclear safety and are currently ranked 146th, tied with Zimbabwe.[248]

Evidence of the seriousness of this concern, and the vulnerability it creates for nuclear power operators in advanced industrial countries, recently came to the forefront in Europe when German government officials and utility executives leveled sharp criticism at the nuclear export promotion activities of French President Nicolas Sarkozy.[249] Since his election in May 2007, Sarkozy has offered French reactors to Georgia, Libya, the UAE, Saudi Arabia, Egypt, Morocco, and Algeria.[250] In response, German executives and diplomats have openly expressed concern that if there is a serious accident with the EPR in one of these places, "that will be the end of the nuclear renaissance."[251] Unlike Chernobyl, one anonymous executive noted, "if something goes badly wrong we won't be able to blame it all on second-rate Soviet technology."[252]

E. *Environmental Contamination from Nuclear Fuel Cycle Activities*

Uranium mining, milling, conversion, enrichment, reprocessing, and nuclear waste disposal activities have historically produced and continue to cause significant levels of environmental contamination and harm to the health of nuclear industry workers and residents of affected communities.[253] Waste from uranium mining takes the form of both waste rock and tailings.[254] The percentage of uranium in naturally occurring high-grade ore bodies is very low, creating the need for plants that concentrate the ore into something called "yellowcake" (uranium oxide, U_3O_8).[255]

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247. TRANSPARENCY INT'L, *supra* note 242.

248. *Id.*

249. *See* Mark Hibbs, *German Leaders Question Selling EPRs to New Nuclear Developing Countries*, NUCLEONICS WEEK, Feb. 14, 2008, at 1, 13.

250. *See id.* at 1.

251. *Id.* at 13.

252. *Id.*

253. *See, e.g.*, PEMBINA INST., URANIUM MINING: NUCLEAR POWER'S DIRTY SECRET 1–4 (2007), *available at* http://pubs.pembina.org/reports/ClearingAir_UraniumMining.pdf.

254. *Id.* at 1–2.

255. *See* Bernard P. Haggerty, *"TRU" Cooperative Regulatory Federalism: Radioactive Waste Transportation Safety in the West*, 22 J. LAND RESOURCES & ENVTL. L. 41, 45–46

Tailings are formed when uranium ore is crushed and chemically treated—usually with sulfuric acid and other chemicals—to leach out the uranium.[256] The tailings—the waste from the uranium mining process—are normally transferred in a slurry pipeline and dumped into engineered impoundments.[257] These piles, or settling ponds, of toxic residues are usually only partially contained and often contaminate ground and surface waters.[258] Leach residues contain most of the radioactive decay products of uranium, including Thorium-230, Radium-226, and Radon-222 (radon gas).[259] Tailings also contain sulfuric acid, ammonia, heavy metals, arsenic, and other process chemicals.[260] Because Thorium-230 is long-lived, radium and radon are continually produced in the tailings and released over a long period of time.[261]

According to the National Institute of Occupational Safety and Health, a strong exposure-dependent link exists between uranium mining and cancer and other lung diseases, such as silicosis, among veterans of the first uranium mining boom.[262] The Navajo Nation's bitter experience with uranium mining has led the Nation to ban uranium on its lands.[263] Meanwhile, uranium mining technology has progressed, and in-situ leaching has replaced hard-rock mining and milling in many locations.[264] Leaching by-

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(2002); U.S. Nuclear Regulatory Comm'n, Yellowcake, http://www.nrc.gov/reading-rm/basic-ref/glossary/yellowcake.html (last visited Feb. 24, 2010).

256. PEMBINA INST., *supra* note 253, at 1.

257. *See* U.S. NUCLEAR REGULATORY COMM'N, URANIUM MILL TAILINGS 3 (2006), *available at* http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/mill-tailings.pdf.

258. PEMBINA INST., *supra* note 253, at 1.

259. *See* Inst. for Energy and Envtl. Research, Uranium: Its Uses and Hazards, http://www.ieer.org/fctsheet/uranium.html (last visited Feb. 24, 2010).

260. PEMBINA INST., *supra* note 253, at 1–2.

261. *See* Inst. for Energy and Envtl. Research, *supra* note 259.

262. *See* NAT'L INST. FOR OCCUPATIONAL SAFETY & HEALTH, U.S. DEP'T OF HEALTH & HUMAN SERVS., HEALTH EFFECTS OF OCCUPATIONAL EXPOSURE TO RESPIRABLE CRYSTALLINE SILICA iv, 7 tbl.2 (2002), *available at* http://www.cdc.gov/niosh/docs/2002-129/02-129a.html; NAT'L INST. FOR OCCUPATIONAL SAFETY & HEALTH, U.S. DEP'T OF HEALTH & HUMAN SERVS., A RECOMMENDED STANDARD FOR OCCUPATIONAL EXPOSURE TO RADON PROGENY IN UNDERGROUND MINES 32 (1987), *available at* http://www.cdc.gov/niosh/88-101.html.

263. *See* Press Release, Office of the President & Vice President, The Navajo Nation, Navajo President Joe Shirley, Jr., Tells Congressional Subcommittee Nation Will Not Watch Another Generation Harmed by Uranium Mining (Mar. 30, 2008), *available at* http://www.navajo.org/ (follow "News from January 2008 to December 2008" hyperlink; then follow "Month of March 2008 News" hyperlink; then follow "March 30, 2008" hyperlink).

264. *See* INT'L ATOMIC ENERGY AGENCY, MANUAL OF ACID IN SITU LEACH URANIUM MINING TECHNOLOGY 1 (2001), *available at* http://www-pub.iaea.org/MTCD/publications/

products consist of huge volumes of wastewater, radioactive sludge, and contaminated aquifers.[265] Over time, hundreds of millions, and in some cases billions, of gallons of water are removed from the mined aquifer, often in parched areas that can ill afford such massive groundwater withdrawals.[266]

Most leach-mined aquifers remain contaminated by excessive concentrations of calcium, magnesium, potassium, ammonia bicarbonate, chloride, sulfate, nitrate, alkalinity, arsenic, iron, manganese, molybdenum, radium-226, selenium, and uranium.[267] After partial cleanup has been achieved, one operator after another has routinely been granted amendments to their NRC uranium recovery license, reducing required cleanup levels to those that have already been achieved, and allowing termination of the license.[268] No aquifer leach-mined for uranium has ever been restored to the water quality levels specified in the original uranium recovery permit.[269]

The process of uranium enrichment leaves a huge tails inventory of corrosive depleted uranium hexafluoride that must someday be disposed of safely, either through re-enrichment or through a costly reconversion process that separates the depleted uranium from the toxic hydrogen-fluoride, which has many industrial uses.[270] At taxpayer expense, DOE is currently building two such reconversion plants, estimated to cost $577 million, to process a backlog of uranium tails from enrichment.[271] It will take twenty-five years to process all 600,000 tons of depleted uranium hexafluoride,[272] for an as-yet unknown cost, surely not to be paid by the nuclear industry.

PDF/te_1239_pm.pdf; Gavin M. Mudd, *Critical Renew of Acid In Situ Leach Uranium Mining: 1. USA and Australia*, 41 ENVTL. GEOLOGY 390, 390–91 (2001).

265. *See* INT'L ATOMIC ENERGY AGENCY, *supra* note 264, at 221.

266. *See* Kari Lydersen, *Manufacturing Thirst: The Hidden Water Costs of Our Industrial Economy*, EARTH ISLAND J., Autumn 2008, at 52, 52–54.

267. *See* Method for the Renovation of an Aquifer, U.S. Patent No. 4,260,193 col.1 ll.25–31 (filed Jun. 7, 1979) (issued Apr. 7, 1981).

268. *See* Jodi Peterson, *Underground Movement*, HIGH COUNTRY NEWS, Oct. 1, 2007, at 4, 5.

269. *See id.*

270. *See* OFFICE OF ENVTL. MGMT., *supra* note 162, at 45, *available at* http://www.em.doe.gov/pdfs/NDAA%20Report-(01-15-09)a.pdf; Letter from U.S. Government Accountability Office to Congressional Requesters 2 (Mar. 31, 2008), *available at* http://www.gao.gov/new.items/d08606r.pdf.

271. OFFICE OF ENVTL. MGMT., *supra* note 160, at 45.

272. *Id.*

F. *Spent Fuel Reprocessing Is Not a Solution to the Nuclear Waste Disposal Problem*

Often touted as a solution to the problem of managing the accumulation of spent fuel from nuclear reactors,[273] spent-fuel reprocessing creates a stream of highly radioactive liquid waste that must be treated and immobilized in glass logs or blocks and then isolated from the biosphere for many thousands of years.[274] It also creates a long-lived intermediate level solid waste stream contaminated with plutonium that must likewise be isolated in an underground repository.[275]

Reprocessing plants in France and the United Kingdom typically discharge hundreds of millions of liters of untreated low-level liquid radioactive wastes annually into the English Channel,[276] as well as vent short-lived radioactive gases to the atmosphere.[277]

Proliferation implications aside, the French plutonium separation and Mixed Oxide ("MOX") fuel recycle program demonstrates that this path does not provide a cost-effective solution to the problem of nuclear waste disposal.[278] Despite reprocessing all of its spent LEU fuel, recycled MOX fuel supplies only 30% of the fuel for twenty of France's fifty-eight reactors, or about 10% of its total fuel requirements.[279] The facilities required to accomplish these tasks costs tens of billions of dollars,[280] but do not contribute one kW of low-carbon electricity above that which is available from conventional nuclear or other low-carbon generating technologies.[281]

After one pass through the reactor, the spent MOX fuel assemblies in France are not reprocessed, but rather are placed in storage for an indefinite period and booked as an asset until the plu-

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273. Arjun Makhijani, *France's Nuclear Fix?*, SCI. FOR DEMOCRATIC ACTION, Jan. 2008, at 5, 5, *available at* http://www.ieer.org/sdafiles/15-2.pdf.

274. *Id.*

275. *Id.*

276. *See id.*

277. *See* Peter Fairley, *Nuclear Wasteland*, IEEE SPECTRUM, Feb. 2007, at 38, 41.

278. *See id.* at 43.

279. Makhijani, *supra* note 273, at 5.

280. *Id.* at 6.

281. *See* Arjun Makhijani, *Nuclear Power Costs: Higher and Higher*, SCI. FOR DEMOCRATIC ACTION, Jan. 2008, at 1, 3–4, *available at* http://www.ieer.org/sdafiles/15-2.pdf.

tonium they contain can be used to fuel a fast breeder reactor cycle.[282] But that day may never come. This fuel cycle is so costly that it is unlikely to become economically viable for many decades, if ever.[283] This bookkeeping maneuver allows the French nuclear program to defer recognition of the significant costs involved in having to either reprocess the MOX fuel a second time or repackage and dispose of it in an underground repository in a manner analogous to conventional LEU spent fuel. Plutonium MOX fuel costs more than three times as much as low-enriched uranium fuel—$8890 per kilogram of initial heavy metal ("kgIHM") for MOX versus $2040 per kgIHM for LEU in a 2003 MIT analysis—which equates to an electricity cost premium of $0.172 per kWh for the MOX fuel.[284]

France still requires a deep geologic repository to store the highly radioactive glass logs encasing the high-level wastes from reprocessing and the MOX program cannot absorb the more than fifty metric tons of separated French plutonium piling up in tens of thousands of containers at La Hague.[285] In addition, this plutonium, along with the tanks of lethal high-level radioactive waste from which it was separated, must be defended around-the-clock against the risks of theft, sabotage, and terrorist attack.

G. *Massive Water Withdrawals and Thermal Discharges to the Aquatic Environment by Nuclear Power Plants*

About two-thirds of the thermal energy produced in a nuclear reactor is discharged to the environment as waste heat,[286] frequently pushing temperatures in receiving lakes and rivers beyond both their ecological carrying capacities and legal limits on the temperature of the receiving waters.[287] If the allowable temperature rise in the receiving waters is 30°F, a 1600 MWe

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282. *See* Fairley, *supra* note 277, at 43.

283. *See id.*

284. MASS. INST. OF TECH., *supra* note 76, at 146 tbl.A-5.D.1, 147 tbl.A-5.D.2, 149. Tables A-5.D.1 and A-5.D.2 show once-through VOX fuel cycle and single recycle MOX fuel cycle cost breakdowns. *Id.* at 146–47.

285. Makhijani, *supra* note 273, at 6.

286. DAVID LOCHBAUM, UNION OF CONCERNED SCIENTISTS, GOT WATER? 2 (2007), *available at* http://www.ucsusa.org/assets/documents/nuclear_power/20071204-ucs-brief-got-water.pdf.

287. *See generally* Pollution Issues, Thermal Pollution, http://www.pollutionissues.com/Te-Un/Thermal-Pollution.html (last visited Feb. 24, 2010).

reactor requires more than 762,000 gallons of cooling water per minute flowing through its condensers.[288] If the temperature rise is limited to 20°F, the required coolant flow rate increases to 1,144,000 gallons per minute.[289] Cooling water intake structures kill trillions of fish each year nationally as the result of impingement on intake screens and entrainment through those facilities.[290] Several reactors around the country are the target of lawsuits by state agencies and environmental groups seeking to compel installation of the best available cooling technologies to stop this wanton destruction of marine life.[291] Section 316(b) of the Clean Water Act requires "that the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact."[292]

A nuclear reactor can also consume water more intensively than any other power generation technology—at the rate of 2400 gallons per million BTU.[293] Nuclear reactors intrinsically pose an unattractive environmental tradeoff: endure fish kills and thermal pollution of local water bodies through the daily intake and discharge of billions of gallons of once-through cooling water, or endure tens-of-millions gallons of water permanently lost daily to other uses by employing semi-closed loop "evaporative" cooling tower systems.[294] The evaporative cooling tower systems do not return heated water to a local water body; instead, they withdraw cool make-up water from that local water body, competing with other consumptive uses.[295]

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288. LOCHBAUM, *supra* note 286, at 14.

289. *Id.* at 4.

290. *See* James R. May & Maya K. van Rossum, *The Quick and the Dead: Fish Entrainment, Entrapment, and the Implementation and Application of Section 316(b) of the Clean Water Act*, 20 VT. L. REV. 373, 381–82 (1995); *see also* OFFICE OF WATER, U.S. ENVTL. PROT. AGENCY, ECONOMIC ANALYSIS OF THE FINAL REGULATION, ADDRESSING COOLING WATER INTAKE STRUCTURE FOR NEW FACILITIES, ch.11 tbls.11-2, 11-3, 11-4, 11-5, 11-6, 11-7, 11-8, 11-9, 11-10, 11-11, 11-12 & 11-13 (2001).

291. *See, e.g.*, Lisa W. Foderaro, *State Proposal Would Reduce Fish Deaths at Indian Point*, N.Y. TIMES, Nov. 13, 2003, at B1.

292. Clean Water Act of 1972 § 316(b), 33 U.S.C. § 1326(b) (2006).

293. TAMIM YOUNOS ET AL., VA. POLYTECHNIC INST. & STATE UNIV., VA. WATER RES. RESEARCH CTR., WATER DEPENDENCY OF ENERGY PRODUCTION AND POWER GENERATION SYSTEMS 8 tbl.4 (2009).

294. *See* LOCHBAUM, *supra* note 286, at 2–4, 6–7.

295. *See id.* at 6–7.

Cooling water requirements and impacts are a limiting factor for the siting of new nuclear plants in some areas of the country, such as the Southeast and the intermountain West, where population growth and prolonged dry weather conditions have created a severe competition for freshwater resources.[296] The U.S. government projects that in the next ten years "at least 36 states will face water shortages."[297]

Recent summer heat waves in the American Midwest and Southeast and in Central Europe have caused reactors to reduce power or shut down entirely when cooling water intake temperatures exceeded design limits.[298]

H. *Seismic Concerns*

In large areas of the world—Japan, Indonesia, Pakistan, China, Iran, Turkey, the Andean nations, and California, to name a few—the threat of powerful earthquakes may complicate and possibly even preclude the siting of nuclear power plants.[299]

296. *See Drought Could Shut Down Nuclear Power Plants: Southeast Water Shortage a Factor in Huge Cooling Requirements*, MSNBC, Jan. 23, 2008, http://www.msnbc.msn.com/id/22804065.

297. YOUNOS ET AL., *supra* note 293, at 1 (citing U.S. GEN. ACCOUNTING OFFICE, GAO-03-514, FRESHWATER SUPPLY: STATES' VIEWS OF HOW FEDERAL AGENCIES COULD HELP THEM MEET THE CHALLENGES OF EXPECTED SHORTAGES 64 (2003); OFFICE OF ENVTL. MGMT., *supra* note 160, at 29).

298. *See Drought Could Shut Down Nuclear Power Plants*, *supra* note 296.

299. *See generally* Martin Fackler, *Japan's Quake-Prone Atomic Plant Prompts Wider Worry*, N.Y. TIMES, July 25, 2007, at A3 (discussing the ramifications of an earthquake on Japan's existing nuclear industry); Richard Tanter et al., *Nuclear Power, Risk Management and Democratic Accountability in Indonesia: Volcanic, Regulatory and Financial Risk in the Muria Peninsula Nuclear Power Proposal*, ASIAN-PAC. J., Dec. 21, 2009, http://www.japanfocus.org/-Arabella-Imhoff/3270 (discussing the siting of nuclear reactors in Indonesia); Nadeem Iqbal, *Pakistan's Nuclear Program Built on Shifting Sands*, ASIA TIMES, Dec. 23, 1999, http://www.atimes.com/ind-pak/AL23Df01.html (discussing the siting of Pakistan's Chashma nuclear power plant in an earthquake-prone area of the country); Gethin Chamberlain, *Chinese Earthquake: Nuclear Sites Alerted*, TELEGRAPH (London), May 17, 2008, http://www.telegraph.co.uk/news/worldnews/asia/1974263/Chinese-earthquake-nuclear-sites-alerted.html (discussing damage to nuclear reactors in China after earthquake); *Bushehr Design: Russian, But Not Chernobyl*, VOICE OF AM. NEWS, June 9, 2009, http://www1.voanews.com/english/news/a-13-2009-06-09-voa55-68818137.html (discussing impact of earthquake study on design of Iranian reactor at Bushehr); DAVID H. MARTIN, NUCLEAR AWARENESS PROJECT, NUCLEAR THREAT IN THE EASTERN MEDITERRANEAN: THE CASE AGAINST TURKEY'S AKKUYU NUCLEAR PLANT iii, 55–61 (2000), *available at* http://www.cnp.ca/issues/nuc-threat-mediterranean.pdf (analyzing the earth risk at Turkey's proposed Akkuyu nuclear power site); NUCLEOELECTRIC WORKING GROUP, CHILEAN COMMISSION OF NUCLEAR ENERGY, THE NUCLEOELECTRIC OPTION IN CHILE 27–28 (J. Zanelli ed., 2007), *available* at http://www.cchen.cl/mediateca/PDF/report_zanelli.

Worldwide estimates are that "20% of nuclear reactors are operating in areas of significant seismic activity."[300] Evidence of the importance of this problem was demonstrated in 2007, when a beyond-design-basis earthquake damaged the largest power station in the world, Japan's seven-unit, 7965 MWe Kashiwazaki-Kariwa complex.[301] This led to a reconsideration of earthquake resistance specifications and to costly structural upgrades at numerous other Japanese nuclear plants, while spurring a public debate about the wisdom of further increasing the earthquake-prone nation's dependence on huge multi-unit nuclear power stations.[302]

The quake obviously had a huge financial impact on Tokyo Electric Power Company ("TEPCO"). For fiscal year 2007, the year of the earthquake, the company reported the financial impact of the earthquake at 615 billion yen ($6.8 billion).[303] In fiscal year 2008, the amount increased to 649 billion yen ($7.1 billion).[304] Even with the economic impact expected to decrease significantly in fiscal year 2009—to 262 billion yen ($2.9 billion)[305]—the incremental costs of the earthquake total $16.8 billion, an incredible sum. Additionally, TEPCO's carbon emissions have increased 24% compared to 2006, the year before the earthquake.[306] When a power generating investment as large and costly as a nuclear power plant, much less seven of them, goes down, you

pdf (discussing the challenges faced by Chile in constructing nuclear power stations); David Sneed, *Nuclear Regulators Dealing with Multiple Diablo Issues*, TRIB. (San Luis Obispo, Ca.), Jan. 13, 2010, at A1 ("The newly discovered Shoreline Fault, less than one mile offshore of the Diablo site, has not been thoroughly studied yet, but it clearly exacerbates an already precarious situation.").

300. WORLD NUCLEAR ASS'N, NUCLEAR POWER PLANTS AND EARTHQUAKES 1 (2009), http://www.world-nuclear.org/info/inf18.html (follow "Download this page as a PDF" hyperlink).

301. *See id.* at 3–4; *see also* Fackler, *supra* note 299, at A3.

302. Fackler, *supra* note 299, at A3.

303. Press Release, Tokyo Elec. Power Co., Financial Results for Fiscal Year 2007 (Apr. 30, 2008), *available at* https://www4.tepco.co.jp/en/press/corp-com/release/08043001-e.html (follow "Impact of Niigata-Chuetsu-Oki Earthquake on revenues/Expenses" hyperlink).

304. Press Release, Tokyo Elec. Power Co., Financial Results for Fiscal Year 2008 (Apr. 30, 2009), *available at* http://www.tepco.co.jp/en/press/corp-com/release/09043001-e.html (follow "Impact of Niigata-Chuetsu-Oki Earthquake on Revenues/Expenses" hyperlink).

305. Press Release, Tokyo Elec. Power Co., FY 2009 Third Quarter Financial Results (Jan. 29, 2010), *available at* http://www.tepco.co.jp/en/press/corp-com/release/10012902-e.html (follow "Impact of Niigata-Chuetsu-Oki Earthquake on Revenues/Expenses" hyperlink).

306. TEPCO GROUP, SUSTAINABILITY REPORT 2009, at 19 (2009), http://tepco.co.jp/en/challenge/environ/pdf-1/09report-e.pdf.

pay the piper. This is the type of risk that should keep utility executives awake at night. Is it not preferable to have one's generating assets arrayed in such a way that impairment of one, or even a few of them, would not impose such disastrous results both in terms of financial impact and carbon emissions?

I. *A New Form of Energy Dependence*

For many developing countries, significant dependence on nuclear power would merely exchange one form of foreign fuel dependence for another. Most nuclear countries, including the United States, lack sufficient high-quality uranium resources to satisfy their nuclear fuel demand domestically.[307] Uranium concentrate, and in most cases enriched and fabricated fuel, must be imported.[308] However, as we have seen, the understandable desire to achieve energy independence, when pursued in the nuclear realm, can have destabilizing consequences. Whether or not the declared energy security motive is genuine, it can lead to a country's clandestine acquisition or indigenous development of its own autonomous sensitive nuclear fuel cycle facilities, and these can be used to produce the materials needed for nuclear weapons.

J. *Nuclear Facilities Can Be Magnets for Attack*

Nuclear reactors and their associated spent fuel pools and fuel cycle facilities can become targets in wartime, as we have seen repeatedly in the Middle East: Israel attacked Iraq's research reactor in 1981;[309] Iraq attacked Iran's partially completed Bushehr reactors during the Iran-Iraq War in the 1980s;[310] Iraq fired Scud missiles at Israel's Dimona military production reactor during the first Gulf War;[311] and in September 2007 Israel launched a successful aerial attack on what it reportedly believed to be a North Korean supplied nuclear facility in eastern Syria.[312] Presi-

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307. *See* U.S. ENERGY INFO. ADMIN., URANIUM MARKETING ANNUAL REPORT (2009), http://www.eia.doe.gov/cneaf/nuclear/umar/umar.pdf.

308. *See id.*

309. Flora Lewis, *Sequel to Hiroshima*, N.Y. TIMES, June 12, 1981, at A27.

310. GlobalSecurity.org, Weapons of Mass Destruction: Bushehr Background, http://www.globalsecurity.org/wmd/world/iran/bushehr-intro.htm (last visited Feb. 24, 2010).

311. R. W. Apple, Jr., *War in the Gulf: The Overview; U.S. Troops Clash with Iraqi Forces on Saudi Frontier*, N.Y. TIMES, Feb. 18, 1991, at A1.

312. David E. Sanger & Mark Mazzetti, *Israel Struck Syrian Nuclear Project, Analysts*

dent Bush worried publicly in October 2007 about the possibility that the threat of an Iranian attack on nuclear-armed Israel could trigger "World War III," suggesting we might be wise to avert this possibility by "preventing [the Iranians] from having the knowledge necessary to make a nuclear weapon."[313]

K. *A Final Road Block to Nuclear Disarmament?*

For those bent on fulfilling the promise of the Nuclear Non-Proliferation Treaty—by actually *completing* the good faith negotiations on nuclear disarmament called for in the treaty[314]—the continued growth and spread of nuclear power, especially sensitive fuel cycle facilities, is worrisome. This could place a floor under future nuclear arms reductions and derail the prospects for genuine nuclear disarmament. The problem arises because a technically competent nuclear establishment with enrichment and/or reprocessing capabilities represents the nucleus of a future bomb program, whether or not there is present political intent to move in that direction.

For example, faced with Japan's large civil reprocessing and plutonium recycling effort,[315] with its latent capability for bomb-making, China might well reason that there is little benefit to gain from negotiations over the future of its already small stockpile of nuclear weapons. By the same token, why would Pakistan abandon its arsenal when faced with India's ambiguous capability for swiftly producing sizable amounts of weapons-grade plutonium using its civil breeder reactors and reprocessing plant?[316] Could one realistically expect Israel to give up its nuclear arsenal if Iran retains exclusive national control over its uranium enrichment and reprocessing capabilities?

The alternative to this cul-de-sac for nuclear disarmament has always been the fond but fuzzy prospect—as old as the nuclear

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Say, N.Y. TIMES, Oct. 14, 2007, at A1.

313. Matt Spetalnick, *Bush: Threat of World War III If Iran Goes Nuclear*, REUTERS, Oct. 17, 2007, http://www.reuters.com/article/idUSN17329743.

314. Nuclear Non-Proliferation Treaty, *supra* note 1, art. VI.

315. *See Japanese, South Korean Plutonium Plants Raise Security Concerns in Region*, WMD INSIGHTS, Feb. 2006, at 8, 8–10, http://www.wmdinsights.com/PDF/FP_FebIssue.pdf.

316. *See* CafeTerra, India's First Fast Breeder Nuclear Reactor (Feb. 1, 2009), http://www.cafeterra.info/2009/02/indias-first-fast-breeder-reactor.html.

age itself—of "international ownership and control" of all sensitive nuclear fuel cycle facilities, or even all nuclear facilities, including uranium mines. But with the UN Security Council and international affairs generally dominated by the nuclear-armed "Permanent Five,"[317] the idea of creating a civil nuclear condominium to match the current military one does not hold a wide appeal for the non-weapon states. On the contrary, their interest in acquiring nuclear fuel cycle facilities was predictably peaked, rather than diminished, by the Bush administration's clumsy GNEP plan for a global fuel cycle oligopoly, led by the United States, that would enrich, reclaim, and recycle nuclear fuel to the rest of the world—for a hefty fee, of course.[318]

IV. CONCLUSION: IMPLICATIONS OF THE ANALYSIS FOR POLICY

Taken together, all the considerations reviewed above suggest that an appropriate stance toward new-build nuclear power capacity could be appropriately summarized by the maxim: "Buy only what you are unable to avoid in the course of meeting decarbonization timetables that are dictated by the best science available."

As a high-cost, subsidy-dependent, radioactive-waste-generating, thermal-polluting, water-wasting, and non-renewable energy resource, with a fuel cycle that is linked to both serious environmental harms and weapons proliferation, and that still carries with it a very low probability of a very high-consequence accident, nuclear power clearly should not be one of the leading energy choices for decarbonization. In fact, the more relevant question is whether its serious harms and risks put nuclear power beyond the pale for environmentalists.

And here the short answer is no. The simple reason is that, like it or not, we are already implicitly depending on the current installed base of nuclear reactors to help us make the transition away from dirty coal and phase-in renewable generation. To rule out nuclear power entirely would logically require us to press for

317. *See UN Pushes for Disarmament Despite Nuclear Armed Security Council Members*, WORLD BULLETIN, Sept. 25, 2009, http://www.worldbulletin.net/news-detail.php?id=47616.

318. *See* THOMAS COCHRAN & CHRISTOPHER PAINE, NATURAL RES. DEF. COUNCIL, PEDDLING PLUTONIUM: NUCLEAR ENERGY PLAN WOULD MAKE THE WORLD MORE DANGEROUS 5 (2006), *available at* http://www.nrdc.org/nuclear/gnep/agnep.pdf.

the early shut-down of the existing installed base of reactors, which would make the transition to a low-carbon energy system even more daunting than it already is.

That said, there can be no enthusiasm for nuclear power in its present incarnation. Since nuclear power technology changes at a glacial pace compared to other energy technologies and requires long amortization periods to recover its costs and provide an appropriate risk-adjusted return on invested capital, the reactor technology proposed for deployment today will likely be the dominant technology for at least the next half-century.

Rather than reject nuclear power outright, our stance should be to press for more stringent regulation of its fuel cycle activities, strongly oppose its proliferation-prone incarnations, and insist on a level playing field with more sustainable energy technologies. The playing field can be leveled by limiting further tax subsidies and loan guarantees—and other proposed giveaways in the pending climate bill—while promoting the decoupling of utility earnings from electricity production so that a utility earns the same amount from saving a kW as it does from generating one. National and state policy should require the use of integrated resource planning[319] in markets where nuclear plants do not currently compete head-to-head with cheaper, cleaner sources of electricity, so that legislators and ratepayers can perceive the rational alternatives to new nuclear power deployments.

The keys to minimizing new nuclear deployments are (1) reducing future demand through massive doses of end-use efficiency; (2) reconfiguring local and regional grids to meet increasing fractions of the system load from less costly distributed sources of low-carbon generation; and (3) scaling-up wind, Concentrating Solar Thermal, utility-scale photovoltaic ("PV"), and biogas generation in their relevant regions, and delivering it to where it is needed via low-impact, high-voltage direct current buried cable transmission.

Can we realistically set our sights on phasing out both coal use and nuclear power simultaneously as we make the transition to a low-carbon economy? In the next twenty years or so, the answer is very likely no. Current nuclear capacity—in addition to natural

319. *See, e.g.*, 16 U.S.C. § 2621(d)(7) (2006) (requiring each electric utility to employ integrated resource planning).

gas—will be needed to underpin the transition away from coal. However, by 2030 it is at least conceivable that the United States and other countries could begin a gradual phase-out of nuclear power as renewables are introduced on a massive scale and the grid is modernized to accept, store, and distribute renewable energy from multiple sources.

The year 2030 is an important target date, as it marks the period when the U.S. reactors that have received twenty-year license extensions—probably most of them by then—will begin reaching the sixty-year mark and presumably be shut down and eventually decommissioned. Over the following twenty years, almost all of the current fleet of U.S. power reactors is slated for retirement, leaving behind whatever new nuclear capacity is built in the interim. Since nuclear power is currently one of the most costly decarbonization options, and is burdened with a long train of non-carbon externalities, basic economic principles suggest that large amounts of investment capital should not be allocated to it until the cost of an additional MWe from currently cheaper, cleaner technologies exceeds the cost of an additional MWe of nuclear power, and by a margin that at least equals the socialized costs of nuclear power's currently un-priced non-carbon externalities.

The sheer size of the energy resources available from efficiency savings, waste heat co-generation, wind, solar PV, and solar thermal suggests that an eventual transition away from nuclear power is possible from a fundamental energy resource perspective. If one then adds the prospect of significant biogas, energy storage, and transmission capacity being added in the electricity generation sector to firm-up the supply from diverse renewable sources, there is no *technical* reason why a transition to a carbon- and nuclear-free electricity sector cannot ultimately be achieved. The timing of such a transition is obviously impossible to forecast in advance.

We have two decades in which to evaluate the performance of a few units of the next generation of nuclear power plants before we would need to commit to (1) replacing some or all of the current installed based of reactors, (2) shifting to a significantly different set of nuclear technologies, or (3) beginning the phase-out of nuclear power. We cannot completely discard the possibility that nuclear power technology may yet transform itself into something more manageable, flexible, economical, and benign, with diminished environmental impacts and a higher degree of proliferation resistance provided by both inherent design features and greatly improved international institutional controls.

While it appears unlikely that this nuclear evolution will take place, there are two reasons to at least stay open to it while working toward an eventual non-nuclear low-carbon future. First, the down-and-dirty politics of U.S. energy production and use may well impede achievement of optimal rates of deployment for energy efficiency and renewables, thereby stalling or preventing a transition away from nuclear power in addition to slowing the phase out of dirty coal plants. In this eventuality, potentially cheaper modular, smaller-scale nuclear technologies might be welcome as a second best fallback option, if only to escape the costs and pitfalls of current generation nuclear technology.

Second, by the time of the next Intergovernmental Panel on Climate Change Panel Report in September 2014,[320] we may discover that climate change is accelerating and that we are truly in a desperate "all-hands-on-deck" situation, in which considerations of economic efficiency, nuclear security, fish kills, thermal discharges, low levels of radioactive contamination, and consumptive water use are secondary to immediate concerns about the survival of entire nations and ecosystems. In that case, despite its manifest deficiencies, we may *need* to deploy more nuclear power, alongside every other low-carbon technology we can think of, and essentially gamble that we are not unleashing the nuclear dogs of war by doing so. Not an attractive corner to be in, but we may well wind up there. That is why both nuclear power proponents and opponents should be able to coalesce around the need to radically upgrade current international controls on the nuclear fuel cycle.

Rather than counterpose the simultaneous pursuit of a carbon-free and nuclear-weapons-free world—by prematurely capitulating to the notion that nuclear power is foreordained to play an expanding role in global decarbonization—U.S. policy should fully integrate its climate change and non-proliferation concerns by vigorously promoting energy efficiency and renewable energy at home and abroad as the springboard to a *safer* as well as lower-

320. *See* Intergovernmental Panel on Climate Change, Activities, http://www.ipcc.ch/activities/activities.htm (last visited Feb. 24, 2010).

carbon world. We should seek to make the tapping of sufficient clean indigenous renewable energy resources in developing nations and countries of proliferation concern—often one and the same—the highest national security priority, and demand allocation of a significant portion of current national security funding to foreign grant aid and low-interest loans for this purpose, using both bilateral and multilateral aid mechanisms.

The best possible American ambassadors for climate policy, nuclear non-proliferation, and counter-terrorism would be solar arrays and wind generators bringing electric power, the Internet, and virtual classrooms to the impoverished backwaters of the Middle East and South Asia, where the terrorists of tomorrow are growing up today, still just children in search of a future.

If Iran were well-endowed with concentrated solar power plants, PV arrays, geothermal plants, wind farms, and 70% efficient fuel cell power plants fueled by its abundant resource of natural gas, Iranian leaders might still claim that they need nuclear power to meet their country's energy needs. But no one—not even their own people—would believe them.