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An Unattainable Wedge: Four Limiting Effects on the Expansion of Nuclear Power

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An Unattainable Wedge:  
Four Limiting Effects on the Expansion of Nuclear Power

By: Tanya Mortensen, J.D., University of Houston, May 2009

Abstract: With a cap and trade system likely imminent, concerns about the costs of generating electricity and how electrical generators can best mitigate the effects of a carbon trade system are resurfacing. As a result, interests in nuclear power are resurging world-wide. Although, the purpose of this paper is aimed at national decision making, the problems and processes that confront decision makers internationally are effectively the same as those confronting decision makers in the United States. This paper examines the feasibility of using nuclear power as a wedge to reduce CO\textsubscript{2} emissions, and puts forth four effects that may prevent or inhibit the growth of the nuclear power industry: (1) the effect of cultural perception, (2) the effect of nuclear waste policy, (3) the effect of non-static permit prices, and (4) the effect of smart-grid technology. Consequently, the expansion of nuclear energy as a wedge to reduce greenhouse gas emissions may be impractical.

As international efforts continue to move toward a cap and trade system for greenhouse gases (GHGs), it remains to be seen what role the United States may play in such efforts. Traditionally, the United States has taken a soft approach to international climate change by choosing to ratify only those efforts which are voluntary or non-binding.\textsuperscript{1} A soft international stance, however, does not mean that the U.S. will take a soft domestic approach. Indeed, a U.S. cap and trade system may be forthcoming.

\textsuperscript{1} U.S. opposition to binding international treaties can be seen in the Kyoto Protocol. After the U.S. became a signatory to the Kyoto Protocol, the Byrd-Hagel Resolution unanimously passed by the U.S. Senate advised the Clinton Administration not to accept binding obligations under the Kyoto Protocol unless developing countries did the same. As a result, the Kyoto Protocol was never ratified. S. Rep. No. 105-54, at 4 (1997). The United States, however, did agree to the Asia Pacific Partnership on Clean Development and Climate Change on January 12, 2006 which was a non-binding effort to advance climate change initiatives. See Bureau of Pub. Affairs, U.S. Dep’t of State, \textit{U.S. Gov’t Website for the Asia-Pacific P’ship on Clean Dev. and Climate}, http://www.app.gov/ (last visited April 9, 2009).
President Barack Obama’s pre-election campaign stressed the importance of instituting a cap and trade system, and promised to reduce greenhouse gas emissions to 80% of 1990 levels by 2050. Since 1990, greenhouse gas emissions in the U.S. have increased by about 17.1%. In furtherance of that promise, an attempt was made to attach a cap and trade system to the 2009 budget reconciliation process and failed. Still, the Omnibus Spending Bill, signed into law on March 11, 2009, required the EPA to finalize a proposed rule to require industries to file an annual report on greenhouse gas emissions (GHG) by June 26, 2009. Just a few weeks later, the EPA issued a long awaited “endangerment” finding for greenhouse gas emissions. An “endangerment finding” is a necessary precursor that triggers the EPA’s non-discretionary duty to regulate harmful pollutants under the Clean Air Act (CAA). Such a finding is likely to trigger a cascade of permitting requirements on carbon emissions in the very near future. As a result, the electric industry is preparing for the inevitable establishment of a carbon allowance and trade system by examining the feasibility of carbon reducing technologies and alternatives. At the top of the list for many: nuclear power.

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6 Danish et. al., supra n.4 at 2.
7 Clean Air Act, 42 U.S.C. § 7408.
8 Danish et. al., supra n.4.
Forty three new reactors representing 371,927 MWe (megawatts electrical) are currently under construction around the world and another 374 have been ordered or proposed.\textsuperscript{10} Although the United States has been somewhat more reluctant than the rest of the world to expand its existing stock of nuclear power plants, these sentiments may be changing.\textsuperscript{11} The Nuclear Regulatory Commission (NRC) has already received twenty-six new applications for nuclear power reactors since 2007.\textsuperscript{12} Not all of these plants will ultimately be built (even if the NRC approves the applications) but at least six applicants already have the financial backing for construction pending NRC approval.\textsuperscript{13}

Using nuclear power as a wedge to reduce primary baseload carbon emissions may prove to be less practical than originally thought. This paper examines the feasibility of using nuclear power as a wedge to reduce CO\textsubscript{2} emissions, and puts forth four effects that may prevent or inhibit the growth of the nuclear power industry: (1) the effect of cultural perception, (2) the effect of nuclear waste policy, (3) the effect of non-static permit prices, and (4) the effect of smart-grid technology.


An Introduction to Cap & Trade and the Nuclear Wedge Debate

In 2000, Princeton University received a $20 million grant to study and develop a solution to the greenhouse gas problem. Further funds were pledged by BP ($15 million) and Ford Motor Company ($5 million). Four years later, Robert Socolow and Stephen Pacala of Princeton University released an outreach model known as the stabilization triangle in which existing technologies could be used to stabilize carbon dioxide emissions for the next 50 years. The model spurred a scholarly debate concerning the best way to tackle an extremely large carbon dioxide emission problem.

According to the Socolow-Pacala model, the ocean and land biosphere act as a filter removing carbon dioxide from the air at a rate of four billion tons per year. Meanwhile, fossil fuel combustion adds about eight billion tons per year. Currently, the earth’s atmosphere contains a little more than 800 billion tons of carbon dioxide, but the amount is steadily climbing. Unless significant changes are made, yearly contributions to the total carbon content of the atmosphere are expected to double. Socolow and Pacala surmised that if carbon emissions were sustained at the current level (by eliminating eight billion tons of carbon output)

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15 Id.
17 Id.
19 Id.
20 Id.
21 Id.
for the next 50 years, the doubling of CO$_2$ would be avoided.\textsuperscript{22} As a solution, the Princeton professors divided the eight billion ton emission triangle into eight smaller one million ton wedges. As the carbon wedge model gained popularity, The Natural Resources Defense Council computed the size of one “U.S. wedge” to be one gigaton carbon dioxide equivalent (Gt CO$_2$ eq.), or 175 gigawatts electrical (GWe).\textsuperscript{23} The Socolow-Pacala model presents 15 different strategies in four categories that could lower carbon dioxide emissions.\textsuperscript{24} The four categories are: efficiency and conservation, strategies to reduce emissions from fossil fuels, nuclear energy, and the use of renewable energy and biostorage technologies.\textsuperscript{25} This paper focuses only on the use of nuclear power for electricity.

**The Nuclear Wedge, Problem or Solution?**

By 2020, the extended licenses of 18 U.S. nuclear power plants will expire.\textsuperscript{26} Simultaneously, the DOE expects the demand for electricity to increases 10-15% even though per capita energy use may decline.\textsuperscript{27} Assuming that all expiring nuclear reactors are replaced, by 2030 electric prices could grow 10.4-10.8 cents per KWh (almost double the current national average).\textsuperscript{28} The imposition of a carbon trading system (hereinafter referred to simply as a carbon tax), however, will further increase electric prices in proportion to the electric fuel’s carbon

\textsuperscript{22} S. Pacala & R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Tech.*, 305 SCIENCE 968 (2004).


\textsuperscript{24} Pacala *supra* n.22.

\textsuperscript{25} Id.


\textsuperscript{28} Id. at *Mkt. Trends*, 73.
emissions. Although it is perhaps impossible to determine exactly how much the price of
electricity would increase under a free market carbon trading system, a carbon tax of $100 per
ton would raise electric prices 30-34% (1-4 cents per KWh), and increase the general price of
goods 1.5-2.8%.  

If no new nuclear power plants are built, the entire fleet of U.S. nuclear reactors will expire enlarging the climate problem by 10% of a global wedge or 40% of a U.S. wedge. Supposing the existing U.S. fleet is expanded by the 26 proposed power plants, however, the new plants would add an extra 12.5% (or roughly 40 GWe) of electrical generating capacity to the U.S. and reduce emissions by about 22.8% of one U.S. carbon wedge. Thus, proponents of nuclear energy have advocated the use of nuclear power as a strategy to reduce carbon emissions. But even if nuclear energy becomes economically feasible, there are other problems that might prevent or inhibit the resurgence of nuclear use.

29 ANN. ENERGY OUTLOOK 2009 supra n.27 at Executive Summary, 3.
30 $100 per ton is a relatively high carbon price estimate.
33 See Hotinski supra n.18 at 6 (for the proposition that phasing out all world nuclear power plants would add 1/3 of a wedge to world emissions); INFO. DIG. supra n.26 at 26 (U.S. nuclear fleet makes up 32% of world nuclear capacity) (.32*.33 ≈ .106 or 10.6%).
34 See Energy Info. Admin., U.S. HOUSEHOLD ELECT. REP. (July 2005); A CBO STUDY supra n.45 at Ch. 1, 9.
Modern Energy Usage

World energy consumption is growing at a rate of 3.2% per year. In 2005 the world consumed 462 quadrillion BTUs (quads) of energy. One quad is approximately equal to 33.43 gigawatts of energy. Thirty-five percent of that consumption was supplied by liquid hydrocarbons, the rest was supplied by: coal, 25.3%; natural gas, 20.7%; nuclear, 6.3%; hydro-power, 2.2%; combustible renewable fuels, 10%; and other sources, 0.5%. By 2030, however, the world may consume as much as 695 quads of energy per year. In 2007, the United States alone consumed approximately one-fifth of world demand or 101.6 quadrillion BTUs of energy. By 2030, U.S. energy demand is expected to account for one-fourth of total world consumption. Most of this consumption, about 40%, goes to electric power generation.

Traditional Baseload Power Fuels

Electric generation world-wide has relied primarily on fossil fuels since its inception. Fossil fuel combustion however produces harmful GHG’s such as: Carbon Dioxide (CO₂),

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36 Id.
37 See, Univ. of Ill. Urbana-Champaign, Dep’t of Materials Sci. and Eng’g, Energy Glossary http://matse1.mse.uiuc.edu/energy/glos.html (last visited March 27, 2009).
39 INTL ENERGY OUTLOOK 2008 supra n.11.
41 INTL ENERGY OUTLOOK 2008 supra n.11.
42 ANN. ENERGY REV. supra n.40 at Figure 2.1(a) (available at http://www.eia.doe.gov/emeu/aer/pdf/pages/sec2_2.pdf).
Methane (CH$_4$), Nitrous Oxide (N$_2$O), Sulfur Dioxide (SO$_2$), and Fluorinated Gases. These GHGs contribute to extreme weather patterns such as: arctic ice sheet melting, drought, heavy precipitation, heat waves, and intense tropical cyclones.

Low fuel, capital costs, and the abundance of local fuel sources make coal the most popular electric fuel in the United States. Forty-nine percent of electric generation in the United States relies on coal. Coal is the dirtiest fossil fuel and emits 209 pounds of CO$_2$, 13 pounds of SO$_2$, and 6 pounds of N$_2$O per million watt-hours (MWh) of electricity produced. Other by-products of coal combustion include: fly ash, fluidized bed combustion residues, flu gas, desulfurization sludge, and bottom ash. As a result, coal power plants are responsible for 83% of electricity related greenhouse emissions in the United States.

Natural gas, on the other hand, is the cleanest burning fossil fuel and generates 21% of electricity in the United States. Natural gas emits 119 pounds of CO$_2$, 0.1 pounds of SO$_2$, and 1.7 pounds of N$_2$O per MWh. In total, natural gas is responsible for 15% of GHG emissions from electrical generation in the United States. Despite the cleaner burning nature of natural gas,

46 ANN. ENERGY REV. *supra* n.40 at Figure 8.2a.
47 Ross Wingo, Sterling Burnett, *Nuclear Renaissance: Atoms to Power the Future*, Nat’l Ctr. for Pol’y Analysis, Brief Analysis No. 635 (October 21, 2008); A CBO STUDY supra n.45 at Ch. 2, 21.
50 ANN. ENERGY REV. *supra* n.40 at Figure 8.2a.
51 Wingo *supra* n.47.
gas plants are rarely used for baseload power generation – mostly because gas is extremely price volatile.\textsuperscript{52} Prices can change by as much as 200\% in a short time frame.\textsuperscript{53} Instead, the low capital costs of natural gas plants make them attractive for use as peak cycling facilities.\textsuperscript{54}

Petroleum is rarely used for baseload electric generation because of high fuel costs and the potential for supply interruption.\textsuperscript{55} Generating plants that use petroleum emit 12 pounds of SO\textsubscript{2} and 4 pounds of N\textsubscript{2}O per MWh.\textsuperscript{56} Petroleum power plants have steady declined in the Unites States since the Oil Embargo of 1973. Today less than 2\% of electric generation comes from petroleum.\textsuperscript{57}

**Nontraditional Baseload Power Fuels**

Nuclear power does not generate GHGs, but it does create hazardous radioactive wastes that must be disposed of somewhere.\textsuperscript{58} A spent nuclear fuel rod is 96\% uranium and 4\% other isotopes created by fission.\textsuperscript{59} These fission by-products have half lives\textsuperscript{60} longer than a million

\textsuperscript{52} A CBO STUDY \textit{supra} n.45 at Ch. 2, 20.
\textsuperscript{53} \textit{Id.} at 19.
\textsuperscript{54} A CBO STUDY \textit{supra} n.45.
\textsuperscript{56} Wingo \textit{supra} n.47 at 2.
\textsuperscript{57} \textit{Elec. Generation supra} n. 55.
\textsuperscript{60} A half life is the measure of the average lifetime of a radioactive substance or unstable subatomic particle. One half life is equal to the amount of time required for half of any particle to decay. For example, the half life of the naturally occurring radioactive metal thorium is 8 minutes. If 100 grams of thorium existed, then in 8 minutes there would be 50 grams of thorium and 50 grams of various other substances; in 16 minutes there would be 25 grams of thorium; in 24 minutes there would be 12.5 grams, etc.
years.\footnote{Id.} For instance, iodine-129 has a half life of 17 million years, and plutonium-239 has a half life of 24,360 years.\footnote{Id.} Other by-products of fission include: cesium-137, strontium-90, uranium-234, neptunium-237, plutonium-238, americium-241, and californium.\footnote{See World Nuclear Ass’n, \textit{Waste Mgmt. in the Nuclear Fuel Cycle} (Aug. 2008) http://www.world-nuclear.org/info/inf04.htm (last visited March 27, 2009); Nuclear Info. and Res. Serv., \textit{Radioactive Waste Project} http://www.nirs.org/radwaste/radwaste.htm (last visited March 27, 2009).} In addition to the isotopes produced by fission, nuclear plant decommissioning produces a significant amount of waste caused by steel’s prolonged exposure to radioactive materials such as: iron-55, cobalt-60, nickel-63, and carbon-14.\footnote{Id.} Today, nuclear power accounts for 19\% of U.S. electric generating capacity.\footnote{Id.} These plants are highly efficient and have extremely long operating lives compared to other types of power plants.\footnote{ANN. ENERGY REV. \textit{supra} n.40 at Figure 8.2a.} High capital costs, however, have inhibited the attractiveness of nuclear technology for the past 30 years.\footnote{See Larry Parker and Mark Holt, \textit{Nuclear Power: Outlook for New U.S. Reactors}, CRS REP. FOR CONG., CRS-5 (Cong. Research Serv., March 9, 2007).}

Hydroelectric power is a cheap renewable source of energy that produces few GHGs and little thermal pollution.\footnote{A CBO STUDY \textit{supra} n.45 at Ch. 1, 13.} Some of the limitations of hydroelectric power include: environmental damage to riparian\footnote{Elec. Generation \textit{supra} n.55.} habitats, water pollution, navigable waterway passage restriction, high capital costs, displacement of human populations, and large land and water flow requirements.\footnote{Riparian means, “relating to the banks of a natural course of water.” Plant communities along a river’s margin are called riparian vegetation. Riparian zones areas are significant because they impact soil conservation, biodiversity, and aquatic ecosystems. Stephanie Parkyn, No: 1171-4662, \textit{Rev. of Riparian Buffer Zone Effectiveness}, MAF TECHNICAL PAPER NO: 2004/05, 7 (N.Z. Ministry of Agric. and Forestry, September 2004) (available at http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/resource-management/review-riparian-buffer-zone-effectiveness/techpaper-04-05-riparian-effectiveness.pdf).}
Hydroelectric power produces 19% of electricity world-wide, but in the United States, only about 6% of electric capacity comes from hydroelectric power.\textsuperscript{71} Other various energy technologies supply about 5% of U.S. electrical production.\textsuperscript{72}

**Modern Technologies**

The American Recovery and Reinvestment Act of 2009 provided $3.4 billion for carbon capture experimentation.\textsuperscript{73} Carbon dioxide capture and storage (CCS) is a new process that separates \( \text{CO}_2 \) from energy related sources and transports it to a storage location for long term isolation from the environment.\textsuperscript{74} Large point sources emit nearly 13 gigatons of \( \text{CO}_2 \) per year.\textsuperscript{75} The captured \( \text{CO}_2 \) can then be stored in geological formations such as empty natural gas reservoirs, or converted to mineral carbonates for use in industrial processes – although industrial conversion is not expected to significantly contribute to \( \text{CO}_2 \) abatement.\textsuperscript{76} The Intergovernmental Panel on Climate Change (IPCC) estimates that there is roughly 1,100 gigatons of underground storage space worldwide.\textsuperscript{77} All of the component parts of a potential CCS system exist, but implementation is still waiting for the right economic condition.\textsuperscript{78} CCS technology would

\textsuperscript{71} Id.
\textsuperscript{72} ANN. ENERGY REV. supra n.40 at Figure 8.2a.
\textsuperscript{74} Juan Carlos Abanades, et. al., Carbon Dioxide Capture and Storage, IPCC SPECIAL REP. FOR WORKING GROUP III, Summary for Policymakers, 3 (Intergovernmental Panel of Climate Change, Sess. VIII, Montreal Can., 22-24 Sept. 2005).
\textsuperscript{76} Id. at 8.
\textsuperscript{77} Geological Sequestration supra n.75.
\textsuperscript{78} Id. at 8.
increase the cost of electricity by as much as 1.6 to 8.3 cents per kWh.\(^7\) The implementation of CCS technology would also increase the amount of fuel needed for electrical generation.\(^8\)

The U.S. Energy Policy Act of 2005 and the Advanced Energy Initiative of 2006 encourage the construction of advanced nuclear reactors by offering incentives for construction, fast-track licensing, research/design funding, and liability protection.\(^8\) There are two types of advanced reactors: Generation III+ and Generation IV.\(^8\) Generation III+ reactors are ready for commercial operation and include: the Westinghouse AP1000,\(^8\) Areva EPR,\(^8\) GE ESBWR,\(^8\) and CANDU ACR1000.\(^6\) These reactors are modular which enable them to be built in less than four years.\(^7\) They also incorporate passive safety features such as using gravity to cool the reactors rather than an external pumping system which eliminates the risk of leaks caused by the degradation of pressurized pipes.\(^8\)

Generation IV reactors are a product of International cooperative design efforts. In July 2001, the U.S. Department of Energy (DOE) convened the first meeting of the Generation IV

\(^{7}\) Abanades, et. al. supra n.74.

\(^{8}\) Abanades, et. al. supra n.74.


\(^{8}\) Id.


\(^{8}\) The Areva EPR is a European designed “pressurized reactor.”


\(^{8}\) Koomey supra n.81.

International Forum (GIF), a panel consisting of nuclear technology experts from nine countries, to discuss the development of new nuclear technology.\textsuperscript{89} Today GIF members include: Argentina, Brazil, Canada, China, France, Japan, Republic of Korea, the Russian Federation, Republic of South Africa, Switzerland, the United Kingdom, the United States, and the European Union’s Atomic Energy Commission (Euratom). GIF designed six different categories of next generation advanced nuclear technology which feature increased modularity, proliferation resistance, and alternative fuel cycles;\textsuperscript{90} these reactors are expected to be construction ready in n 15-20 years.\textsuperscript{91}

### Legislative Background

#### Atomic Energy Act of 1946

Fear of nuclear energy’s dangerous potential drove decisions about nuclear energy from the very inception of the technology. Shortly after Columbia University’s first successful fission experiment in the United States, Albert Einstein and Leo Szilard wrote a letter to President Roosevelt warning him of the potential danger of allowing Germany to be the first country to develop a nuclear weapon.\textsuperscript{92} Although the letter was initially overlooked, one month later Hitler invaded Poland starting WWII.\textsuperscript{93} Just days later, Roosevelt responded by funding the first

\begin{footnotesize}
\begin{enumerate}
\item Koomey supra n.81 at 5630.
\item Letter from Albert Einstein (with Leo Szilard), to President Franklin Roosevelt, (Aug. 2, 1939) (on file at the Franklin D. Roosevelt Library and Museum) (available at http://www.cfo.doe.gov/me70/manhattan/einstein_letter Photograph.htm).
\end{enumerate}
\end{footnotesize}
nuclear task force. The mission: to determine the feasibility of becoming the first nuclear weapon state.94

Yet even after the end of WWII, fear of nuclear proliferation fueled the political debates over long term management of the now robust nuclear program.95 Two prominent scientists, namely Vannevar Bush and James B. Conant, proposed draft legislation to establish a twelve member atomic energy commission comprised of eight civilians and four military appointees to manage the nuclear program.96 With the destruction of Nagasaki and Hiroshima still fresh, however, some were uncomfortable releasing nuclear control into civilian hands. In fact, the May-Johnson bill, originally supported by President Harry Truman, called for strict military control over nuclear science with harsh penalties for security violations. At the same time, an opposing bill, the McMahon bill, was circulating the senate calling for complete civilian control of the nuclear program.97 Ultimately, the McMahon bill underwent a series of gradual alterations and by the time it passed both houses it more closely resembled Bush and Conant’s early draft legislation.98

On August 1, 1946, President Truman signed the McMahon bill, officially titled the Atomic Energy Act of 1946 into force.99 The Atomic Energy Act of 1946 established the United States Atomic Energy Commission (AEC) with five full time civilian presidential appointees

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98 Civilian Control supra n.96.
99 Morland supra n.97.
overseeing operational divisions: research, production, engineering, and military application. 100

The act required the AEC to report to a newly created Joint Committee on Atomic Energy (JCAE) comprised of nine Senate members and nine House Representatives. 101 More importantly, the Atomic Energy Act of 1946 defined a new legal standard for “restricted data,” which covered “all data concerning “atomic weapons,” “fissionable material,” and “fissionable material in the production of power.” 102 Prior to WWII, government gag orders for militarily sensitive information were temporary, 103 but after the Atomic Energy Act of 1946, all nuclear information was “born secret.” 104 The born secret doctrine was the United State’s first long term gag order, and initiated an era of clandestine government decision making characterized by fear and suspicion.

In fact, the failure of the United States and Great Britain to fully inform their Russian ally about the atomic bomb set the stage for a postwar rivalry between the U.S. and Russia. 105 Referring to Russia’s postwar imposition of communist governments upon the countries under its military control, British Prime Minister Winston Churchill warned the world that an “iron curtain” was descending upon Eastern Europe. One year later President Truman announced the “Truman Doctrine” which funded military assistance to nations opposing communism. 106 Believing that a 3rd World War might be imminent, both the United States and Russia began stockpiling nuclear weapons. 107

100 Civilian Control supra n.96.
101 Id.
102 Morland supra n.97.
104 Morland supra n.97 at 1402.
106 Id.
107 Morland supra n.97 at 1407.
Atoms for Peace

In an attempt to alleviate growing concern over the United State’s immense nuclear arsenal, President Eisenhower gave a speech at the United Nations (UN) in December, 1953 titled “Atoms for Peace.” Although the “Atoms for Peace” proposal suggested the establishment of an international nuclear material stockpile under the control of the UN for the pursuit of peaceful scientific uses, the program’s inception had more to do with creating a “check” for the nuclear dilemma than it did about moving nuclear power away from military purposes. The International Atomic Energy Agency (IAEA) was organized in 1957 as an independent international agency to promote “safe, secure, and peaceful nuclear technologies.” While the science of nuclear power is mostly inseparable from the science of nuclear weapons, what limits a nation’s ability to develop nuclear weapons is their access to weapon’s grade resources and the technology needed to deliver a weapon. Consequently, the IAEA today is primarily responsible for monitoring the nuclear activities of non-nuclear weapon states to prevent the diversion of nuclear energy from peaceful purposes, i.e. medicine, electricity, and agriculture, to the development of nuclear weapons.

Atomic Energy Act of 1954

One year after President Eisenhower’s speech before the UN, the United States passed an amendment to the Atomic Energy Act of 1946. The Atomic Energy Act of 1954 was enacted

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108 Joseph P. Tomain, Nuclear Futures, 15 DUKE ENVTL. L. & POL’Y F. 221, 227 (Spring, 2005).
111 Cochran supra n.23 at 6.
112 Tomain supra n.108 at 227.
for the policy purpose of “promot[ing] world peace, improve[ing] general welfare . . . and strengthen[ing] free competition in private enterprise.”\textsuperscript{113} The Act allowed private enterprise to participate in nuclear science for the first time, and required civilian uses of nuclear materials and facilities to be licensed by the Nuclear Regulatory Commission (NRC).\textsuperscript{114} The Act also required that a bilateral nuclear cooperation agreement be negotiated before any NRC authorized nuclear technology was sold or exported to a foreign country.\textsuperscript{115}

**Price-Anderson Act of 1957**

The Atomic Energy Act alone was not enough to encourage private investment in nuclear power.\textsuperscript{116} With nuclear insurance unavailable and the potential liability of a nuclear accident nearly limitless, nuclear energy as a business investment simply was not attractive.\textsuperscript{117} In 1957, Congress responded to the misgivings of the energy industry with the Price-Anderson Act.\textsuperscript{118} The Price-Anderson Act effectively limited the amount of liability that a nuclear operator or manufacturer would incur in the event of an accident by establishing a government indemnification scheme.\textsuperscript{119} The following few years were dubbed “The Nuclear Bandwagon Market” by some scholars as dozens of new nuclear operators applied for construction


\textsuperscript{114} Id.


\textsuperscript{116} Tomain, *supra* n.108 at 227.

\textsuperscript{117} Id.


\textsuperscript{119} Tomain *supra* n.108 at 227.
permits.\textsuperscript{120} Although the Price-Anderson Act was temporary, it has been reauthorized every 10 years since its inception.\textsuperscript{121}

**Energy Reorganization Act of 1977**

Responding to the persistent effect of the Arab Oil Embargo of 1973-1974, the Energy Reorganization Act of 1977 amended the Energy Reorganization Act of 1974 to coordinate all the energy organizations of the federal government under the DOE, and to withdraw federal support of reprocessing spent nuclear fuel (SNF).\textsuperscript{122} The Carter Administration saw the reprocessing of SNF as a proliferation risk because it produced more weapons grade plutonium (only 10kg is needed to make a nuclear weapon) and hoped that if the U.S. took an anti-reprocessing stance other countries would follow suit.\textsuperscript{123} Few did.\textsuperscript{124}

**Energy Policy Act of 2005**

Once commercial nuclear power began to flourish, concern over proliferation resurfaced. In the 1970’s and 1980’s Congress passed a number of laws that imposed sanctions on countries that attempted to illegally acquire nuclear weapons;\textsuperscript{125} both the Arms Export Control Act and the Foreign Assistance Act contained such provisions.\textsuperscript{126} Then in 1987, Congress enacted the Nuclear Nonproliferation Act to strengthen the Atomic Energy Act’s limitation on nuclear

\textsuperscript{120} J. Samuel Walker, *Containing the Atom: Nuclear Regulation in a Changing Env’t, 1963-1971* ch. 2 (1992); Tomain *supra* n.108 at 227.

\textsuperscript{121} *Id.*


\textsuperscript{124} *Id.*

\textsuperscript{125} Behrens *supra* n.115.

exports.\textsuperscript{127} The Act required any country, except the five weapon states, who wished to import a nuclear technology to comply with all IAEA safeguards.\textsuperscript{128} For the next 13 years, the United States Congress remained relatively silent on both the issues of nuclear proliferation and energy in general until the passage of the Energy Policy Act of 2005.\textsuperscript{129} The Energy Policy Act of 2005 provided approximately $4.3 billion in stimulus for the nuclear industry and prohibited the sale, export, or transfer of nuclear materials and nuclear technology to any state that sponsors terrorism.\textsuperscript{130}

**Megatons to Megawatts Program**

Despite the United State’s efforts to prevent nuclear proliferation, today there are sixteen states with nuclear weapons, two states with alleged nuclear weapons programs, and one state with a dismantled nuclear program.\textsuperscript{131} Over 189 countries are party to the Nuclear Nonproliferation Treaty of 1968 (NPT), but the nuclear armed signatories include: the United Kingdom, the United States, France, Russia, and China.\textsuperscript{132} The NPT is commonly described as having three pillars: non-proliferation, disarmament, and the right to use nuclear technology for peaceful purposes.


\textsuperscript{128} Behrens supra n.115.


\textsuperscript{130} Id. at § 632.


peacefully. India, North Korea, Pakistan, and Israel are nuclear armed countries that are non-signatories to the NPT, but Israel has never publicly admitted to having nuclear weapons. South Africa dismantled its nuclear weapons program in the 1990s. Belgium, Germany, Italy, Netherlands, Turkey, Canada, and Greece are nuclear sharing states. The following countries have nuclear power reactors: the United States, France, Japan, Russia, Germany, South Korea, Ukraine, Canada, the United Kingdom, Sweden, China, Spain, Belgium, Taiwan, India, Czech Republic, Switzerland, Bulgaria, Finland, Slovakia, Brazil, South Africa, Hungry, Romania, Mexico, Lithuania, Argentina, Slovenia, the Netherlands, Pakistan, Armenia, and Iran.

Since 1994, the United States purchased Russian nuclear warheads to fuel U.S. nuclear reactors through a commercially financed partnership called “Megatons to Megawatts.” Acting as executive agent for Russia, Techsnabexport (TENEX) Inc. recycles Russian warheads by converting them into low enriched uranium (LEU) and then shipping the LEU to the United States. The executive agent for the U.S., USEC Inc., purchases the fuel, markets it to USEC’s utility customers, and sells TENEX an equal quantity of un-enriched uranium for use in Russia’s nuclear reactors. This program has eliminated over 20,000 nuclear warheads since its inception, and has provided electrical fuel for one in every ten American homes.

133 Id.
134 Norris supra n.131.
139 Id.
140 Id.
141 Id.
Cultural Perceptions of Risk and Fear

Different cultures often have different perceptions of risk and fear. Consider health risks for example: most Americans like ice in their soft drinks, but many Germans believe putting ice in a soft drink is unhealthy. Likewise people often have differing perceptions of separate aspects of related risks even within the same culture. For instance, the French public is highly accepting of nuclear power and its potential for collateral risks. Seventy-five percent of French electricity is generated from nuclear power plants. Yet, when it came time to develop a nuclear waste facility, large demonstrations and riots erupted all over France.

Differences in cultural perceptions of risk and fear can often be explained by: (1) familiarity with positive or negative paradigms, (2) social influence and group polarization, (3) media preoccupation, and (4) actual differences in risk among cultural groups. Studies show that the U.S. public’s attitude toward nuclear energy are formed almost entirely by their own perception of the technology, rather than by politics or by demographics such as income, education, and gender – but, the media may play a role in influencing many American’s perception of nuclear technology.

145 Id.
146 Id.
147 Sunstein supra n.142 at 75-100.
148 Eric S. Beckjord et. al., ISBN 0-615-12420-8, The Future of Nuclear Power: An Interdisciplinary MIT Study, 6 (Mass. Inst. of Tech, 2003); Peter Houts, Paul D. Cleary, and Teh-Wei Hu, Teh-Wei Hu, Penn. State Univ. Studies No. 49, THE THREE MILE ISLAND CRISIS: PSYCHOLOGICAL, SOC., AND ECON. IMPACTS ON THE SURROUNDING POPULATION, 84-85 (The Penn. State Univ. Press, 1988) (showing that the majority of TMI evacuees based their decision to evacuate on media coverage, but that the evacuees perception of the quality of media coverage was dependant upon their pre-evacuation perception of the TMI nuclear power plant).
The Effects of Three Mile Island and Chernobyl

The morning of March 28, 1979, a series of mechanical and judgmental errors caused the protective blanket of water surrounding reactor core #2 at Three Mile Island (TMI), Pennsylvania to leak. Believing the problem to be minor, Metropolitan Edison, the plant’s operator, announced that there was no danger to the public. By the end of the next day, two-thirds of the reactor’s water had escaped and part of the core melted. Two days later, a high radiation reading was recorded above the vent stack. Responding to the possibility of public health consequences, the chairman of the NRC recommended: (1) the evacuation of pregnant women and preschool children within five miles of TMI, (2) local school closings, and (3) that citizens within 10 miles stay indoors.

What followed can only be described as something short of hysteria. Local towns ran warning sirens. Some people left messages on their homes believing they would never return. The media covered the event nonstop focusing on the “undeterminable amount of radiation released,” and the possibility of a hydrogen bubble causing a nuclear explosion. More than 140,000 people (about twelve times the NRC’s suggestion) left their homes. The public outcry that followed the TMI crisis nearly forced the General Public Utility (the parent company of the plant’s operator) into bankruptcy. As a result, the only new nuclear power

\[\text{References:}\]

149 Houts supra n.148 at ix.
150 Id.
151 Id.
152 Id. at 3.
153 Id.
154 Id.
155 Id. at 3.
156 Id. at 5.
157 Id. at x.
plant to be completed after TMI, was ultimately shut down before generating its first watt of electricity due to persistent protesting.159

On April 26, 1986, a flawed reactor design coupled with operator error caused Unit 4 of the Chernobyl nuclear power plant in the Union of Soviet Socialist Republics (USSR, present day Ukraine) to explode, rupturing the reactor’s containment vessel.160 The subsequent fire burned for ten days afterwards emitting large amounts of radioactive material such as Iodine-131 and Caesium-137 into the environment.161 Compared to other nuclear events, the Chernobyl accident released 400 times more radioactive pollution than the bomb dropped on Hiroshima, and about 600 times less pollution that the sum radiation released from world-wide nuclear testing in the 50s and 60s.162

Following the accident over 600,000 “liquidators” took part in the recovery effort, and approximately 336,000 people were relocated.163 Because Chernobyl was located in a dense forest, however, 90 percent of the fallout was filtered by the forest and concentrated in the leaf

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158 TMI caused no deaths or injuries, and no significant environmental effects other than the minimal amount of radioactive gas released. Id; Eric R. Pogue, The Catastrophe Model of Risk Regulation and the Regulatory Legacy of Three Mile Island and Love Canal, 15 Penn St. Envtl. L. Rev. 463, 470 (Spring, 2007); The Rep. of the President's Comm’n on the Accident at Three Mile Island, The Need for Change: The Legacy of TMI, at 13 (Oct. 1979).


161 Id.

162 Id.


164 Kinley supra n.160.
litter.\textsuperscript{164} Thirty-nine short-term deaths were caused within a few months of the accident.\textsuperscript{165} Of 4,000 children who developed thyroid cancer from radiation exposure, 15 have died.\textsuperscript{166}

Although the international scientific consensus estimates that as many as 100,000 fatal cancers may be expected when the exposed population nears old age, the estimate is only slightly above the expectation for an unexposed population; leading some to believe that the Chernobyl studies are inconclusive.\textsuperscript{167} In contrast to the TMI accident, the Ukraine government supported the relocation of 336,000 people rather than just the portion of the population with the highest risk such as preschool aged children.\textsuperscript{168} Other governments might have considered the adverse effects of public exposure to low level radiation outweighed by the psychological, sociological, and economic impact of relocating 336,000 people.\textsuperscript{169} On the other hand, it is quite possible that the risk faced by TMI residents was significantly different than the risks faced by the Ukrainian residents. Clearly, the Soviet nuclear operators were less trained than their American counterparts, and Chernobyl Unit 4 was not the only reactor at the Chernobyl site.\textsuperscript{170}

The Chernobyl and TMI accidents incited a passionate group of anti-nuclear protestors who were instrumental in causing the shut down of: the Shoreham, Yankee Rowe, Millstone I, Rancho Seco, Maine Yankee, and about a dozen other nuclear power plants in the United

\textsuperscript{165} Kinley \textit{supra} n.160 at 14.
\textsuperscript{166} Id. at 16.
\textsuperscript{167} Id; World Nuclear Assoc., \textit{Chernobyl Myths and Reality} http://www.world-nuclear.org/why/chernobyl.html (last visited April 1, 2009).
\textsuperscript{168} Houts \textit{supra} n.149.
\textsuperscript{169} Sunstein \textit{supra} n.142 at 83.
\textsuperscript{170} World Nuclear Assoc., Chernobyl Accident, http://www.world-nuclear.org/info/chernobyl/inf07.html (last visited April 1, 2009).
States. By the mid 90s, the number of nuclear engineering programs in the United States dropped from over 47 to less than 25. But the Chernobyl and TMI accidents also spurred an unexpected cooperation between the United States and Russia. By 1989, over 1,000 Soviet nuclear engineers had traveled to the United States to compare nuclear safety programs and share information and experience. As a result, both Russian and American nuclear operators have improved their safety standards and operational/maintenance efficiency – significantly lowering the operating costs of nuclear power.

**The Effect of Pop Culture and Early Childhood Education**

Responding to the growing concerns of the cold war era, Congress enacted the Federal Civil Defense Act of 1950 to fund projects for the protection of the public from atomic attack. Although building fallout shelters for the entire public proved uneconomical, the Civil Defense Administration invested in civil education programs that printed pamphlets teaching people how to build their own fallout shelters, instituted warning systems, and taught children how to respond to atomic attacks.

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173 *Id.*


175 *Id.*

176 *Id.*


The Civil Defense Administration also invested heavily in pop culture, underwriting films and novels such as 1951 film by archer productions: *Duck and Cover*.\(^{179}\) Duck and Cover featured an animated turtle that taught children how to duck under their desk or go inside at the first sign of an explosion.\(^{180}\) Although the Civil Defense Administration was eventually succeeded by the Federal Emergency Management Agency and Homeland Security, the Department of Defense continued funding pop culture projects even after the dissolution of the Civil Defense Administration.\(^{181}\) As it turned out, nuclear fiction was a best-seller even without government support. Today, Americans still celebrate many of these pop culture icons such as *Captain Atom* (a comic book superhero who gained his power from a nuclear explosion) and the 1985 edition of *Superman* (in which the “man of steel” had a nightmare about being the only survivor of a nuclear “holocaust”).\(^{182}\) Chernobyl and Three Mile Island also inspired a genre of pop culture novels that featured accidents involving nuclear reactors, civilian laboratories, and nuclear power plant waste such as: Jerry Earl Brown’s *Under the City of Angels*, and Jack Womack’s *Ambient*.\(^{183}\) But is it possible that these government sponsored programs and pop culture fixations may have had a perverse effect on an entire generation’s perception of nuclear power? America’s trouble with nuclear waste policy may suggest that it did.


\(^{180}\) Id.


Nuclear Waste

The Nuclear Waste Policy Act

Enacted in 1982, the Nuclear Waste Policy Act (NWPA) required the DOE to identify a list of suitable sites for two geological repositories, (one in the Eastern U.S., and one in the western U.S.) and establish the criteria for their selection.\(^{184}\) The capacity of the first repository was limited to 70,000 metric tons of heavy metal (MTHM); 63,000 MTHM for civilian SNF and 7,000 MTHM for defense related waste.

The act required the DOE to begin accepting SNF by Jan. 31, 1998.\(^{185}\) Once the site was chosen, the DOE would have the responsibility to construct and close the repository. The NRC was given responsibility to oversee the licensing process.\(^{186}\) The repositories would be paid for out of the Nuclear Waste Fund which required all commercial nuclear generators to pay 1/10 (one mil) of a cent for every kilowatt-hour of nuclear energy used (approximately $572 million a year), and a one time fee for expenses incurred prior to the fund’s establishment.\(^{187}\)

In 1986, three sites were approved for site characterization by the President: Deaf Smith County, Texas; Hanford, Washington; and Yucca Mountain, Nevada.\(^{188}\) Unbeknownst to many, however, the Hanford site was secretly contaminated – the full extent of which would not be unclassified for many years.\(^{189}\) The Texas site was also laden with problems: it had the greatest


\(^{185}\) Mullet supra n.184 at 399.

\(^{186}\) 42 U.S.C. §§ 10141(b), 10191(2) (2000).


\(^{188}\) 51 C.F.R. 19783 (June 2, 1986); *Nevada v. Herrington*, 827 F.2d 1394, 1397 (9th Cir. 1987).

potential for human harm due to the nearest population center being located directly downwind from the repository; it was located in a salt formation which would advance the degradation of the waste packages and prevent their removal once inserted; and all of the land had to be purchased or acquired via eminent domain.\textsuperscript{190} Yucca Mountain, on the other hand, was strongly favored by the DOE which initially started studying Yucca Mountain in 1977 just one week after the department’s organization.\textsuperscript{191}

In 1987, Congress passed the Nuclear Waste Policy Act Amendment (NWPAA) which effectively eliminated the DOE’s authority to build a second repository and by-passed the site selection process for the first repository by allowing the Secretary of Energy to proceed with the site characterization of Yucca Mountain.\textsuperscript{192} Thus although, the NWPAA did much to advance the construction of a repository, it also left no clear alternative short of a Congressional action in the event of failure.

Thirty-two years of research and $10 billion later, scientists discovered that the Yucca Mountain area may have been damaged from nuclear testing during WWII, and is therefore scientifically less suitable as a repository location than originally believed.\textsuperscript{193} As a result, the


\textsuperscript{193} J. Fairley, E. Sonnenthal, Preliminary Conceptual Model of Flow Pathways Based on Cl-36 and Other Envl. Isotopes, in Unsaturated Zone Model, at 399 (G.S. Bodvarsson & T.M. Bandurraga eds., 1996); see G.S. Bodvarsson, T.M. Bandurraga, Dev. and Calibration of the Three-Dimensional Site-Scale Unsaturated Zone Model of Yucca Mountain, Nev., at 265 (1996).
progress of the project was significantly delayed by litigation over the Environmental Protection Agency’s (EPA) safety standards for Yucca Mountain.\textsuperscript{194} A number of states chose to take issue with the EPA’s “25 millirem for 10,000 year”\textsuperscript{195} rule claiming the DOE needed to show safe radiation levels beyond 10,000 years – even though regulating that far into the future is somewhat unreasonable.\textsuperscript{196} Today, the EPA divides the safety rule into two time frames: 15 millirems for the first 10,000 years; and 350 millirems for the next 990,000 years.\textsuperscript{197} The irony of the Yucca Mountain safety litigation, however, is that scientists predict radiation exposure from the site to be less than 1 millirem a year for the next million years.\textsuperscript{198}

With nowhere to put the SNF, the January 31, 1998 deadline passed, and the DOE began incurring liabilities at a rate of several hundred million dollars a year for failing to take title to the waste.\textsuperscript{199} Yet even in the face of increasing controversy and reduced funding, the DOE managed to file an application for a construction license in 2008. Even if the project is granted a construction license and funded by Congress, however, the earliest construction could begin is 2013.\textsuperscript{200}

\textsuperscript{194} Natural Res. Def. Council, Inc. v. EPA, 824 F.2d 1258, 1263 (1st Cir. 1987); Nuclear Energy Inst., Inc. v. EPA, 373 F.3d 1251, 1266 (D.C. Cir. 2004).
\textsuperscript{195} Millirems per year as used by the EPA measures the average annual public exposure to radiation from Yucca Mountain. In comparison, a person is exposed to 1 millirem of radiation by watching 3 hours of color television a day for a year; and smoking just one cigarette a day/year exposes a person to approximately 36 millirems. Office of Civilian Radioactive Waste Mgmt., Dep’t of Energy, DOE/YMP-062, \textit{The Nat’l Repository at Yucca Mountain: Solving a Nat’l Problem Now} (Las Vegas, Nev., July 2008) (available at http://www.ocrwm.doe.gov).
\textsuperscript{196} 824 F.2d 1258 (1st Cir. 1987).
\textsuperscript{197} 40 C.F.R. 197.
Rate of Nuclear Waste Accumulation

Because no repository for permanent SNF disposal exists, more than 58,000 metric tons of heavy metal (MTHM) commercial SNF and 12,800 MTHM of defense related SNF is being “temporarily” stored at 126 commercial power plants and DOE storage sites across the nation.\footnote{Office of Civilian Radioactive Waste Mgmt., Dept. of Energy, The Rep. to the President and the Cong. by the Sec’y of Energy on the Need for a Second Repository, DOE/RW-0595, at 1 (December 2008) (available at http://www.rw doe.gov/info_library/program_docs/Second_Repository_Rpt_120908.pdf) [hereinafter Need for Second Repository]; Amanda Leiter, The Perils of a Half-Built Bridge: Risk Perception, Shifting Majorities, and the Nuclear Power Debate, 35 ECOLOGY L.Q. 31, 61 (2008).} If no new power plants are built, 130,000 MTHM of commercial SNF will need a disposal plan by the time the licenses of all currently operating nuclear power plants expire.\footnote{Id.} Deployment of enough new nuclear reactors in the United States to displace one U.S. carbon dioxide wedge would generate enough SNF to require another “Yucca Mountain” every 12 years.\footnote{Leiter supra n.201.} As a result, in 2008 the DOE discretely modified the cost of its Civilian Radioactive Waste Management program to include the funding necessary to increase Yucca Mountain’s storage capacity from 70,000 MTHM to 122,100 MTHM.\footnote{Office of Civilian Radioactive Waste Mgmt., Dep’t of Energy, DOE/RW-0591, Analysis of the Total Sys. Life Cycle Cost of the Civilian Radioactive Waste Mgmt. Program: Fiscal Year 2007, v (July 2008).}

Meanwhile, the DOE’s liability to nuclear waste generators for breaching its Standard Disposal Contracts is nearing $7 billion.\footnote{Letter from Sec’y of Energy, U.S. Dep’t of Energy, to Richard B. Cheney, Pres. of the Senate (March 6, 2007) (available at http://www.ocrwm doe.gov/info_library/newsroom/documents/2007bill.pdf); see 10 C.F.R. § 961.11 (1983) (standard contract provisions).} This amount is expected to grow by several hundred million each year the construction of a repository is delayed.\footnote{Id.} Yet, after twenty-nine years of research, the federal government may be attempting a change of direction.\footnote{Id.} In March 2009, the Obama Administration proposed a federal budget plan that eliminated all funding for Yucca
Mountain, except what is needed to answer inquiries from the Nuclear Regulatory Commission, "while the Administration devises a new strategy toward nuclear waste disposal." Although such an action will delay progress at Yucca Mountain, unless the NWPA is repealed or amended, it is not likely that the project will be completely terminated. Still, with Yucca Mountain’s construction further delayed and nuclear generators running out of on-site interim storage space, the NRC may choose not to issue any new operating licenses until there is a clear path for the disposal of the new fleet’s SNF.

The Effect of CO₂ Permit Price Changes (In three stages)

Stage 1: The initial effects of CO₂ permit prices

Once a carbon tax is initiated, utilities are likely to look toward natural gas as a least cost and less risk alternative to coal. Initially, electric prices are not expected to substantially increase since fairly cheap natural gas plants can quickly replace coal fired plants. But, since natural gas production in the United States has already peaked, the price volatile nature of natural gas would likely make nuclear power plants price competitive by 2030. Although LNG imports are an option, LNG is costlier and produces more GHGs than regular natural gas.


209 Conti supra n.27 at Mkt. Trends, 73; Gulf Coast Power Assoc. supra n.9.

210 ANNUAL ENERGY OUTLOOK 2009 supra n. 27 at Electricity Projections, 72.

211 Id.

Generally, a LNG plant would produce about half the carbon of a coal fired plant, but the combustion and processing required to transport LNG adds another 20 - 40% to GHG emissions.213

Once increased demand makes natural gas less competitive, future plant construction decisions will largely depend on expectations of interest rates, material availability, and CO₂ market trading rates.214 Clean coal, nuclear, and renewable technologies are capital intensive and are sensitive to interest rates and cost-recovery periods.215 In fact, capital expenditures make up the vast majority of a nuclear reactor’s costs.216 Nuclear power plants have a cost-recovery period of 40 to 60 years which is significantly longer than other types of plants, and unlike fossil fuel plants, fuel costs of a nuclear power plant are nominal.217 Because a nuclear power plant has high capital costs, nuclear plants are designed to have larger generating capacities and longer operating lives than other types of power plants, (except some hydroelectric plants like the Hoover Dam).218

**Cost structure comparison of Nuclear Energy**

Assuming that the problem with radioactive waste does not become inhibitive of nuclear power’s expansion, modern studies indicate that nuclear power could compete with coal at a
carbon tax rate of $15-$20 per metric ton. Likewise, nuclear power can compete with natural gas at a carbon tax greater than $30. If the carbon tax rate rises higher than $45 per metric ton, nuclear power would be competitive with all other types of power, even without Energy Policy Act incentives. Because no modern nuclear power plants have yet been built in the United States, it is still possible that regulatory delays could increase plant construction costs despite Japan’s proven ability to timely construct these modular plants.

Earlier studies that did not include nuclear power’s recent advances in operating and construction efficiency, however, indicated that it would take a carbon tax of $50-$100 per metric ton to make nuclear power competitive with other types of power.

A few practical matters make investing in nuclear power plants somewhat more difficult. Nuclear power plants take decades to plan and construct. Since the early 60s and 70s, the economy of the United States has changed drastically. The United States no longer has the domestic industry necessary to produce the larger steel components of a nuclear power plant, and would have to rely on Japan Steel Works Ltd. to make the primary containment vessel (the structure that prevents radiation from leaking into the atmosphere). Japanese Steel Works is the only steel plant in the world that is large enough to make nuclear reactor vessels. The

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219 Parker supra n.66 at CRS-22;
220 Parker supra n.66 at CRS-22.
221 A CBO STUDY supra n.45 at Ch. 1, 2.
223 Cochran supra n.23 at 11.
225 Yoshifumi Takemoto and Alan Katz, Samurai-Sword Maker’s Reactor Monopoly May Cool Nuclear Revival, BLOOMBERG NEWS (March 12, 008) http://bloomberg.com/apps/news?pid=20601109&sid=aaVMzCTMz3ms&refer=home; A CBO STUDY supra n.45 at Ch. 3, 30.
226 Id.
company can fabricate four containment vessels per year, and already has a world-wide waiting list.\textsuperscript{227}

**Stage 2: The effects of government policy**

Assuming that the nuclear industry becomes price competitive and it overcomes the practical obstacles of building enough new nuclear plants to keep up with or exceed the retiring fleet, how will fluctuating permit prices affect the nuclear industry? If government emission restrictions progress faster than renewable fuel and CCS technology, nuclear power will be most attractive power source in the “dirtiest” air pollution zones. Utility investment choices will largely depend on the investor’s faith in continued government support of renewable technologies.\textsuperscript{228}

Supposing technology advances faster than government GHG restrictions, nuclear power’s continued feasibility will depend on the magnitude of the technological advancement.\textsuperscript{229} If the magnitude of technological advancement is less than the shift in electrical demand, prices will continue to increase and nuclear power will remain competitive.\textsuperscript{230} But, where the magnitude of the technological advancement is greater than the increase in demand, the technologically advanced renewable source or CCS technology will become more attractive than nuclear power.\textsuperscript{231} This scenario begs the question: is investing in long term nuclear power

\begin{itemize}
\item \textsuperscript{227} Id.
\item \textsuperscript{229} See R. Larry Reynolds, Demand and Supply in a Mkt. Sys., Basic Microeconomics Outline, Part II, Ch. 8, 1-4 (Jan. 2007) (available at http://www.idbsu.edu/econ/lreyhol/web/PDF/short_8_Dem_supp.pdf) (discussing the difference between a change in quantity demanded and a shift in the demand or supply curve).
\item \textsuperscript{230} Id. at 4-12 (showing how supply shifts due to technological advancement, and how demand shifts due to population increases).
\item \textsuperscript{231} Id.
\end{itemize}
projects worth the risk? Clearly government policy, can and probably will “manipulate” the “free” market. If the government primarily uses a carbon cap to incentivize renewable fuel technologies rather than just lower carbon dioxide emissions, nuclear power may be too risky an investment.

**Stage 3: Falling Permit Prices**

Assuming that a cap and trade system is successful in lowering carbon emissions, eventually the market price of a carbon permit will begin to fall and level off.²³² The idea is that the energy industry will be frozen in time with whatever technologies are currently working until the population grows enough to make energy research lucrative once more.²³³ This is largely because the marginal abatement cost increases when electrical prices increase faster than it decreases when electrical prices fall.²³⁴ With a cap and trade system still looming on the horizon, no one can be sure exactly how the system will be implemented. Since permits would be marketable, taxing permit sales may become irresistibly attractive.²³⁵

Although the United States generally abstains from double taxation, there is no guarantee that a cap and trade system will not tax the “tax.”²³⁶ Double taxation would create a significant monetary incentive to interfere with falling permit prices by prematurely and continually reducing the emission cap. Can a responsively sluggish nuclear power industry with its decade long planning process, high capital costs, and long term capital recovery periods survive in this

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²³² *Id.* at 2-4.


²³⁴ *Id.*


²³⁶ *Id.*
type of energy market? Presuming that nuclear energy is still attractive in a fluctuating market, will reviving nuclear energy just delay the inevitable? If the nuclear power industry were expanded by one U.S. wedge, the U.S. would only have enough known uranium resources to last 35 to 58 years.\textsuperscript{237} This time frame could be extended should the U.S. adopt recycling, find new uranium sources, or expand the nuclear industry less than one wedge.\textsuperscript{238} Still, these types of unanswered questions may negatively influence an investor’s willingness to engage in nuclear ventures.

**Smart Grid Technology**

**What is Smart-Grid?**

Smart-Grid Technology is a package of technologies some new and some dating back to the beginning of electrification which seek to alter the traditional centralized grid system to make the electrical grid more secure, reliable, intelligent, distributed, and environmentally friendly.\textsuperscript{239}

The Energy Independence and Security Act of 2007 defines Smart-Grid technology as:

An advanced system that includes: (1) increased use of information controls; (2) optimization of grid operations and resources; (3) use of distributed resources and renewable energy; (4) development and integration of demand response, demand-side resources, energy-efficiency resources, smart appliances, advanced electricity storage, peak-shaving technologies,\textsuperscript{240} smart metering, advanced communications, and distribution.

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\textsuperscript{238} See Grant supra n.237.


\textsuperscript{240} Peak shaving involves boosting the natural gas (or other fuel) with additives to help stretch the fuel when prices are high. A popular shaving mixture contains 75% natural gas and 25% propane/air. Although peak shaving reduces costs, it can also increase pollution when used in a regular “manual fixed setting” type of plant. In order to prevent this increase in pollution, modern peak shaving technology requires a computer driven modification of the plant to make sure valve settings match the density of the fuel used. See SECO/Warwick Corp., *Atmosphere Maint. Tips: Problems Caused by Peak Shaving*, METAL MINUTES HEAT PROCESSING NEWS (2008) http://www.secowarwick.com/metalminutes/maintenancetips/peakshaving.htm (last visited May 1, 2009).
automation; (5) transfer of information to consumers in a timely manner to allow for personalized control decisions; and (6) development of standards for the communication and interoperability of appliances and equipment connected to the electric grid.  

Most Smart-Grid systems incorporate decentralized generating substations run by independent processors but linked into a “plug-and-play” type grid – much like the internet.  

The benefits of this type of system are diverse. By making the grid accessible, alternative and renewable fuel sources like wind turbines and solar power which are more economical on smaller scales can contribute to energy production. Traditional power plants that produce heat as a by-product can use the heat for industrial purposes rather than discharging it into the atmosphere. A more “intelligent” grid means access to information that can be used to increase efficient electrical use. Smart meters give consumers up to the minute electrical prices helping them make informed financial and conservation decisions, while helping electrical generators make better decisions about when to generate more electricity and which fuel source to use. Additionally, a smart-grid system with smart meters would automatically identify a problem and “heal” itself in the event of an electrical outage, preventing blackouts and decreasing the number of electricians needed on the ground in a given area.  

Currently, conventional power plants generate electricity in large centralized facilities transporting the energy long distances in order to take advantage of economical, geological, 

242 Id.  
243 Fred Bosselman, Joel B. Eisen, Jim Rossi, David B. Spence, and Jacqueline Weaver, ENERGY, ECON. AND THE ENV’T: CASES AND MATERIALS 2ND ED., Ch.13, 1067 (Foundation Press, 2006).  
244 Id. at 1066.  
246 Id.  
geographical, and human health benefits.\textsuperscript{248} Today, many industrial and commercial buildings already own microturbines to generate electricity in the event of a power shortage.\textsuperscript{249} Microturbines can come in the form of small scale traditional reciprocating generators, fuel cells, photovoltaics,\textsuperscript{250} micro-wind turbines, and other renewable generators.\textsuperscript{251} This generating potential is rarely utilized because independent operators cannot “plug” into the grid causing them to choose either the centralized grid or their own back-up generators. But in many cases, commercial buildings can use renewable energy sources and save money through the Smart-Grid system without loosing the dependability of the supergrid.\textsuperscript{252}

Smart-grid technology would enable commercial, industrial, and other microturbine operators to generate their own electricity to use or store lowering their electrical demand on the grid.\textsuperscript{253} On-site generation prevents heat waste and lowers energy consumption.\textsuperscript{254} If utility electric prices rose higher than their own cost of generating electricity, microturbine operators could even sell their electricity over the grid, making a profit and reducing the overall cost of electricity. Thus, distributed generation can help the electrical industry cope with the growing demand of the commercial sector and its associated growth in carbon emissions.\textsuperscript{255}

\textsuperscript{248} Bosselman \textit{supra} n.243 at 1066.
\textsuperscript{249} \textit{Id.}
\textsuperscript{250} Photovoltaics refer to a field of semiconductor technology involving the direct conversion of electromagnetic radiation as sunlight, into electricity. Photovoltaics differ from traditional solar technology because it directly converts solar energy into an electrical current rather than into thermal energy. Random House Inc., \textit{Photovoltaics}, \textsc{Dictionary.com Unabridged} V.1.1 (May 4, 2009) http://dictionary1.classic.reference.com/browse/Photovoltaics.
\textsuperscript{253} \textit{Id.} at 9.
\textsuperscript{254} Bosselman \textit{supra} n.38 at 1066.
\textsuperscript{255} \textit{Id.} at 9, 10.
Governmental support for Smart Grids & DER

Although Smart-Grids may seem futuristic, many Smart-Grids utilizing a variety of the benefits aforementioned are currently under construction across the United States. Both the Energy Policy Act of 2005 and the American Recovery and Reinvestment Act of 2009 provided incentives for Smart-Grid Technology. The Energy Policy Act of 2005 made tax energy credits available for businesses that operate microturbines and other renewable energy sources. The American Recovery and Reinvestment Act of 2009 allotted $11 billion for Smart-Grid Technology, $6.3 billion for state and local governments to invest in energy efficiency, $6 million in federal loan guarantees for renewable energy and electric transmission technologies, $4.5 billion for the Office of Electricity and Energy Reliability to modernize its grid as a Smart-Grid, $4.5 billion for state and federal government buildings to increase energy efficiency, $3.5 million for the Western Area Power Administration to upgrade its power transmission system, $2.5 billion for energy efficiency research, $3.2 billion for energy conservation grants, $300 million to buy energy efficient appliances, $250 million to increase energy efficiency in low income housing.

Smart-Grid technology is not just limited to the United States, either. Saudi Arabia is already building a series of co-generation plants throughout the Kingdom in order to reduce domestic drain on the national grid and preserve petroleum reserves for international trade. The Saudis are also taking steps to interconnect the Saudi Arabia power grids with Kuwait,

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256 Danny Bardbury, Houston prepares for $640m smart grid blast off: Project to roll out smart meters capable of providing energy use data four times an hour moves forward, BUS. GREEN (Feb. 4, 2009).
Bahrain, and Qatar by 2009.\textsuperscript{260} The government of Ontario, Canada passed the \textit{Energy Conservation Responsibility Act} in 2006 which requires the installation of smart meters on all Ontario businesses by 2010.\textsuperscript{261} China will have its broadband enabled Smart-Grid running by 2012.\textsuperscript{262} Similarly, the EU began working on its Smart-Grid in 2005 but doesn’t expect to complete the grid until after 2020.\textsuperscript{263}

Clearly, the current trend is supportive of Smart-Grid Technology, but is nuclear power incompatible with Smart-Grid? Nuclear power manages its high capital cost structure via economies of scale.\textsuperscript{264} In fact, nuclear power generators often provide power for more than one state. In the technical sense, nuclear power can transmit electricity across a smart-grid just like any other electric provider. Whether or not nuclear power will thrive under a smart-grid infrastructure, however, is questionable. Alternative renewable fuel technologies like photovoltaics and micro-wind turbines are more efficient when operated on smaller scale. Thus, at the very least, alternative renewable fuel technologies will become more attractive as the smart-grid enables smaller plants to “plug in.” Because many states now require the state energy portfolio to include the use of clean renewable fuels, (which usually exclude nuclear energy as a clean renewable fuel source) sizable incentives are available for these technologies from both the state and federal governments.\textsuperscript{265} Assuming nuclear energy does become competitive under a

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\textsuperscript{260} \textit{Id.}
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\textsuperscript{264} See Whitfield \textit{supra} n.217.
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carbon tax, it remains unclear whether or not nuclear energy could remain competitive as renewable technologies begin to gain access to local markets.

**Conclusion**

The United States is closer than ever before to implementing a cap and trade system in the very near future. Although the price of the carbon permits will have a lot to do with energy generation decisions, most electric generators will almost certainly move to natural gas as an alternative to coal powered electrical plants in the short run. As natural gas becomes scarcer, high capital sources of low emission energy generation like nuclear and wind power may become more attractive. Four effects might prevent or inhibit the spread of nuclear power as a wedge to reduce carbon emissions.

First, if cultural perceptions of nuclear risk have been adversely affected by early childhood education and pop culture, Americans may view any nuclear expansion as unduly risky – even if nuclear power is the most feasible and efficient way to reduce carbon emissions. Without public support, or at least public indifference, nuclear expansion may be impossible.

Second, trends in the U.S.’s nuclear waste disposal policy may inhibit nuclear expansion. Yucca Mountain is going nowhere fast and will already be at capacity if it is ever built. In the meantime, new nuclear power plants will have to plan on keeping all of their SNF on site, probably in dry cask storage yards. At a minimum, the problem with nuclear waste will cause extra disposal costs for nuclear generators. At worst, the NRC may not license any more nuclear power plants until there is a clear path for the permanent disposal of the new fleet’s SNF.

Third, a marketable cap and trade system almost certainly means electric prices will significantly fluctuate over the next 50 to 60 years – possibly in three distinct stages. Fluctuating prices could have a negative impact on investors’ willingness to engage in nuclear ventures. In
fact, a less favorable scenario could predict a sudden surge of interest in nuclear power plants followed by a series of systematic plant closings, similar to the 80s, as nuclear power ceases to be competitive in the long run.

Finally, the advent of Smart-Grid Technology may impede a nuclear power plant’s ability to utilize the plant’s economies of scale to recoup its high capital expenditures. Even if Smart-Grid has no direct effect on nuclear power, it will certainly make renewable energy sources such as wind power and photovoltaics more attractive as a competitor by enabling them to take advantage of their own mid-sized returns to scale.

Thus, although the arrival of a carbon cap and trade system has encouraged many debates about the potential role of nuclear power in reducing GHGs, decision makers should not be overly confident in the future of nuclear power. A complete resurrection of nuclear power may be as imprudent as allowing nuclear power to fizzle out too quickly. Indeed, the economic and environmental wellbeing of this country and the rest of the world will largely depend on the manner in which we approach energy policy decisions.