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The Intercivilizational Inequities of Nuclear Power Weighed against the Intergenerational Inequities of Carbon Based Energy

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ARTICLES

THE INTERCIVILIZATIONAL INEQUITIES OF NUCLEAR POWER WEIGHED AGAINST THE INTERGENERATIONAL INEQUITIES OF CARBON BASED ENERGY

*Karl S. Coplan**

Sometime toward the end of the industrial revolution, western industrial countries discovered a new way to power their steam engines, which had previously been powered by burning wood and coal. This energy source promised to power the machines of civilization and progress far into the future. This energy source seemed at the time to be cheap and limitless, and contained an energy density (energy potential per unit weight) far exceeding those of fuels previously used to power steam engines.¹ Unfortunately for the generations that would follow, the early proponents of this energy source simply ignored the waste by-product of this fuel cycle. The wastes produced by this fuel will likely, at a minimum, render currently populated places in the world uninhabitable, and, at worst, threaten the survival of the human species. These impacts will affect generations far into the future.

Although this paragraph could well describe the climate impacts of burning fossil fuels, I am not talking about the carbon cycle and global warming. I am talking about the impacts of nuclear energy production. Proponents of nuclear energy tout the energy source as the most promising offset to greenhouse gases produced in electricity generation. These proponents eagerly await the additional direct and indirect subsidies for new nuclear power plants that would flow from various carbon tax and emissions trading schemes. Carbon

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1. The energy density of uranium is 560,000 gigajoules per tonne, compared to 27 gigajoules for coal, and 40 gigajoules for fuel oil. IOR Energy Pty Ltd, *Engineering Conversion Factors*, http://astron.berkeley.edu/~wright/fuel_energy.html (last visited Jan. 16, 2007).

emissions trading and offset schemes will subsidize the nuclear energy industry indirectly, by making competing fossil fuel based energy more expensive, and by potentially offering marketable offset credits for new nuclear energy generation projects that displace existing carbon-based energy generation.

This essay explains that such encouragement of nuclear energy production as a “solution” to fossil fuel-induced climate change will create environmental problems equally as grave as those posed by a carbon-based energy economy. Both nuclear energy and fossil energy impose enormous environmental externalities that are not captured by the economics of energy production and distribution. While emissions trading schemes seek to harness market-based efficiencies to accomplish pre-determined reductions, they neither seek to nor succeed in capturing the environmental externalities of energy generation. By creating a set of incentives without capturing all of the externalities, these trading schemes will simply distort the market, possibly leading to a worse overall damage to the environment than global warming by itself.

Ultimately, nuclear power production as an alternative to carbon-based energy production simply presents a choice of evils. Efforts to reduce carbon emissions must not come at the expense of distorting energy markets in a way that exacerbates the equally insurmountable problems posed by the multi-millennial storage of hazardous nuclear waste.

I. CARBON TRADING SCHEMES, ENVIRONMENTAL EXTERNALITIES, AND NUCLEAR POWER

A. *Regulation of Environmental Externalities*

The body of environmental law has often been characterized as a necessary response to the failure of free markets to capture environmental externalities.² In the paradigmatic “Tragedy of the Commons,”³ it is the free market for wool and mutton that lead unrestrained shepherders to overgraze the common fields in order to

2. See, e.g., ROBERT L. GLICKSMAN ET AL., *ENVIRONMENTAL PROTECTION: LAW AND POLICY* 53-55 (4th ed. 2003); FRED BOSSELMAN ET AL., *ENERGY, ECONOMICS AND THE ENVIRONMENT* 41-43 (2000).

3. Garrett Hardin, *The Tragedy of the Commons*, 162 *SCIENCE* 1243 (1968) (excerpted in GLICKSMAN, *supra* note 2, at 47-50).

increase their short term profits, at the cost of destruction of the very resource necessary for their livelihood. The environmental “cost” of damage to the grazing field is considered an “externality,” as the shepherds do not pay for use of the field, and thus have no market incentives to reduce that use. Unfortunately, the global carbon-based energy economy is a frightening example of the tragedy of the commons, as energy producers rapidly consume an essential global resource, the carbon absorbing capacity of the global ecosystem, without having to pay for it.

Traditional environmental regulation responds to the tragedy of the commons by imposing enforceable limits on the rate of use of the common resource. These limits may be based on an assessment of the assimilative capacity of the environmental resource, such as water quality based limits under the Clean Water Act,⁴ or on available technologies to reduce the units of environmental harm per units of economic goods, such as technology based limitations.⁵ These regulations internalize the environmental costs of production to the extent that the producer must now pay the costs of avoiding environmental harm as necessary to meet regulatory standards. These regulations do not completely internalize environmental costs to the extent that the producers continue to impose environmental impacts below the regulatory threshold at no cost. If the regulatory threshold is set at a level that still causes harms to the environmental commons, these costs are still “external” to the market.

B. Market Efficiencies and Trading Schemes

Emissions trading programs seek to import market efficiencies into the regulatory scheme.⁶ Instead of requiring all producers to reduce environmental emissions equally, those who can reduce their pollution more efficiently are allowed to sell their excess “pollution rights” to those producers who would have to pay more to achieve the same reduction. When functional, an emissions trading scheme

4. See Clean Water Act, 33 U.S.C §§ 301(b)(1)(C), 302, 303(d) (2002); 33 U.S.C. §§ 1311(b)(1)(C), 1312, 1313(d) (2002).

5. See Clean Water Act, 33 U.S.C. § 301(b)(2), 33 U.S.C. § 1311(b)(2) (2002). See generally Thomas O. McGarity, *Economic Dynamics of Environmental Law And The Static Efficiency: The Goals of Environmental Legislation*, 31 B.C. ENVTL. AFF. L. REV. 529 (2004).

6. See generally, Bruce A. Ackerman & Richard B. Stewart, *Reforming Environmental Law: The Democratic Case for Market Incentives*, 13 COLUM. J. ENVTL. L. 171 (1988).

uses market efficiencies to achieve the same decrease in environmental impact at a lower overall societal cost.⁷

Such a trading scheme does not, however, internalize the environmental externalities to any greater extent than the underlying regulatory limits. The money collected in the sale of tradable emissions rights does not necessarily go to remedying the environmental problems caused by the emissions permitted.⁸ Worse still, if the pollution rights are sold by government with proceeds going to general revenue rather than complete mitigation of the environmental harm, government becomes a partner in the polluting enterprise and has an interest in continuing the environmental pollution to maintain the revenue stream.⁹ Such trading schemes have also been criticized for discouraging technological innovation by rewarding the dischargers that can make the easiest, short term reductions and allowing the dischargers with more technologically challenging reductions to buy their way out of emissions control at the lower cost.¹⁰

The most successful environmental trading scheme to date has been the "cap and trade" scheme established for sulfur oxide emissions that cause acid rain.¹¹ This trading scheme established a cap on acid rain emissions designed to achieve an overall reduction in emissions.¹² The market for the tradable credits stabilized at a cost per ton far below the initial industry estimates of costs to comply, indicating either that the market efficiencies were effective in reducing compliance costs, or that industry vastly overstated the costs of compliance while fighting the regulations.¹³

Sulfur trading works environmentally as well as economically because the pollutant impacts in question are regional, so reductions at

7. *Id.* at 176-177 & *passim*.

8. *Cf.* 42 U.S.C. § 7651o (c)(6) (2000) (providing that proceeds of auctioned sulfur emissions allowances under the Clean Air Act be returned, pro rata, to the regulated sulfur emissions sources).

9. This situation is similar to the awkward position of the states in the tobacco litigation settlement, which came to depend on the revenue stream generated by tobacco sales. *See* Myron Levin, *States' Tobacco Settlement Has Failed to Clear the Air*, L.A. TIMES, Nov. 9, 2003, at C1.

10. David M. Driesen, *Free Lunch or Cheap Fix?: The Emissions Trading Idea And The Climate Change Convention*, 26 B.C. ENVTL. AFF. L. REV. 1 (1998).

11. *See* Ann Powers, *Reducing Nitrogen Pollution on Long Island Sound: Is There a Place for Pollutant Trading?*, 23 COLUM. J. ENVTL. L. 137, 153-163 (1998).

12. Clean Air Act 403, 42 U.S.C. 7651b (1995); *see generally* Powers, *supra* note 11, at 156-162.

13. *See* Powers, *supra* note 11, at 158-159.

one source can properly offset emissions at another source that may be hundreds of miles away.¹⁴ The sulfur trading system is simple and direct: an existing emitter must reduce its permitted discharge by one ton in order to have a one-ton credit to sell to another emitter that would otherwise exceed its limit.¹⁵ No one earns credits by “sequestering” sulfur dioxide, or adding lime to the eastern lakes affected by acid rain.¹⁶

C. Carbon Trading Schemes: The Regional Greenhouse Gas Initiative

Like sulfur trading, greenhouse gas reductions also are susceptible to cap and trade emissions control systems.¹⁷ Greenhouse gas impacts are global, not local or regional, so trading between regions and even continents has environmental benefits.¹⁸ Carbon trading schemes such as the one envisioned by the Regional Greenhouse Gas Initiative (RGGI),¹⁹ however, take the market incentives of the sulfur trading schemes a step further. Not only do they allow the creation of tradable credits by existing carbon generators who use new technology to reduce the carbon dioxide emissions while generating the same amount of power, but they also allow tradable credits to be generated by those who engage in projects to sequester carbon dioxide (such as reforestation projects) and by those who reduce emis-

14. See Henry A. Waxman, *An Overview of the Clean Air Act Amendments of 1990*, 21 ENVTL. L. 1721, 1753 (1991).

15. See 42 U.S.C. § 7651b; 7651a(3) (2006) (defining allowance to mean the right to emit one ton of sulfur dioxide).

16. See 42 USC 7651c(f) (2006) (providing for allowances for renewable energy and conservation, but not for sulfur dioxide sequestration or mitigation measures).

17. See generally, Gary C. Bryner, *Carbon Markets: Reducing Greenhouse Gas Emissions Through Emissions Trading*, 17 TUL. ENVTL. L.J. 267 (2004).

18. Carbon dioxide emissions are diffused throughout the atmosphere, so emissions reductions are equally valuable wherever they take place. See COMM. ON THE SCIENCE OF CLIMATE CHANGE, NATIONAL RESEARCH COUNCIL, CLIMATE CHANGE SCIENCE: AN ANALYSIS OF SOME KEY QUESTIONS, 1-5 (2001), available at <http://books.nap.edu/html/climatechange/climatechange.pdf>. (discussing global nature of anthropogenic greenhouse gas emissions).

19. For information about the Regional Greenhouse Gas Initiative, see generally Regional Greenhouse Gas Initiative, <http://www.rggi.org> (last visited January 14, 2007).

sions of non-energy related greenhouse gases (such as landfill gas capture).²⁰

The RGGI also provides for potential direct subsidies to non-carbon-emitting sources in two ways. First, at least twenty-five percent of the carbon dioxide allowances (or proceeds from their sale) are to be dedicated to renewable energy, “non-emitting” electrical energy sources, and conservation reductions at the discretion of the states.²¹ Since nuclear energy is a non-emitting energy source, participating states may subsidize the nuclear industry with the proceeds of the carbon allowances.²² Second, the RGGI leaves the method of allocating carbon dioxide allowances up to the states.²³ Allocation based on electrical generation capacity is permitted, which means that in theory, existing nuclear power plants might receive carbon allowance allocations, which they do not need, based on their generating capacity.²⁴ Proceeds from the sale of these allowances would be a direct subsidy to nuclear generation.²⁵

In addition to these potential direct subsidies to nuclear power, a carbon cap and trade scheme also provides other direct and indirect subsidies to nuclear power. By raising the cost of competing fossil fuel based power, nuclear generators enjoy a competitive price advantage and can raise their own prices.²⁶ Even more directly, because of the way that electrical generation capacity is allocated and priced by the Independent Systems Operator for each state, any in-

20. Regional Greenhouse Gas Initiative Memorandum of Understanding, 2.F(1) (Dec. 20, 2005), available at http://www.rggi.org/docs/mou_12_20_05.pdf [hereinafter RGGI MOU].

21. RGGI MOU, *supra* note 20, at 2G(1).

22. For this reason, the industry association Nuclear Energy Institute has applauded the RGGI agreement, specifically claiming that nuclear power will be eligible for these “non-emitting” allowances. Press Release, Nuclear Energy Institute, Regional Greenhouse Gas Initiative Carbon Dioxide Cap-and-Trade Program Treats Nuclear and Renewables Equally, <http://www.nei.org/index.asp?catnum=2&catid=337> (last visited January 14, 2007).

23. RGGI MOU, *supra* note 20, at 2G.

24. *See id.*

25. If nuclear power plants receive unneeded carbon allocations and sell them, the proceeds from this sale would constitute additional revenue to nuclear power plants, at the expense of carbon emitting fossil fueled plants; resulting in a subsidy from the fossil fuel plants to the nuclear plants.

26. *See* Daniel N. Gifford, *Federalism, Efficiency, The Commerce Clause, and The Sherman Act: Why We Should Follow A Consistent Free-Market Policy*, 44 EMORY L.J. 1227, n.20 (1995) (explaining how a cost increase to competitive goods constitutes a subsidy).

crease in the price for fossil fuel based electricity provided by the lowest marginal cost supplier is automatically passed on to the nuclear generators, which are usually base-load generators.²⁷

These indirect subsidies to nuclear power might not be a bad thing, if the only goal were to reduce greenhouse gas emissions. The problem arises in that these subsidies seek to improve the internalization of environmental costs in one market (carbon-based electrical generation) by creating market distortions in another market (non-emitting electrical generation) that may also have its own environmental externalities. The bottom line is that, whatever greenhouse gas reducing benefits carbon trading achieves may come at the cost of imposing additional environmental and economic externalities in another sphere. It is worth examining those externalities, especially the externalities of nuclear power generation, before uncritically embracing a carbon trading scheme that subsidizes nuclear power generation. Unfortunately, nuclear power has its own set of externalities that would be worsened by any subsidy built into a carbon trading scheme.

II. WASTE EXTERNALITIES OF NUCLEAR POWER

A. Wastes Generated

Nuclear power generation uses fuel rods composed of Uranium 235 and Uranium 238.²⁸ The nuclear fission process generates heat,

27. As noted in the stakeholder workshop sessions predicate to the RGGI, the value of carbon allowances necessary to produce the marginal-low cost energy producer will be "bid in" by the utilities as part of their costs. REGIONAL GREENHOUSE GAS INITIATIVE STAKEHOLDER GROUP MEETING PROCESS 27-29 (Sept. 21, 2005) (cost of allowances to be included in bid price), *available at* http://www.rggi.org/docs/final_summary_9_21_05.pdf. This carbon allowance cost will thus be added to the price received by all generators dispatched on that day, whether they use carbon allowances or not. *See* Peter Cramton, Report on Competitive Bidding Behavior in Uniform-Price Auction Markets on Behalf of Duke Energy, San Diego Gas & Electric Company, FERC Docket No. EL00-95-075 (Mar. 20, 2003) (explaining how Independent System Operator single clearing price bid systems operate to pay all suppliers the highest marginal price bid in for electricity supply in the market), *available at* <http://www.cramton.umd.edu/papers2000-2004/cramton-bidding-behavior-in-electricity-markets.pdf>.

28. *See* U.S. Dep't of Energy, Energy Information Administration, *Introduction to Nuclear Power*, <http://www.eia.doe.gov/cneaf/nuclear/page/intro.html> (last visited October 20, 2006).

which is transferred from the reactor vessel to generate steam to run turbines.²⁹ The fission process also creates radioactive byproducts in the fuel rods.³⁰ After a period of time (about five years),³¹ the fuel rods no longer generate enough heat for economical power generation, and must be removed and stored or disposed.

These “spent” fuel rods consist of 96% uranium and 4% other isotopes created by the fission process.³² These isotopes include Cesium 137, Iodine 129, Cesium 137, and Plutonium 239.³³ Some of these isotopes have half lives running into the millions of years, such as Iodine 129, which has a half life of 17 million years.³⁴ Plutonium 239 has a half life of 24,360 years.³⁵ An isotope is not “safe” at the end of its half life; rather, it has become half as dangerous, and after another “half life” will become a quarter as dangerous.³⁶ These radioactive isotopes emit ionizing radiation.³⁷ In addition, the spent fuel rods continue to generate heat for decades after removal from the nuclear power plant, further complicating storage and disposal.³⁸

Dangerous human exposure can occur either by proximity to the spent fuel or by release of constituents into the biosphere, resulting in human exposure through ingestion or respiration, or by simple

29. *Id.*

30. Nat’l Research Council Comm. on the Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report (2005) [hereinafter, NRC Spent Fuel Report].

31. *Id.* at 17-19.

32. U.S. DEP’T OF ENERGY, REPORT TO CONGRESS ON ADVANCED FUEL CYCLE INITIATIVE: THE FUTURE PATH FOR ADVANCED SPENT FUEL TREATMENT AND TRANSMUTATION RESEARCH, II-2 and Table II-1 (2003), available at http://www.ne.doe.gov/reports/AFCI_CongRpt2003.pdf

33. See COMM. ON TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS, NAT’L RESEARCH COUNCIL, TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS, 18-19 (1995), available at <http://newton.nap.edu/books/0309052890/html/2.html>, [hereinafter NRC YUCCA MOUNTAIN REPORT].

34. *Id.*

35. *Id.*

36. According the Encyclopedia Britannica, the “half life” of an unstable atomic isotope is the “time required for the number of disintegrations per second of a radioactive material to decrease by one-half.” Accordingly, after the half life of a radioactive isotope, it will still be emitting radiation, but at one half its original rate. After another half-life, the rate will be decreased to one half of one half, or one quarter.

37. See U. S. Envtl. Prot. Agency, *Radiation Information: Ionizing Radiation Fact Sheet Series: No. 1*, <http://www.epa.gov/radiation/docs/ionize/402-f-98-009.htm> (last visited October 20, 2006).

38. NRC Spent Fuel Report, *supra* note 30, at 17-18.

proximity to places where these radionuclides collect.³⁹ Ionizing radiation causes human health effects by attacking human cells.⁴⁰ In high doses, ionizing radiation will kill human cells, causing internal organ failure and death.⁴¹ In low to moderate doses, ionizing radiation causes cell mutation and disruption of DNA, which causes cancers, birth defects, and improper development.⁴²

B. Current Disposition of Nuclear Waste

As of 2003, there were 50,000 metric tons of spent nuclear fuel in the United States.⁴³ The majority of this fuel is stored in spent fuel pools at existing operating or decommissioned nuclear power plants.⁴⁴ The spent fuel pools hold the spent fuel rods under water.⁴⁵ The water both carries off the continuing decay heat and shields workers and the surrounding environment from escaping radiation.⁴⁶ The spent fuel pools were originally designed to hold spent nuclear fuel only until it cooled sufficiently to transport to a permanent disposal site or reprocessing facility.⁴⁷ As no permanent disposal site has opened and no commercial reprocessing industry was ever developed, the spent fuel pools have ended up storing on-site most of the spent fuel generated during the entire history of nuclear power generation.⁴⁸ In order to make room for the extra fuel rods, nuclear power plants have packed the spent fuel rods closer together than the original design contemplated, increasing the risk of a fuel-heat induced fire should the spent fuel pools lose their cooling water.⁴⁹

39. INSTITUTE OF MEDICINE, AN EVALUATION OF RADIATION EXPOSURE GUIDANCE FOR MILITARY OPERATIONS: INTERIM REPORT, 13-14 (1997) available at <http://www.nap.edu/catalog/5853.html#toc>.

40. NRC YUCCA MOUNTAIN REPORT, *supra* note 33, at 34-36.

41. *Id.* at 34-39.

42. *Id.*

43. NRC Spent Fuel Report, *supra* note 30, at 20.

44. *Id.* at 20.

45. *Id.* at 19-20.

46. *Id.* at 38.

47. *Id.* at 21.

48. *Id.* at 20.

49. *Id.* at 23. These spent fuel pools are thus a likely terrorist target, as loss of cooling water can lead to a thermal reaction with the zirconium fuel cladding to generate hydrogen and a fire, dispersing the spent fuel inventory into the environment. *Id.* at 38-39. The spent fuel at one plant could render thousands of square miles uninhabitable.

As the spent fuel pools become full at the higher density configuration, power plant owners have begun to move the older (and cooler) spent fuel rods out of the spent fuel pool and into "dry cask" storage.⁵⁰ These dry cask storage containers consist of concrete and steel cylinders, which are vented to allow continued air-cooling of the decay heat still produced by radioactive isotopes.⁵¹ Currently, about 6,200 metric tons of spent fuel is stored in these dry casks, mostly located at the sites that generated them.⁵² The proportion of spent fuel stored in dry casks is likely to increase, as spent fuel pools are filled to capacity and new spent fuel is generated at the rate of 2,000 metric tons per year in this country.⁵³ These dry cask storage units are only required to have a design life of twenty years.⁵⁴

Dry cask storage represents a sort of limbo for spent nuclear fuel. Unless the United States develops and opens a long term repository with sufficient capacity to accept the volume of waste generated, or develops commercial fuel reprocessing capacity, the spent fuel pools and dry cask storage facilities are likely to be the ultimate disposal sites for nuclear power generation wastes in this country.⁵⁵ As discussed below, neither of these alternative disposal systems is likely to be developed adequately, so dry cask storage at the generation sites is the most likely outcome. The generation sites are located throughout the United States, and many are located in coastal and in metropolitan areas.

C. The Unlikely Alternative Disposal Methods

The current dry-cask limbo for spent nuclear fuel was not planned. At the outset of commercial nuclear energy generation, the assumption was that spent fuel would be sent to a reprocessing facility and

50. NRC Spent Fuel Report, *supra* note 30, at 23.

51. *Id.* at 61.

52. *Id.* at 20.

53. *Id.*

54. 10 C.F.R. § 72.236(g) (2000); *see also* U.S. NUCLEAR REGULATORY COMM'N, STANDARD REVIEW PLAN FOR DRY CASK STORAGE SYSTEMS, FINAL REPORT (1997), *available at* <http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1536/>.

55. This conclusion follows logically from the fact that four decades after commencement of commercial nuclear generation, nearly all the wastes generated by the nuclear industry remain at the original temporary storage facilities; the fuel pools. As the NRC Spent Fuel Report itself concludes, "Thus, onsite storage of spent fuel is likely to continue for at least several decades." NRC Spent Fuel Report, *supra* note 30, at 23.

reused after a sufficient cooling off period in the power plant spent fuel pool.⁵⁶ When commercial reprocessing of fuel proved unsafe and economically nonviable the government and the nuclear industry focused on deep geological burial as the appropriate means to discard of spent nuclear fuel.⁵⁷ The political impossibility of siting adequate disposal facilities has now led the pendulum to swing back towards reprocessing as a possible solution.⁵⁸

Unfortunately, neither deep geological burial nor reprocessing appear to be likely solutions to the waste disposal problems, and both pose serious risks. In the meantime, the spent fuels continue to pile up at nuclear generation sites.⁵⁹

1. Yucca Mountain Deep Geological Repository

The Nuclear Waste Policy Act of 1982⁶⁰ (NWPA) directed the Department of Energy (DOE) to develop, construct, and operate a deep burial geological waste repository for high-level civilian and military nuclear wastes. In 1987, Congress amended the Nuclear Waste Policy Act to direct the DOE to focus on one site: Yucca Mountain in the Nevada desert.⁶¹ Following a lengthy evaluation process, in 2002 the DOE recommended the Yucca Mountain site to the President for approval, the President approved the recommendation, and, pursuant to the NWPA, Congress enacted a joint resolution approving the site.⁶²

A complete discussion of the pros and cons of Yucca Mountain as a nuclear waste disposal site is beyond the scope of this essay. However, it is a classic understatement to say that the Yucca Mountain waste disposal site remains controversial, particularly within Nevada. Despite a statutory mandate requiring the facility to open by 1998, the DOE has yet to receive a license for the facility or to

56. NRC Spent Fuel Report, *supra* note 30, at 21, 100-101.

57. *Id.*; NRC YUCCA MOUNTAIN REPORT, *supra* note 33, at 15-16.

58. *See infra* notes 82-87 and accompanying text.

59. NRC Spent Fuel Report, *supra* note 30 at 20-23.

60. 42 U.S.C. § § 10101-10270 (2000).

61. Nuclear Waste Policy Amendments Act of 1987, Pub. L. No. 100-203, 101 Stat. 1330-227 (1987) (codified at 42 U.S.C. §§ 10101 – 10270 (1994)).

62. *See* Pub. L. No. 107-200, 116 Stat. 735 (2002) (codified at 42 U.S.C. § 10135 note (Supp. IV 2004)). For a more complete discussion of the statutory and regulatory history of the Yucca Mountain designation process, *see generally* Nuclear Energy Inst., Inc. v. U.S. Env'tl. Prot. Agency, 373 F.3d 1251, 1260-1261 (D.C. Cir. 2004) (*per curiam*).

start construction.⁶³ In 2004, the D.C. Circuit undercut the entire regulatory basis underlying the licensing procedure when it struck down regulations adopted by the Environmental Protection Agency (EPA) establishing criteria for public exposure from the Yucca Mountain nuclear waste repository.⁶⁴ The court held that the EPA regulations failed to comply with the mandates of the NWPA because the EPA limited its consideration of exposure pathways to a period of 10,000 years following disposal, while the time of peak risk for release of radionuclides to the environment was on the order of hundreds of thousands to millions of years, after presumed disintegration of disposal casks.⁶⁵ This 10,000 year limit was directly contrary to the recommendation of the National Research Council of the National Academy of Sciences, which pointed out that the peak risk of release would come after 10,000 years, and that geologic processes at the site could be predicted over a million year time-frame.⁶⁶

Like the spent nuclear fuel it is supposed to dispose of, Yucca Mountain remains in limbo. As recently as February 2006, the Energy Secretary was quoted as saying that the DOE could not predict a date for the opening of the Yucca Mountain waste repository.⁶⁷

Nevertheless, the question of whether, when, and should Yucca Mountain open as a high-level nuclear waste repository is somewhat academic to the question of long term disposal of the wastes from ongoing nuclear energy production. Yucca Mountain is even more irrelevant to the question of disposal of wastes generated by increased nuclear generation capacity constructed as a means to reduce greenhouse gas emissions. This is because, as designed, Yucca Mountain will barely have the capacity to accept all of the civilian nuclear waste that has already been generated and is sitting in limbo at nuclear power plant sites and it has no reserve capacity.⁶⁸ The statutory capacity of Yucca Mountain is 70,000 metric tons of high level nuclear waste.⁶⁹ Ten percent of this capacity is reserved for

63. Matthew L. Wald, *Big Question Marks on Nuclear Waste Facility*, N.Y. TIMES, Feb. 14, 2006, at C4.

64. *Nuclear Energy Inst., Inc. v. U.S. Envtl. Prot. Agency*, 373 F.3d 1251 (D.C. Cir. 2004)(per curiam).

65. *Id.* at 1266-1274

66. NRC YUCCA MOUNTAIN REPORT, *supra* note 33.

67. Wald, *supra* note 63, at C4.

68. *See infra* notes 69-72 and accompanying text.

69. 42 U.S.C. § 10134(d) (2006).

military nuclear wastes, leaving 63,000 metric tons of capacity.⁷⁰ As of 2003, there were already 50,000 metric tons of civilian nuclear waste in this country awaiting a disposal site, and we are generating an additional 2,000 metric tons per year.⁷¹ At that rate, the entire capacity of Yucca Mountain would be used by the year 2009 – before any possible opening date of the facility.⁷²

Yucca Mountain was undoubtedly selected as a disposal site both for its geologic stability and its location in a sparsely populated state with less political power.⁷³ Even so, Yucca Mountain has proven to be a political nightmare. Finding and approving a second site in a more populous state would seem to be impossible as long as our political system survives. Given our inability as a nation to establish an adequately sized nuclear waste repository during the first fifty years of nuclear power generation, there is no reason to expect us to site, design, and construct a second such facility.

2. Reprocessing

Spent nuclear power plant fuel consists of 96% uranium and 4% plutonium and other long-lived radionuclides.⁷⁴ In theory, if the uranium could be separated from the plutonium and purified, it could be reused as reactor fuel, as could plutonium.⁷⁵ This is the theory behind nuclear fuel reprocessing.

Reprocessing poses its own set of political and moral risks. Plutonium is much more highly radioactive and poisonous than uranium.⁷⁶ Plutonium is also the ideal fuel for atomic bomb construction; just a few pounds of it in the wrong hands would allow the con-

70. See Dep't of Energy, Supplement to the Final Env'tl. Impact Statement for a Geological Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV, 71 FED. REG. 60490-01 n.5 (October 13, 2006).

71. NRC Spent Fuel Report, *supra* note 30, at 20.

72. *Id.* The last scheduled opening date for Yucca Mountain was 2010, before the court setback. *Id.* at 23.

73. See Lizette Alvarez, *Senate and Clinton Still Stalled on Nuclear Waste Disposal*, N. Y. TIMES, Feb. 11, 2000, at A16.

74. U.S. DEP'T OF ENERGY, *supra* note 32, at II-2.

75. *Id.*, *passim*; NRC Spent Fuel Report, *supra* note 30 at 100.

76. See U.S. DEP'T OF ENERGY, *supra* note 32, at I-1; U.S. DEP'T OF ENERGY, REPORT TO SUBCOMMITTEE ON ENERGY AND POWER, COMMITTEE ON COMMERCE, HOUSE OF REPRESENTATIVES, PLUTONIUM NEEDS, COSTS, AND MANAGEMENT PROGRAMS, 4 (1997) available at <http://www.gao.gov/archive/1997/rc97098.pdf>.

struction of a crude atomic weapon.⁷⁷ This weapons proliferation risk led President Jimmy Carter to ban the reprocessing of spent nuclear fuel into plutonium in 1977.⁷⁸

Nuclear fuel reprocessing has had a checkered history in the United States. One commercial fuel reprocessing facility was constructed in West Valley, New York by Getty Oil Company.⁷⁹ This facility never achieved profitability and left behind a one billion dollar cleanup bill, borne by the public, after it closed.⁸⁰ Although nuclear fuel containing plutonium can theoretically be burned in existing commercial reactors, their owners have been extremely reluctant to accept the highly radioactive fuel.⁸¹

Nevertheless, faced with a Yucca Mountain repository that is already booked solid with the last forty years of nuclear waste, an Administration that supports nuclear power is taking a new look at fuel reprocessing as a way to increase the disposal capacity of Yucca Mountain while promoting new nuclear reactors. The DOE issued a report to Congress recommending the development of new reprocessing technologies that would generate uranium that is sufficiently pure for re-use in nuclear generating facilities, while also leaving the plutonium bound up with even more hazardous radionuclides that would make the plutonium unattractive to bomb-makers.⁸² The reduction in volume of the wastes to be disposed would extend the life of the Yucca Mountain waste repository.⁸³ The plutonium fuel would run through a new generation of "fast" electron reactors, which would destroy the plutonium and other dangerous radionuclides while generating heat for electricity generation.⁸⁴

Congress has obliged the DOE proposal by providing \$50 million for research and development of these reprocessing technologies. Nevertheless, experts on nuclear waste reprocessing remain skeptical. Success for this reprocessing proposal would require the siting and construction of a series of reprocessing facilities and nearby

77. See Union of Concerned Scientists, *Global Security: Nuclear Terrorism* http://www.ucsusa.org/global_security/nuclear_terrorism/ (last visited October 20, 2006).

78. Statement by the President on His Decisions Following a Review of U.S. Policy, 1977 Pub. Papers 587-88.

79. Wald, *supra* note 63 at F3.

80. *Id.*

81. *See id.*

82. U.S. DEP'T OF ENERGY, *supra* note 32.

83. *Id.* at I-1; II-1-4.

84. *Id.*

dedicated nuclear power plants.⁸⁵ The new power plants would have to be near to the reprocessing facilities because the plutonium fuel would be so dangerous that it could not safely be transported.⁸⁶ Siting such facilities is likely to be a political impossibility.⁸⁷

Meanwhile, the waste generated by existing nuclear power plants continues to pile up, and will slowly be moved into onsite dry-cask storage containers with a design life span of twenty years.⁸⁸

D. Extreme Long Term Fate of Nuclear Wastes: Predicting Economic, Political, and Climate Systems in Geological Time

It goes without saying that piling hazardous nuclear wastes, with half lives running into millions of years, into casks designed to last decades at most, is a recipe for disaster. The fact is that no political or economic system can assure the security or integrity of waste for a period of time even remotely approaching the time period during which such waste poses extreme health, environmental, and nuclear proliferation risks.

To put the 24,000 year half life of plutonium in context, keep in mind that recorded human history has lasted for only 5,000 years. Thirty-thousand years ago, Neanderthals still populated the European continent. In that time period, the continental glaciers of the Wisconsin age had advanced and retreated.⁸⁹ No political system or civilization has lasted through even a remotely comparable time frame: the Chinese civilization (generally considered among the world's oldest extant) has been in existence a mere 10,000 years. The Roman Empire lasted a mere 1,500 years.

If the past is any prediction of the future, the nuclear wastes we are now taking from storage pools and placing in casks will outlast our political system. These current (and likely permanent) disposal locations are located primarily at the sites of the nuclear power plants that have generated these wastes.⁹⁰ Many of these power plants are located near major metropolitan areas: over 161 million people cur-

85. Wald, *supra* note 63, at F3.

86. *Id.*

87. *Id.*

88. See *supra* notes 53-54 and accompanying text.

89. See John S. Schlee, United States Geological Survey, *Our Changing Continent* (2000), <http://pubs.usgs.gov/gip/continents/> (map showing extent of Wisconsin glaciation 18,000 years ago).

90. For a map of the current locations of spent fuel storage in the United States, see NRC Spent Fuel Report, *supra* note 30, at 21.

rently live within seventy-five miles of a nuclear power plant.⁹¹ Each spent fuel inventory contains enough radionuclides, if widely dispersed, to render thousands of square miles uninhabitable.⁹²

Given the time periods involved, release of these radionuclides into the environment becomes an eventual near certainty. No political system will last forever. The civil strife following the eventual collapse of the United States' political system (to say nothing of the other nuclear power generating nations of the world) will leave these radioactive inventories open to potential diversion by terrorists and warring civil factions.⁹³ It is not credible to assert that some future political system will, at great expense, take responsible care of the wastes we generate now when we are unable and unwilling to take care of these wastes at the richest time in the history of the richest nation on earth.⁹⁴

And even if these casks are left undisturbed by political strife, environmental factors will claim them eventually. Many of these waste repositories are located in coastal areas subject to rises in global sea levels.⁹⁵ Many of these waste repositories are also located in areas covered by continental glaciers in the last glacial pe-

91. U.S. Dept't of Energy, Office of Civilian Radioactive Waste Mgmt., Fact Sheet: What Are Spent Nuclear Fuel And High-Level Radio Active Waist? (2004), <http://www.ocrwm.doe.gov/factsheets/doeymp0338.shtml>.

92. Dr. Gordon Thompson has calculated that the spent fuel pool inventory at the Indian Point nuclear power plant has sufficient radioactivity to render an area of 95,000 square kilometers uninhabitable. This constitutes 75% of the land area of New York State. Declaration of 7 December 2001 by Dr. Gordon Thompson in Support of Petition of Riverkeeper, Inc., Power Auth. Of the State of NY (Nuclear Power Plant and Indian Point, Unit 3), CLI-01-14, 53 N.R.C. 488 (2001) *available at* http://riverkeeper.org/document.php/41/Thompson_Declar.doc.

93. In his book *Collapse*, Jared Diamond recounts the history of several civilizations that have collapsed due to inability to cope with environmental change, including human wrought environmental changes. One common theme in such societal collapses is a period of civil strife and violence as the society rejects the political systems that lead to the environmental stresses. JARED DIAMOND, *COLLAPSE: HOW SOCIETIES CHOOSE TO FAIL OR SUCCEED* (2005).

94. As noted in the COMM. ON TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS, NAT'L RESEARCH COUNCIL, TECHNICAL BASIS FOR YUCCA MOUNTAIN STANDARD 55 (1995), some in the nuclear industry have advocated leaving the spent fuel at the generation sites where, it is assumed, it can be monitored and disposed of properly in the future.

95. See NRC Spent Fuel Report, *supra* note 30, at 21, Figure 1.3 (map showing location of dry cask fuel storage facilities).

riod, which ended around eighteen thousand years ago.⁹⁶ Either eventuality would be sufficient to cause widespread dispersal of the radioactive inventories of these nuclear wastes, rendering thousands of square miles uninhabitable. And given the vast time periods involved – up to millions of years for some radionuclides – both global warming and global cooling are possible before these wastes have naturally decayed to the point where they no longer pose a threat.⁹⁷

III. THE RISK EXTERNALITIES OF NUCLEAR POWER

The economic costs and environmental hazards of disposal of spent nuclear fuel remain the largest unresolved obstacles to expansion of nuclear power as a way of reducing greenhouse gas emissions. But nuclear power generation poses other environmental and economic externalities as well. The current regulatory scheme governing nuclear energy in this country fails to take these externalities into account as either a regulatory or an economic matter.

A. Accident Risks

Every operating nuclear power plant poses some risk of a severe accident, including an uncontrolled nuclear reaction that leads to core meltdown and potentially huge releases of radioactivity into the environment. The nuclear industry estimates the chances of a severe reactor accident to be about one out of every 10,000 reactor years of operation.⁹⁸ While this may sound like a small risk, it means that with 100 operating nuclear power plants in the United States, we can expect one severe accident every 100 years. If these 100 plants keep operating indefinitely into the future, or are replaced in kind to mitigate global carbon emissions, a severe reactor accident is virtually certain in this country in the future.

Moreover, if we were to construct the 200 additional nuclear power plants in this country necessary to meet the Phase I carbon

96. For a map showing the extent of continental glaciers in North America during the last glacial period, see Schlee, *supra* note 89.

97. As noted, the 24,000 year half life of plutonium exceeds the time since the last major glaciation of North America, during the Wisconsin period. See *supra* note 96 and accompanying text.

98. MARK HOLT & CARL E. BEHRENS, CRS ISSUE BRIEF FOR CONGRESS: NUCLEAR ENERGY POLICY CRS-1 (June 4, 2003), available at <http://usinfo.state.gov/usa/infousa/tech/energy/nuclear.pdf>.

reductions contemplated by the Kyoto Protocol,⁹⁹ that same one-in-ten thousand chance of a severe reactor accident would turn into an expectation of one severe reactor accident every thirty years. Combined with all the other nuclear reactors around the world – and assuming that all such reactors are at least as safe and well operated as those in the United States – severe nuclear reactor accidents would be expected to occur ever few years.

The consequences of a severe nuclear reactor accident can be hard to predict. However, using the most recent models and making optimistic assumptions about the success of evacuation efforts and evacuation travel times, the Riverkeeper organization has estimated that a reactor meltdown at one of the Indian Point nuclear power units fifty miles north of New York City would result in as many as 44,000 short term fatalities from radiation exposure, 518,000 latent cancer fatalities, \$2 trillion in property damage, and the relocation of eleven million people.¹⁰⁰ The Nuclear Regulatory Commission's 1982 report estimates the consequences of a severe reactor accident at Indian Point as 46,000 Peak Early Fatalities, 141,000 Peak Early Injuries, and 13,000 Peak Deaths from cancer, along with \$274 billion (1982 dollars) in property damage.¹⁰¹

These risks are borne by the exposed population, not by the nuclear generation industry. Under the Price-Anderson Act, the liability of the nuclear industry as a whole is limited to approximately \$10 billion.¹⁰² This exemption from the costs for ensuring against these risks constitutes a huge additional subsidy to the nuclear generation industry, amounting, by some estimates, to as much as thirty cents per kilowatt hour of electricity generated.¹⁰³

99. Phillip Ward, *Nuclear Power: No Solution to Climate Change*, NUCLEAR MONITOR, 9-10 (2005) available at <http://www.nirs.org/mononline/nukesclimate-changereport.pdf>.

100. Edwin S. Lyman, *Chernobyl on the Hudson? The Health and Economic Impacts of a Terrorist Attack at the Indian Point Nuclear Power Plant*, RIVERKEEPER, INC. (2004) available at http://riverkeeper.org/document.php/317/Chernobyl_on_th.pdf.

101. Sandia Labs, U.S. Nuclear Regulatory Comm'n, Calculation of Reactor Accident Consequences (1982) (commonly referred to as the "CRAC-2 Report"), <http://www.mothersalert.org/crac.html>.

102. 42 U.S.C. § 2210(e) (2005); see U.S. Nuclear Regulatory Comm'n, *Fact Sheet on Nuclear Insurance and Disaster Relief Funds*, available at <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/funds.pdf> (last visited Jan. 15, 2007).

103. Anthony Hayes, *Determining the Price of Price-Anderson Regulation*, REGULATION (2003), available at <http://www.cato.org/pubs/regulation/regv25n4/>

B. Terrorism Risks

The one-in-ten-thousand-reactor-years estimate of operating reactor risk is an estimate of risk based on the normal operation of a nuclear reactor.¹⁰⁴ These estimates simply do not take into account the risk of intentional sabotage causing radioactive dispersal. In the wake of the September 11th attacks, the National Research Council performed an assessment of the chances of a terrorist attack on a nuclear facility in the United States, and concluded that “the potential for a September 11th-style surprise attack in the near term using U.S. assets, such as airplanes, appears to be high.”¹⁰⁵

These risks are not easily quantified, but must be at least as great – or greater – than the risk of accidental reactor mishap. Shockingly, the Nuclear Regulatory Commission (NRC) takes no account of these terrorism risks whatsoever in licensing and regulatory decisions affecting nuclear power generation. The Nuclear Regulatory Commission long ago adopted a policy that terrorism risks were too uncertain to quantify, and thus could not be considered in assessing the siting and potential impacts of nuclear generation and waste storage facilities.¹⁰⁶ The NRC continues to adhere to this policy even in the wake of the September 11th attacks.¹⁰⁷

Like the risks associated with operational nuclear accidents, the risks of sabotage have been shifted to the public at large by the Price-Anderson Act.¹⁰⁸ This risk-shifting constitutes an additional externality of nuclear power generation.

v25n4-8.pdf.

104. See David Lochbaum, *Nuclear Plant Risk Studies, Failing the Grade*, 4-12 (2000) (discussing factors used by nuclear industry in risk analysis), available at http://www.ucsusa.org/assets/documents/clean_energy/nuc_risk.pdf.

105. Comm. on Science and Tech. for Countering Terrorism, Nat’l Research Council, *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism*, 50 (2002) available at <http://www.nap.edu/html/stct/index.html>

106. See *Limerick Ecology Action, Inc. v. Nuclear Regulatory Comm’n*, 869 F.2d 719 (3d Cir. 1989); See also *City of New York v. U. S. Dep’t of Transp.*, 715 F.2d 732 (2d Cir. 1983); Final Rule, Physical Protection for Spent Nuclear Fuel and High-Level Radioactive Waste, 63 Fed. Reg. 26955-01, 955-56 (May 15, 1998).

107. See *In re Private Fuel Storage, L.L.C.*, CLI-02-25, 56 N.R.C. 340 (2002); see also *In re Duke Energy Corp.*, CLI-02-26, 56 N.R.C. 358 (2002).

108. 42 U.S.C. § 2210(e) (2005).

C. Proliferation Risks

As noted, spent nuclear fuel contains Plutonium 239.¹⁰⁹ If nuclear fuel is recycled back into uranium, the plutonium must be separated from the uranium.¹¹⁰ Plutonium 239 is fissionable material for a simple nuclear bomb, requiring only nine pounds.¹¹¹ Separating the uranium from the plutonium is the most challenging technical aspect of developing a nuclear weapon.¹¹² If more Plutonium 239 is made available, the more source material for nuclear weapons will be at risk of diversion.¹¹³ In addition, the same technologies needed to enrich uranium to the point where it is suitable for nuclear power generation can be used to enrich uranium to the point where it is suitable for bomb-making as well.¹¹⁴

Like the risk of terrorism, this risk of proliferation is very difficult to quantify, but in the long term can be assumed to reach a level of probability. One consequence of increased nuclear power generation worldwide would be the increased availability of nuclear weapons and their likely use in an international conflict at some time in the future.

IV. PRACTICALITIES OF NUCLEAR ENERGY PRODUCTION AS AN OFFSET TO GREENHOUSE GAS EMISSIONS

In addition to the long-term environmental and economic externalities implicated by the by-products of nuclear power generation, practical constraints all but preclude reliance on nuclear power as a significant means of reducing greenhouse gas emissions in the time-frame necessary to mitigate the global climate change impacts of carbon-based energy production.

109. See *supra* note 33 and accompanying text.

110. See U.S. DEP'T OF ENERGY, *supra* note 32.

111. Union of Concerned Scientists, *Global Security: Nuclear Terrorism* http://www.ucsusa.org/global_security/nuclear_terrorism/ (last visited October 20, 2006).

112. U.S. DEP'T OF ENERGY, *supra* note 32 at II-6 (difficulty of separating plutonium from spent fuel).

113. See Nuclear Info. and Resource Service, *Plutonium Proliferation and MOX Fuel*, <http://www.nirs.org/factsheets/moxproliferation.htm>

114. See Statement of Pierre Goldschmidt, Deputy Director of the International Atomic Energy Agency, *The Increasing Risk of Nuclear Proliferation: Addressing the Challenge* November 26, 2003 (available at <http://www.iaea.org/NewsCenter/Statements/DDGs/2003/goldschmidt26112003.html>).

First, the process of designing, siting, approving, and constructing nuclear power plants takes too long to permit expansion of nuclear power on the scale that would be necessary.¹¹⁵ According to the Nuclear Information and Resource Service, up to 1,000 new reactors would be needed in the United States alone to replace existing reactors that are reaching the end of their useful life and expand nuclear power generation to the level necessary to meet the Phase I greenhouse gas reductions contemplated by the Kyoto accords.¹¹⁶ Given that no new nuclear plants have been built in the United States in the last twenty years, it is unrealistic to expect that anywhere close to the necessary expansion in nuclear energy generation could be achieved by the Kyoto accord's 2012 Phase I deadline.¹¹⁷

Even if the plants could be built in time, there is not enough nuclear fuel economically available to run them all. According to the Department of Energy, at current rates of consumption, demand will exceed the readily available supplies and stockpiles of uranium fuel by the year 2014.¹¹⁸ According to the Nuclear Information and Resource Service, if nuclear energy generation were expanded as necessary to meet the Phase I reductions of the Kyoto accords, the existing fuel supply would be exhausted within three to four years.¹¹⁹

Nuclear energy would be sustainable only if fuel reprocessing could be perfected to the point where it is economical and safe from proliferation risks. Nuclear energy advocates foresee a "closed fuel

115. The Nuclear Regulatory Commission currently requires an existing plant to apply for a license renewal five years before expiration. See U.S. Nuclear Regulatory Comm'n, *Reactor License Renewal Process: Review Time*, <http://www.nrc.gov/reactors/operating/licensing/renewal/process.html#review-time> (last visited Jan. 17, 2006). An application for a new plant can be expected to take more time than a renewal.

116. Although the United States is not a signatory to the Kyoto accords, the Phase I reductions imposed on the signatory states is a useful yardstick to measure national compliance with carbon reduction goals. Under Phase I of the Kyoto accord, signatory nations included in Annex I are to achieve a 5% reduction in national greenhouse gas emissions, compared to 1990 levels, by the year 2012. Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 10, 1997, 37 I.L.M. 22, 33 available at <http://UNFCCC.int/resource/docs/convkp/kpeng.pdf>.

117. Based on the minimum five year renewal time frame required by the Nuclear Regulatory Commission, application for a sufficient number of new plants would have to be ready to file in 2007 in order to be granted by 2012; even without leaving time for plant construction and testing.

118. U.S. DEP'T OF ENERGY, *supra* note 32, at I-5, figure I-3.

119. Ward, *supra* note 99, at 11.

cycle” where spent nuclear fuel is reprocessed into new nuclear fuel, while the extremely poisonous radionuclides and weapons-grade plutonium are magically transmuted into harmless elements.¹²⁰ This particular form of alchemy remains just over the horizon for the nuclear industry, as it has throughout most of the history of nuclear energy generation.

Given these impracticalities of large scale expansion of nuclear generation capacity, one might ask where the harm lies in increased nuclear generation to the extent possible, in at least partial mitigation of greenhouse gas impacts. If worldwide nuclear generation capacity is ultimately limited by the accessible uranium supply, then, one could argue, the impacts of nuclear power will be self-limiting. Unfortunately, however, resources diverted into nuclear energy development are taken away from other energy technologies more likely to prove sustainable in the long term.¹²¹ A widespread international commitment to nuclear energy as a substantial means of reducing greenhouse gas emissions will increase international pressure to engage in high proliferation risk activities such as plutonium-generating “breeder reactors.”¹²² And even the short-term use of nuclear power production continues to pile up spent fuel waste at insecure sites throughout the world, where it will be vulnerable to climate change impacts as well as the global social unrest that will likely accompany such impacts.¹²³

V. INTERGENERATIONAL IMPACTS AND INTERCIVILIZATIONAL IMPACTS: A COMPARISON OF GLOBAL WARMING EXTERNALITIES AND NUCLEAR ENERGY EXTERNALITIES

The grave danger posed by nuclear energy is a function of the extreme persistence of its wastes and by-products.¹²⁴ Catastrophic

120. See Matthew L. Wald, *Scientists Try to Resolve Nuclear Problem With an Old Technology Made New Again*, N.Y. TIMES, Dec. 27, 2005, at F3.

121. Ward, *supra* note 99, at 14.

122. See *id.* A “breeder reactor” generates heat for energy production while at the same time converting more uranium to plutonium, which is then used to fuel the reactor and generate more heat and more plutonium.

123. Social unrest often follows societal collapse resulting from environmental and climate changes that defeat civilizations’ ability to provide for basic human necessities. See generally, DIAMOND, *supra* note 93.

124. See *supra* notes 34-35 and accompanying text (half lives of radioactive nuclear wastes extending into millions of years).

events that may have a low probability in a given year, decade, or century become near certainties when the time period is extended into hundreds of thousands or millions of years. The chances of glaciation or coastal flooding at waste storage sites (or both), or widespread political disruption and civil unrest may seem remote at present, but are near certainties in the tens of thousands of years before the plutonium fraction of nuclear wastes we generate today has decayed to the point that it is neither poisonous nor capable of annihilating a city in the wrong hands.¹²⁵

These nuclear waste impacts seem as certain to occur as the impacts anticipated from climate change. In order to assess the advisability of increasing nuclear energy generation in an attempt to avoid global climate change, it is worth comparing these impacts.

A. Timing

Scientific consensus holds that we are already feeling the effects of global warming.¹²⁶ The more extreme effects of global climate change are anticipated to occur within the next century.¹²⁷ Scientists also believe that the earth will take centuries to absorb the excess carbon dioxide currently produced by human activity.¹²⁸ Of course, if climate change reaches a “tipping point” through positive feedback mechanisms not yet fully understood, the impacts may last much longer.¹²⁹ Climate change impacts are thus described as “int-

125. See *supra* note 35 and accompanying text. Plutonium has a half life of 24,360 years. Global warming is already upon us; global sea level rise is expected within the next century See *supra* note 95 and accompanying text. The last glaciation occurred 18,000 years ago. See *supra* note 89 and accompanying text; see also NRC YUCCA MOUNTAIN REPORT, *supra* note 33, at 91 (glacial period probable within 10,000 years; several glacial /interglacial periods a near certainty over one million years.). The longest lasting civilization in world history has lasted only 10,000 years.

126. See generally, COMM. ON THE SCIENCE OF CLIMATE CHANGE, *supra* note 18.

127. See IPCC WORKING GROUP 1, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS, 14 (2001) available at http://www.grida.no/climate/ipcc_tar/wg1/figspm-5.htm.

128. *Id.* at 12, available at http://www.grida.no/climate/ipcc_tar/wg1/008.htm#figspm5; COMMITTEE ON THE SCIENCE OF CLIMATE CHANGE, *supra* note 18, at tbl. 1.

129. See James E. Hansen, Presentation at SOLAR 2006 Conference on Renewable Energy (July 10, 2006) available at http://www.columbia.edu/~jeh1/thereat_talk_complete_05Sept2006.pdf.

ergenerational” – that is, future generations of the people now generating the carbon dioxide will suffer the greatest impacts.¹³⁰

By contrast, nuclear power generation waste impacts will last many thousands of years, and even into the millions of years.¹³¹ The greatest impacts may not be felt for tens of thousands of years.¹³² Given that no human civilization has lasted longer than 10,000 years, at least some of the impacts of nuclear power will be imposed on future peoples and political systems we cannot even contemplate. Indeed, given the long persistence of these wastes even in comparison with the timeframe of human evolution, these impacts may even be suffered by other species of humans yet to evolve.¹³³ The impacts of nuclear waste are thus “intercivilizational.”

Either set of impacts seems palpably unfair. However, future generations may enjoy some of the vestigial advantages of the energy wealth enjoyed by the unsustainable energy practices of the current generation. It seems unlikely that future civilizations would enjoy any such advantage. These intercivilizational impacts seem more inequitable than the intergenerational impacts of climate change.

B. Location

The most severe impacts of global warming may not be suffered by the biggest per capita generators of greenhouse gas emissions. The United States has only five percent of the world’s population, yet contributes twenty percent of global greenhouse gas emissions.¹³⁴ Over twenty-three million people in developing nations such as India and Bangladesh live in coastal areas subject to flooding due to global sea-level rise.¹³⁵ Changing rainfall patterns projected

130. See James C. Wood, *Intergenerational Equity and Climate Change*, 8 *GEO. INT’L ENVTL. L. REV.* 293 (1996).

131. See *supra* notes 89-97 and accompanying text.

132. See NRC YUCCA MOUNTAIN REPORT *supra* note 33, at 2 (peak risks likely to occur tens to hundreds of thousands of years after disposal), 119 (peak risks likely to occur after 10,000 years).

133. As one of the impacts of nuclear waste is its mutagenic properties, dispersal of nuclear waste might even hasten the evolution of new human species.

134. Union of Concerned Scientists, *Renewable Energy: Mitigating Global Warming*, Feb. 3, 2006, http://www.ucsusa.org/clean_energy/clean_energy_policies/RES-climate-strategy.html (last visited October 20, 2006).

135. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, VITAL CLIMATE GRAPHICS - THE IMPACTS OF CLIMATE CHANGE, 33-34 (2001) available at <http://www.grida.no/climate/vital/33.htm>; <http://www.grida.no/climate/vital/34a.htm>.

as a result of global warming are expected to reduce crop success in sub-Saharan Africa, while some temperate zones of North America and Russia may see possible increased crop yields due to a longer growing season.¹³⁶ In sum, the foreseeable climate change impacts will be imposed by carbon-producing developed nations on developing nations that have not contributed equally to the problem.

By contrast, in the case of nuclear energy wastes, the land we render uninhabitable may be our own. Radionuclides can certainly be dispersed throughout the atmosphere in gaseous form or aerosol particles and throughout the oceans as particles suspended in liquid.¹³⁷ However, the greatest risk of sickness, death, and uninhabitability lies in the geographic vicinity of the waste disposal sites.¹³⁸ And, of course, the risks of nuclear proliferation might be felt anywhere, but in the current geopolitical climate, they seem most likely to be suffered by the nations that have developed and used nuclear power.¹³⁹

If it were merely a matter of imposing the risks on the political system that received the benefits of the unsustainable energy system, then nuclear power at least seems to impose its hazards more locally and directly on its beneficiaries. The intercivilizational time frame of these impacts overcomes this seeming fairness of nuclear energy impacts: whatever human (or human-like) civilization occupies our continent one hundred thousand years from now should no more

136. See generally INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2001: SYNTHESIS REPORT (2001) available at http://www.grida.no/climate/ipcc_tar/vol4/english/index.htm; UNITED NATIONS ENV'T PROGRAMME, GEO YEAR BOOK 2006, 60-66 (2006) available at <http://www.unep.org/geo/yearbook/yb2006/063.asp>; Michael D. Mastrandrea & Stephen H. Schneider, *Global Warming*, http://www.nasa.gov/worldbook/global_warming_worldbook.html (last visited Jan. 17 2006).

137. For exposure pathways expected for long term storage of nuclear waste, see NAS YUCCA MOUNTAIN REPORT, *supra* note 33, at 82.

138. Of course, nations may also export their nuclear waste impacts by exporting their nuclear wastes. See Patrick E. Tyler, *Russia Sees Payoff in Storing Nuclear Wastes From Other Nations*, N.Y. TIMES, May 26, 2001, at A1. But however unfair this may seem to the people of the recipient country, it is at least a choice of their national political system to accept such wastes. Conversely, the developing nations most at risk for global warming impacts have made no such choice to be subject to these impacts, and have received no compensation for it.

139. An assessment of the risk of nuclear conflict or terrorism in different regions of the world is beyond the scope of this article. Recent acts of mass terrorism, such as the September 11 attacks, and the London and Madrid bombings, have been primarily addressed towards the western developed nations that also enjoy the benefits of nuclear power.

equitably be subject to the environmental costs of our energy production than the Bangladeshis.

C. *Size of Population Affected*

Seventeen million Bangladeshis currently live in coastal regions likely to become uninhabitable in the event of warming-induced sea-level rise.¹⁴⁰ Six million inhabitants of the Nile Delta are at risk.¹⁴¹ According to the National Academy of Sciences, “[a]s many as one billion people, or 20 percent of the world’s population, live on lands likely to be inundated or dramatically changed by rising waters.”¹⁴² It is hard to predict what proportion of these populations would die as a result of massive climate-induced dislocations, whether through flooding in storms or famine and civil strife as a huge refugee population tries to move into neighboring territories. Certainly, the casualties would number in the millions. More deaths will result from climate change-induced famine. According to a report of the United Nations Food and Agriculture Organization, forty nations with a combined population of two billion people are at risk of drastically increased undernourishment.¹⁴³

Fatalities ultimately due to nuclear generation impacts would also be calamitous, but may be less calamitous. As discuss above, a single nuclear accident in a populated region could be expected to cause thousands of short term deaths, and tens of thousands of long term deaths. Detonation of a single nuclear weapon in a city, by terrorists, could cause tens of thousands of deaths, and an all-out nuclear war between two states could undoubtedly cause tens of millions of fatalities.¹⁴⁴ Similarly, the number of people that could be displaced

140. United Nations Environmental Programme, *supra* note 125, at 33.

141. *Id.* at 34.

142. CHERYL SIMON SILVER & RUTH S. DEFRIES, ONE EARTH, ONE FUTURE: OUR CHANGING GLOBAL ENVIRONMENT 92-93 (1992).

143. United Nations Food and Agriculture Organization, Special Event on Impact of Climate Change, Pests and Diseases on Food Security and Poverty Reduction, May 23 – 26, 2005, Background Document at 3 available at http://www.fao.org/newsroom/common/ecg/102623/en/Climate_Change_Background_EN.pdf.

144. International Physicians for the Prevention of Nuclear War, *Effects of a Nuclear Explosion in a Populated Area: New York City, New York*, <http://www.ippnw.org/NukeTerrorism04.html> (calculating 60,000 fatalities from a Hiroshima-sized nuclear weapon detonated in lower Manhattan); M.V. Ramana, IPPNW Global Health Watch Report No. 3, *Bombing Bombay? Effects of Nuclear Weapons and a Case Study of a Hypothetical Explosion* (1999) (concluding that a

in the event of widespread dispersion of the radioactive nuclear inventory of a single spent fuel pool numbers in the millions.¹⁴⁵

The long term human impacts of fossil fuel induced climate change and nuclear waste are thus comparably horrific in scope. Ultimately, the population affected by climate change may be substantially larger than the one affected by nuclear wastes. Nuclear wastes, however, will affect populations much farther into the future than the effects of global warming.¹⁴⁶

VI. CONCLUSION

Although nuclear energy is currently being promoted as part of the solution to global climate change, nuclear energy production causes environmental externalities on a scale equally horrific as those caused by climate change from burning fossil fuels. Nuclear power's externalities are largely intra-national, and would be imposed by the developed nations of the world mainly on their own territory, but are of such long duration that they are fairly characterized as intercivilizational. Fossil fuel climate impacts are more international and global in scope, are intergenerational, and are imposed by the developed nations of the world on the developing nations.

Any carbon regulation scheme that provides subsidies, whether direct or indirect, to nuclear energy generation may increase the ultimate scope of nuclear waste impact. Such schemes would not necessarily achieve a sufficient reduction in greenhouse gas emissions to counter global climate change. Throughout its history, the nuclear energy industry has deferred resolution of the most pressing problem with its fuel cycle: disposal or reprocessing of its high-level radioactive wastes. While new fuel reprocessing technologies may ultimately hold promise for safer handling of nuclear fuel wastes, these technologies cannot be developed in the timeframe necessary to al-

150 megaton nuclear weapon exploded over Bombay could cause as many as 8,000,000 fatalities) available at <http://www.ipnw.org/bombay.pdf>.

145. See *supra* note 100 and accompanying text. A consultant working for the Riverkeeper organization has calculated that the radioactive inventory of the spent fuel pool at Indian Point is sufficient to render three quarters of the land area of New York State uninhabitable. *Id.*

low nuclear energy to play a significant role in the urgent need to reduce greenhouse gas emissions.