

Economic Barriers to the Expansion of Nuclear Power in the United States

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Abstract

The Nuclear Regulatory Commission (NRC) is gearing up for a surge in new nuclear power plant applications for the first time in thirty years. Although a new nuclear power plant has not been built in the U.S. in twenty years, concerns about climate change and an increased interest in energy security have put nuclear power back on the table as a technically viable energy option that can provide base load power without emitting carbon dioxide. However, the history of nuclear technology in the U.S. and lower electricity costs from fossil fuels do not allow nuclear power to be competitive on its own. This situation and the capital costs involved in building a nuclear power plant create tremendous economic barriers for the industry.

Through an examination of economic barriers, this project attempts to determine whether or not new nuclear power plants can be built in the United States. If they can, what are the key indicators that this is so? If not, what policies could possibly reverse this outcome? The methods to answer these questions include a literature review, personal interviews with NRC employees, and a policy analysis. The analysis section focuses on how current and prospective legislation could address barriers to a nuclear expansion.

The results indicate that the competitiveness of nuclear power will be addressed by Production Tax Credits the 2005 Energy Policy Act for the first 5 or 6 plants that are approved by the NRC. Carbon-limiting legislation will assist a nuclear expansion beyond this initial build. An international bottleneck for nuclear-grade materials will slow a nuclear expansion; however, it is likely that the nuclear-grade manufacturing industry will expand. Ultimately, the most significant barrier to a nuclear expansion in the U.S. is the storage of high-level nuclear waste. Yucca Mountain has been embroiled in political controversy since 1982, and the nation's nuclear waste continues to accumulate on-site at 104 operating reactors across the country. Absent technical solutions like reprocessing or the opening of a geologic repository, moving forward with a significant expansion of the commercial nuclear power sector in the U.S. will be difficult.

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I. Introduction

The Nuclear Regulatory Commission (NRC) is gearing up for a surge in new nuclear power plant applications for the first time in thirty years. Construction on a nuclear power plant in the United States has not occurred in twenty years. The reasons behind the potential revival include national concerns about energy security, increasing energy demand from both developed and developing countries, and global climate change. As an established technology with the ability to provide base load power without emitting carbon dioxide, nuclear power is a technically viable energy option. However, in order for nuclear power plants to actually get off the ground, there are economic barriers the industry must overcome.

The history of nuclear technology in the U.S., the accident at Three Mile Island in 1979, the requirements for its regulation, and lower average electricity costs from traditional fossil fuel technologies such as coal and natural gas, do not allow nuclear power to be competitive on its own (Nivola 2004). This initial situation, combined with the enormous capital costs and financial risks involved in building a new power plant, create tremendous obstacles for utilities interested in building new plants. The federal government has moved to counteract these impediments with strong incentives for building new nuclear power plants in the Energy Policy Act of 2005; incentives include tax credits, loan guarantees, and regulatory delay compensation (Holt and Glover 2006).

Even with the federal subsidy, a nuclear revival in the U.S. will not happen easily. There are economic barriers that cannot be entirely overcome with the government subsidies in the Energy Bill references above. This paper examines primary barriers that have existed since the beginning of the industry like cost competitiveness with coal and gas and a risk-aversion among utilities to invest in nuclear. This paper also examines secondary economic barriers that have

arisen in the last five years, since talk of a nuclear revival has gained momentum. The secondary barriers that will be examined are: labor shortages, shortages of nuclear-grade materials, uranium supply, and waste disposal. While the highest barrier to a new nuclear plant is the enormous upfront capital costs, this problem is not confined to the nuclear industry and it has been overcome in the past.

Through an examination of primary and secondary economic barriers, this project attempts to determine whether or not, after thirty years of no new entry, nuclear power plants can be built in the United States. If they can, what are the key indicators that this is so? If not, what policies could possibly reverse this outcome? The analysis section focuses on how current and prospective legislation could address the economic barriers to a nuclear expansion. Ultimately, a significant nuclear expansion in the U.S. will likely be stalled by the most significant barrier, the storage of high-level nuclear waste.

II. Previous Research

Most recent literature on the economics of nuclear power and the future of the industry in the United States focuses on capital costs and the influence of a carbon tax or similar carbon-capping policy on the competitiveness of the industry. In 2003 the Massachusetts Institute of Technology put out a major, multidisciplinary study called “The Future of Nuclear Power” that covered multiple topics over twelve chapters. The chapter devoted to economics includes a calculation of the levelized, “real” life-cycle costs of nuclear power compared to pulverized coal and combined-cycle gas turbine (CCGT) plants. The real levelized cost of a project is equal to the constant dollar (“real”) price of electricity that would be necessary over the life of the plant to cover all operating expenses, interest and principal repayment obligations on debt, taxes, and

provide a return on equity to investors over the life of the project (Deutch 2003). The MIT study calculated a levelized cost of 6.7 ¢/kWh (Deutch 2003). This amount decreases with improvements in construction time and operation and maintenance cost. By comparison, according to the MIT study's base-case estimates, the cost of fossil fuel generation ranges from 4 to 6¢ per kilowatt hour.

The implementation of a carbon tax would reduce the cost of nuclear power relative to fossil fuel. The competitive situation of nuclear power will change if natural gas prices rise significantly, or with subsidies provided for non-carbon producing fuels. Recent estimates indicate that new nuclear plants could compete in the electricity market if there were a tax between \$80 and \$100 per ton of carbon placed on fossil fuels (Sailor, Bodansky et al. 2000), (Deutch 2003), (Energy Information Administration 2007).

A 2004 study by the University of Chicago analyzed the economic factors affecting the future on nuclear power in the United States as requested by the Department of Energy (DOE), through Argonne National Laboratory (ANL). The study finds that capital cost is the most important factor in determining the economic competitiveness of the nuclear industry; without federal financial assistance they predict that new nuclear plants coming online in the next decade will have a levelized cost of \$47 to \$71 per megawatt-hour (MWh) (4.7 – 7.1 ¢/kWh) (The Economic Future of Nuclear Power 2004). These results were obtained from examinations of different construction periods, plant lives, capacity factors and overnight cost estimates. Overnight cost, a term used often in the calculation of power plant construction, refers to the cost of a plant if no interest accrued during construction, as if the plant was completed “overnight” and paid for in lump sum. In reality, the present value of the cost may differ as costs are borne

over time and interest charges accrue during construction. But overnight cost is the standard measure of up front capital costs of a plant.

The University of Chicago study finds that reductions in capital costs between the first new nuclear power plant and an nth plant of the same design will be crucial to eventual commercial possibility (The Economic Future of Nuclear Power 2004). There is a lot of room for improvement between the first commercial nuclear power plant built in 20 years and the second. The Chicago study uses a 3 to 10 percent for future ‘learning rates’ in the U.S. nuclear construction industry, where learning rate is the percent reduction in cost resulting from doubling the number of plants built (The Economic Future of Nuclear Power 2004). The higher the learning rate, the more efficient subsequent nuclear builds become, therefore, reducing overnight costs (Table 1).

Table 1: Conditions Associated with Alternative Learning Rates

| Learning Rate | Pace of Reactor Orders | Construction Market | Reactor Design Standardization | Regulation Impacts |
|----------------------|---------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|---------------------------------------------------------|
| 3% | Spread apart 1 year or more | Not highly competitive, can retain savings from learning | Not highly standardized | Some construction delays |
| 5% | Somewhat more continuous construction | More competitive; more cost reductions from learning passed on to buyers | Narrower array of designs | Delays uncommon |
| 10% | Continuous construction | Highly competitive; all cost reductions passed on | Several designs; sufficient orders for each to achieve standardization learning effects | Construction time reduced and delays largely eliminated |

Source: (The Economic Future of Nuclear Power 2004).

The MIT and University of Chicago studies are informative, but they do not mention the international shortage of materials to build reactor pressure vessels, or the labor shortage. The MIT study does discuss the price and availability of uranium and concludes that, “...even if uranium prices increase as the most attractive deposits are depleted, there is good reason to

expect that prices will not soar to prohibitively high levels”(Deutch 2003). It should be noted that the MIT study was written before the spot-price of uranium soared to \$138 per pound in June of 2007 (Humber and Donville 2007). As of December 10, 2007, the spot-price of uranium has fallen to \$98 per pound (The Ux Consulting Company LLC 2007). Fuel costs make up approximately 26 percent of the overall operating costs of nuclear power plants not including the tenth of a cent per kilowatt hour charged by the Department of Energy for storage costs (Nuclear Energy Institute 2008).

The average fuel cost at a nuclear power plant in 2006 was 0.46 cents / kWh (Nuclear Energy Institute 2008). The average non-fuel O&M cost for a nuclear power plant in 2006 was 1.26 cents / kW; non-fuel costs include the operation, maintenance, administration, and support of a nuclear power plant. These are calculated using costs related to labor, materials and supplies, contractor services, licensing fees, and miscellaneous costs such as employee expenses and regulatory fees (Nuclear Energy Institute 2008).

In 2006, Rothwell modeled the net present value of building an Advanced Boiling Water Reactor in Texas using a real options approach to determine the risk associated with net-revenue uncertainty (Rothwell 2006). The author concluded that a deregulated electricity market could pose too great of a risk for nuclear plant investors because there is no rate of return guaranteed by market regulators. While a deregulated market put pressure on operators to lower construction costs, such an environment would need a new business model to mitigate the cost risks of a new nuclear power plant. Rothwell concludes that unless a new business model is implemented, possibly based on consortiums formed by the DOE, it is unlikely that new nuclear power plants in deregulated electricity markets will be built (Rothwell 2006).

A recent study by Hultman, Koomey and Kammen discusses the financial risks for new nuclear power to achieve its cost objectives from examination of a “three-decade historical database of delivered costs from each of 99 individual U.S. nuclear reactors” (Hultman, Koomey et al. 2007). The authors recognize that the new fleet of nuclear reactors will be of a different generation than the current reactors, but some factors will remain the same. For example, new nuclear reactors will be large-scale site-built projects subject to variability in supplies, labor, technology, water availability, and public opinion (Hultman, Koomey et al. 2007). All of these factors could contribute to cost uncertainty.

To evaluate the overall costs of the existing commercial reactors, the authors compiled a database containing financial data for each reactor in the U.S. nuclear fleet and calculated a lifetime-levelized cost (in 2004 ¢/kWh) for each reactor. The results of the study show a wide distribution of costs that includes a large group of low-cost reactors (3-8¢/kWh) to a significant group of reactors with extremely high costs (12-15¢/kWh) (Hultman, Koomey et al. 2007). While many estimates for the costs of new nuclear reactors predict a normal or lognormal cost distribution, the so-called “high-cost cluster” produced by the Hultman exceeds the prices that traditional financial analysis would predict for new plants (Hultman, Johnathan G. Koomey et al. 2007). The high-cost cluster exceeds the prices that traditional financial analysis would predict for new plants; the historical record of nuclear power clearly demonstrates the potential for high-cost surprises (Hultman, Koomey et al. 2007).

A study in 1999 by Kazimi and Todreas takes an in-depth look at a major challenge for the future of nuclear power, the long-term storage of spent fuel. In the beginning of the commercial nuclear power industry in the U.S., it was anticipated that spent fuel would be reprocessed for the purpose of recovering the uranium and plutonium, which would be recycled

with fresh fuel. The remaining substance would be dissolved in a glass matrix and disposed of as waste. This is the fuel cycle followed by France, England, and Japan (Kazimi and Todreas 1999). A prohibition on reprocessing came into effect during the Carter Administration for nonproliferation purposes. Even though the prohibition was lifted during the Reagan years, the cost of reprocessing, starting with zero reprocessing infrastructures was much higher than the cost of fresh fuel.

Kazimi and Todreas conclude that the current method of nuclear waste storage, dry-casks stored on-site, can nuclear power plant operation for decades to come. However, optimization of the national spent-fuel program could be improved if DOE changed its waste-related fee to base it on waste volume rather than on electricity sales. This would encourage utilities to work towards fuel optimization (Kazimi and Todreas 1999). Also, given the tremendous uncertainty surrounding DOE’s date for accepting spent fuel in a geologic repository, there is a need for a privately-run central interim spent-fuel storage facility. Facilitating private construction of an interim storage facility could be more cost effective than a DOE-funded interim storage facility (Kazimi and Todreas 1999) (Table 2).

Table 2: Comparative Power Costs

| Study | Technology | Real Levelized Cost cents/kwh |
|------------------------|----------------------------------------------|-------------------------------|
| MIT (2002 dollars) | Nuclear | 6.7 |
| | + Reduce construction cost 25% | 5.5 |
| | + Reduce construction time from 5 to 4 years | 5.3 |
| Chicago (2003 dollars) | Nuclear | 5.1 – 8.3 |
| Hultman (2004 dollars) | Nuclear (historical cost of 99 plants) | |
| | 79% of plants built | 3.0-8.0 |
| | 16% of plants built | 8.0-12.0 |
| | 5% of plants built | >12.0 |
| EIA (2005 dollars) | Nuclear (low) | 6.1 |
| | Nuclear (high) | 6.5 |
| | | |

| | | |
|------------------------|----------------------------|---------|
| MIT(2002 dollars) | Pulverized Coal | 4.2 |
| Chicago(2003 dollars) | Pulverized Coal | 3.7-3.7 |
| EIA (2005 dollars) | Pulverized Coal | 5.7 |
| | | |
| MIT (2002 dollars) | CCGT* (low \$3.77/MCF) | 3.8 |
| MIT (2002 dollars) | CCGT (moderate \$4.42/MCF) | 4.1 |
| MIT (2002 dollars) | CCGT (high \$6.72/MCF) | 5.6 |
| Chicago (2003 dollars) | CCGT | 3.5-4.1 |
| EIA (2005 dollars) | CCGT | 5.5 |
| | | |

Source: (Deutch 2003); (The Economic Future of Nuclear Power 2004); (Hultman, Koomey et al. 2007); (Energy Information Administration 2007)

*Gas costs reflect real, levelized acquisition cost per thousand cubic feet (MCF) over the economic life of the project.

Another topic of interest in the nuclear economics literature is the whether or not a nuclear revival can take place with transition in the electric supply industry from a regulated monopoly structure, to unbundled, deregulated markets. In the last ten years, electricity supply industries in the U.S. and Europe have started to move from a regulated, monopoly structure to unbundled companies trading in deregulated wholesale markets (Roques, Nuttal et al. 2006). As of February 2008, the Energy Information Administration (EIA) is reporting restructured electricity markets in fourteen U.S. states. A restructured market, as defined by EIA, means that a “monopoly system of electric utilities has been replaced with competing sellers” (Energy Information Administration 2007). Consumer protection was the original purpose for structured electricity markets. This philosophy is changing and state and federal legislators are moving towards the thinking that consumers will actually benefit more from an industry whose members must compete for customers than from an industry made up of regulated monopolies (Energy Information Administration 2000). Despite fourteen states that are deregulated, since the Enron debacle of 2001, enthusiasm for deregulation has waned considerable.

The impact of deregulation on a potential nuclear plant revival in the U.S. is debatable. Since the attempt at deregulation in the U.S. and Europe, there has been no new nuclear plant built in either location with the exception of one plant being constructed in Finland (2004) and the ordering one plant in France (2005) (Roques, Nuttal et al. 2006). This issue is particularly muddled in the U.S. where the decade-long effort in several states to deregulate has not had the desired effect of increasing competition and lowering utility bills. The future of deregulation in the U.S. is unclear

The old system of monopoly-run nuclear power plants often resulted in cost overruns. Finding the financing for a new plant was easy due to government-backed subsidies, but there were very poor incentives for delivering the plant in a cost-effective way (Roques, Nuttal et al. 2006). One study in 1962 demonstrated that regulated utilities actually rationally prefer to invest in “excessively capital-intensive technologies” and the subordination of utilities to a regulatory body, such as the NRC, leads to other distortions in investment choices (Averch and Johnson 1962). Lowering the risk for investors did nothing to improve construction costs between 1967 and 1977, the decade of the major nuclear build in the U.S (Table 3).

Table 3: Historical Construction Costs

| Historical Construction Costs of 75 Nuclear Power Plants* | | | | |
|------------------------------------------------------------------|-------------------------------------------|----------------------------------------|----------------------------|--|
| Construction Start | Estimated Overnight Costs (\$/kWe) | Actual Overnight Costs (\$/kWe) | Percent Over Budget | |
| 1966 - 1967 | 560.00 | 1,170.00 | 209% | |
| 1968 - 1969 | 679.00 | 2,000.00 | 294% | |
| 1970 - 1971 | 760.00 | 2,650.00 | 348% | |
| 1972 - 1973 | 1,117.00 | 3,555.00 | 318% | |
| 1975 - 1975 | 1,156.00 | 4,410.00 | 381% | |
| 1976 - 1977 | 1,493.00 | 4,008.00 | 269% | |

*Plants were built before the 1979 Three Mile Island disaster and operated until 1986; dollars have been converted to \$2002/kWe; Source: (Joskow 2006)

Until the late 1990s, nuclear power plants were controlled by geographic monopolies that were allowed by statute to charge their customers whatever price it took to earn a market rate of return on their investment (Joskow 2007). Once a state becomes deregulated, this cushion of safety is removed. Investments are motivated by profit and the market is responsible for the choice of technology (Roques, Nuttal et al. 2006). In this environment, nuclear power plants are undesirable for investors because of the inherent risk that is distributed among all stakeholders. The literature on nuclear power and deregulated markets points to three major reasons this risk distribution is unattractive to potential investors in new nuclear power plants.

First, the payback period for a nuclear power plant is much longer than the payback period for a coal or gas fired power plant. Historically, the most optimistic length of time for nuclear payback is five years; for a typical fossil fuel plant, the lead time is only two years (Roques, Nuttal et al. 2006). The reasons for this are related to likely delays in construction time and regulatory setbacks. Second, compared to fossil fuel plants, construction costs for nuclear power plants are much greater. Capital costs make up about 20 percent of the total costs of a natural-gas fired power plant; for nuclear power, capital costs make up approximately 70 percent of the total costs (Roques, Nuttal et al. 2006).

Third, reliable cost estimates are hard to acquire since a nuclear power plant hasn't been built in the United States in about thirty years. The history of nuclear power plant construction includes many with seriously delayed construction times, cost overruns, and public opposition (Roques, Nuttal et al. 2006), (Hultman, Koomey et al. 2007). In a deregulated environment, costs associated with licensing, site studies, and engineering studies will only be recovered if the plant is completed and can earn revenues from its sales (Joskow 2007).

The deregulation rush in the U.S. came to sudden halt with the California power crisis of 2001 leaving many states with regulated monopoly status. However, there are current policy shifts in regulated states towards requiring utilities to compare proposals to build their own generating plants against proposals from independent merchants (Joskow 2007). There is pressure on regulators to include performance incentives for traditional utilities that create positive and negative risks parallel to the risks incurred by independent providers (Joskow 2007). The idea here is that regulated utilities can feel pressure to reduce costs to mimic a competitive market and protect consumers. The general trend of making the electricity market competitive may be unattractive to potential investors in nuclear.

Looking at the deregulated market in Finland is useful because, despite the financial barriers to new nuclear plant construction in a deregulated market, Finland began building Olkiluoto 3 in 2004. The \$3 billion contract is with Areva and Siemens and the overnight costs are \$2,350/kWh in nominal dollars (Joskow 2006). The large capital costs of the plant have been financed by extremely long-term power purchase agreements (Roques, Nuttal et al. 2006). The Finnish electricity company financing the plant is Teollisuuden Voima Oy (TVO), a cooperative group of local utilities and industrial consumers; it is a public-private partnership company, 43 percent government-owned and 57 percent privately owned (Roques, Nuttal et al. 2006). The agreement ensures that shareholders will receive electricity at production cost during the 60 year life of the plant as well as holding useful option on the future carbon price (Roques, Nuttal et al. 2006). Such a cooperatively-held long-term power purchase agreement enables financing at low cost.

III. Brief History of Nuclear Power Plant Costs in the U.S.

Between 1975 and 1985 the nuclear industry in the U.S. transformed from a low-cost, reliable form of energy to a power source that is not only high in cost, but also unreliable and unsafe (Cooke 1985). After the Three Mile Island accident in 1979, no new plants were ordered and applications for 124 new ones were immediately withdrawn (Joskow 2007). At the same time, prices fell for coal and natural gas, fossil fuels that were once thought to be too finite to last into the 21st century, casting doubt on the idea that nuclear would ever be competitive with these older sources (Kazimi and Todreas 1999). Growth in the nuclear industry was halted. Any increases in output came from improving the capacity of existing plants.

According to Cooke (1985), technology didn't doom the nuclear industry, mismanagement did. First, he argues, the federal government and the NRC failed the daily management of the program; these two entities also failed to consider the high economic costs of the regulations it imposed. This point is debatable; the NRC may have very well considered the costs of the regulations it was imposing, but figured the safety of workers and surrounding communities warranted the costs. Second, Cooke argues, utility executives, cushioned by the regulated, monopoly structure, had little incentive to follow cost and construction schedules assuming rate commissioners would bail them out. By 1985, six utilities stopped construction on plants because financial resources had completely run out. Finally, Cooke asserts that state regulatory commissions themselves neglected to step in when exorbitant expenditures for nuclear projects caused large increases in electricity costs to consumers. Between 1974 and 1993, real (inflation-adjusted) non-fuel Operating and Maintenance costs (O&M) for commercial nuclear power plants escalated from approximately \$23 to \$97 per kilowatt of plant capacity. Some of this price escalation was due to high interest rates, and a declining demand in energy (Cooke 1985).

The Three Mile Island (TMI) accident on March 28, 1979 changed the industry forever. TMI, in addition to being the most serious accident in U.S. nuclear history, was also the cause of huge increases in regulatory costs rendering nuclear uncompetitive with coal and natural gas. The accident was caused by a combination of stuck valve and inadequately trained operating personnel which led to the nuclear reactor overheating (Cooke 1985). The partial core meltdown and subsequent radiation leak caused public support for the technology to drop from 70 to 50 percent, where it remains today (Lewis 2008).

In April 1986, a risky and ill-informed test at the Chernobyl plant in the Ukraine led to a major loss-of-coolant episode. As the reactor melted down, the crew at the plant didn't know enough about the plant they were working with to have any idea what to do when things went grievously wrong (Lewis 2008). The reactor melted down severely which produced several explosions and a fire that sent a plume of radioactive fallout into the atmosphere and over the Soviet Union, Europe, and eastern North America. It should be noted that there are no reactors as fire-prone as Chernobyl in the United States, and safety systems have been upgraded dramatically since TMI (Lewis 2008). However, these two accidents are significant events that have changed both the industry and public perception of nuclear power drastically.

After the accident at Three Mile Island, safety concerns rose to prominence and the NRC imposed hundreds of new safety regulations that caused O&M costs for utilities to skyrocket; in some cases, plants that were almost near completion had to be torn down and rebuilt (Cooke 1985) (Hewlett 1996). Additionally, the burden of decision making shifted from the utilities to the NRC. The NRC did not take economics into consideration when imposing regulations on utilities that were unprepared to take on very high-level projects.

Any company that failed to comply with NRC's new requirements had their project shut down temporarily or permanently (Cooke 1985). The most famous case is Long Island Lighting and Co's \$4.2 billion Shoreham nuclear power station which is most likely the most expensive commercial nuclear power plant in the works – at \$0.21/kWh – which never actually opened (Cooke 1985). The financial viability of the industry continued to decline and by 1998, the Department of Energy's Energy Information Administration (EIA) forecasted the gradual demise of the industry (Joskow 2007). Had this prediction been true, the contribution of nuclear power to the U.S. electricity grid, which is now around 20 percent, would be zero by 2030. As it turns out, the nuclear industry addressed many of the cost and safety issues and has since turned itself around.

There are several economic reasons the nuclear industry became more viable. In 1987, nuclear plant operators reduced a significant production cost disadvantage relative to coal-fired power plants (Rothwell and Graber 2005). Throughout the early 1990s, U.S. nuclear power plant operators progressively reduced the duration for refueling, from 90 days to less than 30 days, which resulted in nuclear plants reaching capacity factors of approximately 90 percent (Rothwell and Graber 2005). These major developments demonstrated how changes in plant management could affect plant profitability.

A multivariate regression analysis in 1999 found that economically viable nuclear power plant operations are linked to three factors. First, operating costs in nuclear plants decrease with an increasing equity stake of the nuclear operator, statically significant at over 99 percent. Second, nuclear power plants with more installed generating capacity have lower operating costs than smaller plants, statistically significant at over 99 percent. Third, owners operating relatively few nuclear plants compared to other nuclear power plant owners have lower operating costs,

statistically significant at 98 percent (Sunder, Stephenson et al. 1999). While the results of this study to not eliminate other possible contributing factors, the findings could be helpful when trying to look at the potential success of utilities planning on building new nuclear plants.

The U.S. is currently working with other countries to develop fourth-generation nuclear technology (Gen-IV) which should be safer than current reactors and available at lower total cost (Hultman, Koomey et al. 2007) (David, Kent et al. 2006). The Generation IV International Forum (GIF) was established in January 2000 to study innovative nuclear energy system concepts for meeting future energy needs (The Generation IV International Forum 2008). GIF members include Argentina, Brazil, Canada, The European Atomic Energy Community (Euratom), France, Japan, South Africa, South Korea, Switzerland, United Kingdom, and United States, with the OECD-Nuclear Energy Agency and the International Atomic Energy Agency as permanent observers. Gen-IV technology encompasses improved design from the Generation III machines and more advanced technologies such as gas, liquid sodium or lead cooling and drawing from a larger set of possible fuel cycles (Hultman, Koomey et al. 2007). The Energy Policy Act of 2005 contains incentives for research and development into Gen-IV technology.

In addition to Gen-IV support, the Energy Policy Act of 2005 has several sections devoted to supporting a new nuclear build of Gen-III technology in the U.S. Additionally, the Nuclear Regulatory Commission has been preparing for new nuclear power plant applications since 2006. The following section examines efforts that have been made by the U.S. federal government to promote a nuclear revival.

IV. Recent Government Efforts to Expand Nuclear Power

The first major energy legislation to be enacted in over a decade was The Energy Policy Act of 2005, signed by President Bush on August 8, 2005 (Holt and Glover 2006). The Act includes mandatory reliability standards for the bulk-power system, an increase in renewable fuels standard, tax incentives for domestic energy production, and new statutory standards for improved energy efficiency. Subtitle VI contains strong language for encouraging the construction of new nuclear power plants and authorizes \$1.355 billion in spending on nuclear initiatives (Taxpayers for Common Sense 2005). The signing of this bill into law gives many advantages to the nuclear industry and if these incentives are strong enough to overcome the barriers referenced above, a resurgence of construction could occur, perhaps in the next 10 years.

Subtitle A reauthorizes the Price-Anderson Act until 2025; the act addresses liability for damages to the general public in the event of nuclear incidents (Holt and Glover 2006). The reauthorization raises the maximum annual accident assessment on each reactor from \$10 million to \$15 million; this renewal and adjustment is “widely considered to be a prerequisite for building the new nuclear power plants that are encouraged elsewhere in the act” (Holt and Glover 2006). The Price-Anderson Act is important because it reduces the financial burden for reactor owners following a major nuclear accident.

The birth of the nuclear power industry in the 1950s was made possible, in part, by the limits on liability created by the Price-Anderson Act. The Act is controversial among nuclear power opponents because post-nuclear reaction damages, after \$300 million in insurance carried by the reactor, are paid for by taxpayers. Opponents argue that Price-Anderson essentially subsidizes nuclear power (Holt and Glover 2006). New nuclear power plants probably could not be constructed without the Price-Anderson reauthorization of 2005.

Subtitle B, entitled “General Nuclear Matters,” is full of provisions for the purpose of encouraging the construction of new plants. The most significant example is Section 638, entitled Standby Support for Certain Nuclear Power Plant Delays; this section authorizes the Secretary of Energy to help pay for the cost of regulatory delays at up to six commercial nuclear reactors (Holt and Glover 2006). Further, DOE is authorized to cover all the eligible delay-related costs, such as additional interest, up to \$500 million each, with payments decreasing to \$250 million for the following four reactors (United States Energy Policy Act 2005).

The significance behind Section 638 is that the operating license is given by the NRC to the utility before the plant is built. This eliminates the potential for the denial of an operating license after construction. The 104 operating reactors in the U.S. today were built in a two-step system. First, utilities were issued a construction permit; then, after the reactors were built, utilities applied for an operating license. This proved problematic for the Shoreham plant in New York (which never opened) and Seabrook in New Hampshire. These plants went through years of litigation over their operating licenses while racking up billions of dollars in interest costs (Holt and Glover 2006).

The Energy Policy Act of 1992 allowed the NRC to issue a combined construction and licensing permit; however, the NRC reserved the right to make a final determination whether or not the plant could go online after construction was completed. Section 638 of the 2005 Act essentially insures the first six reactors against having to pay interest costs should the NRC pull the plug at the last minute. If the NRC does pull the plug on a reactor after it has been completed, the utility has the opportunity to address whatever issues the NRC has found and interest payments are waived. Section 638 does not completely take away reactor-owner responsibility. There is a stipulation that the federal payments will not cover the “failure of a reactor owner to

‘take any action required by law or regulation’” This is significant because historically many reactor delays resulted from legal disagreements over whether laws and regulations had been followed during construction (Holt and Glover 2006).

Also included in section 638 is perhaps the strongest nuclear incentive, a 1.8 cents/kilowatt-hour tax credit for electricity produced by nuclear reactors. “The credit is available for up to 6,000 megawatts of new capacity — the equivalent of about five or six new reactors — for the first eight years of operation” (Holt and Glover 2006). The idea behind the incentive is to make nuclear energy more competitive with other electricity generation technologies. Potential nuclear plant operators have a 2008 deadline to file for licenses with the NRC if they want to be eligible for these production tax credits (Mandel 2007).

Other provisions in Subtitle B eliminate antitrust reviews of reactor license applications and ensures adequate staffing at NRC with incentives for both students and retirees to work at the agency, and user fees that fund 90 percent of the NRC budget are extended permanently (Holt and Glover 2006). Funding for the NRC is significant given federal concerns over NRC preparedness for a surge in new power plant applications (Table 4).

Table 4: Summary of the Energy Policy Act of 2005

| Feature of the Energy Policy Act of 2005 | Barrier Addressed |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| Title VI, Tax Credit: 1.8-cent/kWh tax credit for up to 6,000 megawatts of new capacity for the first 8 years of operation | Competitiveness with coal and natural gas |
| Title VI, Loan Guarantees and Regulatory Delay Compensation: cost of regulatory delays covered at up to six new commercial nuclear reactors; delays caused by the failure of a reactor owner to comply with laws or regulations are not covered | Regulatory delays causing increased construction time |
| Title VI, Reauthorization of Price-Anderson Act: Commercial reactor accident damages are paid through a combination of private-sector insurance and a nuclear industry self-insurance system | Risk-adverseness among utilities |

In addition to incentives for the expansion of nuclear power in the 2005 Energy Policy Act, there are other actions at the federal level towards assisting the expansion of new nuclear power. The Nuclear Regulatory Commission itself has been preparing for new reactor applications since 2001. In the summer of 2006, the NRC began taking steps towards a major reorganization of the agency to accommodate projected growth in the nuclear industry. By the summer of 2007, the Office of New Reactors (NRO) had been created for the purpose of handling new reactor applications. Among the 3,000 person staff, only a small percentage of NRC personnel had experience with the process of licensing a new plant. The creation of NRO was a major undertaking. In addition to hiring of hundreds of people, the NRC had to write a new rulebook that would outline the procedure for approving a new nuclear reactor (Gaffigan 2007).

Approximately 70 percent of NRC's workforce in 2006 was devoted to ensuring the safe operation of civilian nuclear power plants; NRC estimates that 500 new critically skilled positions will be added through 2009 to license and inspect new reactors (Wells 2007). The environment at the NRC in the summer of 2007 was hectic with new-hires being brought in and trained on a daily bases. Despite the fact that the role of the NRC is industry oversight, the agency is aware that delays in the license application process could hurt investor confidence and decrease the likelihood of nuclear energy being cost beneficial (Wells 2007). Undoubtedly, the NRC has a stake in the commercial nuclear power sector expanding and continuing to operate safely.

V. Economic Barriers

Labor Shortage

A nuclear revival in the U.S. could be slowed by a major shortage of trained workers. The Nuclear Regulatory commission and the industry are concerned about having enough qualified personnel to build new nuclear power plants. Boilermakers, pipefitters, electricians, and ironworkers are expected to be in short supply; this shortage will be especially dire in states with small populations and limited labor pools (U.S. Department of Energy 2005). It is also expected that plant owners will have trouble recruiting and training the Health Physicists, licensed Reactor Operators, licensed Senior Reactor Operators, and maintenance staffs needed once the plant is built (U.S. Department of Energy 2005). Part of the reason for this shortage is that the average age of an employee in the nuclear industry including mechanics, engineers, and CEOs is 48 and it is estimated that 27 percent of the nation's nuclear power employees, about 15,600 workers, will be retiring in the next five years (Testa 2007). At the same time, the number of university nuclear engineering programs has declined in the U.S. to approximately 29 from 65 (Gongloff 2007).

The peak construction craft labor demands for new nuclear power plants total 1600 people; once the nuclear power plant has been built, 2400 people are required for fuelling the plant and getting it online (Table 5, Table 6). The Bureau of Labor Statistics reports that demand for skilled craft labor will increase 8 percent in the next ten years. Specifically in the nuclear power plant operator sector, BLS reports that job opportunities are expected to be very good for people who are interested in becoming power plant operators, distributors, and dispatchers due to an aging workforce (U.S. Department of Labor Bureau of Labor Statistics 2008).

The Construction Labor Research Council did a study in 2005 on the Craft Labor Supply Outlook for 2005 to 2015. The construction industry is concerned with attracting new participants as the work force in the United States ages. Construction is in great competition with other industries to interest qualified young people in careers (Construction Labor Research Council 2005). Additionally, training in the industry can take years, resulting in lag time between recruiting new entrants and turning them into trained craft workers. The Research Council finds that in the year 2000, the number of 18 to 24 year old males exceeded the number of 55 to 64 year old males by 1.6 million. By 2015, the number of 55 to 64 year old males will be 2.8 million higher than 18 to 24 year olds. In 2000, there were 114 younger males for every 100 older males, but in 2015, there will be 85 younger males for every 100 older males (Construction Labor Research Council 2005). If the Research Council's predictions are correct, the outflow of workers for the industry will be larger than the inflow, creating a craft labor shortage. It should be noted that these studies do not consider labor immigration as a potential solution to the labor shortage issue.

The response to this problem from Exelon, the largest utility in the U.S. is to actively recruit young engineers on undergrad campuses and create a work-place environment that is favorable to young people. After surveying its employees in June of 2006, Exelon discovered that 12 to 38 percent of its workforce could retire in ten years. This discovery launched the recruiting campaign (Testa 2007). Exelon is expected to submit an application to the NRC in 2008 for two new units in Texas. Debbi Shimanis, manager of staffing for Exelon told *Workforce Management* magazine, "Exelon's reach extends from institutions of higher education all the way into high school. 'We may be in sixth, seventh and eighth grades soon'" (Testa 2007). In addition to intense recruiting, Exelon also works with two-year schools to develop nuclear

technology programs. Amir Shahkarami, Exelon's senior vice president of engineering and technical services serves as an advisor to colleges such as Texas A&M and Tulane (Testa 2007). Duke Energy, which filed an application to build a nuclear power plant south of Charlotte, NC, is also planning for the workforce shortage. Duke Energy has relationships with local technical schools for radiation protection and nuclear operation training (Dolan 2007).

The Tennessee Valley Authority (TVA) has created a critical knowledge capturing program to prevent the valuable knowledge of its aging employees from "walking out the door" (Tennessee Valley Authority 2007). The process involves ranking how important someone's knowledge and retirement urgency (on a five point scale) and multiplying these two rankings; therefore, a knowledge-capture score is somewhere between 1 (not urgent) and 25 (critically urgent) (Testa 2007). As of December 17, 2007, TVA has submitted a reactor license application for its Bellefonte site in Alabama.

Despite major recruiting efforts, training, and knowledge capture programs, it will be hard for the industry to make up for the loss of experienced nuclear plant operators. According to the Nuclear Regulatory Commission: "[T]he single most important factor in assuring quality in nuclear plant construction is prior nuclear experience (i.e., licensee experience in having constructed previous nuclear power plants, personnel who have learned how to construct them, experienced architects-engineers, experienced constructors, and experienced NRC inspectors)" (U.S. Nuclear Regulatory Commission 1984). The issue of having the right people constructing, running, and overseeing a nuclear power plant may be the most important.

Table 5: Construction Requirements for a New Nuclear Power Plant

| Craft Description | Craft Percent | Peak Personnel for Average Nuclear Plant | Projection Data from National Employment Matrix | | |
|----------------------------------|---------------|------------------------------------------|-------------------------------------------------|----------------------------|-----------------------------|
| | | | Employment, 2006 | Projected Employment, 2016 | Percentage Change (rounded) |
| Boilermakers | 4 | 60 | 18,000 | 20,000 | 14% |
| Carpenters | 10 | 160 | 1,462,000 | 1,612,000 | 10% |
| Electricians/Instrument Fitters | 18 | 290 | 705,000 | 757,000 | 7% |
| Iron Workers | 18 | 290 | 30,000 | 34,000 | 12% |
| Insulators | 2 | 30 | 28,000 | 31,000 | 9% |
| Construction Laborers | 10 | 160 | 1,232,000 | 1,366,000 | 11% |
| Masons | 2 | 30 | 222,000 | 247,000 | 11% |
| Millwrights | 3 | 50 | 55,000 | 58,000 | 6% |
| Operating Engineers | 8 | 130 | 494,000 | 536,000 | 8% |
| Painters | 2 | 30 | 463,000 | 517,000 | 12% |
| Pipefitters | 17 | 270 | 502,000 | 555,000 | 11% |
| Sheetmetal workers | 3 | 50 | 189,000 | 201,000 | 7% |
| Team Assemblers | 3 | 50 | 1,274,000 | 1,275,000 | 0% |
| Total Construction Labor: | 100 | 1600 | 6,674,000 | 7,209,000 | 8% |

Sources: (U.S. Department of Energy 2005) Table 3-2; (U.S. Department of Labor Bureau of Labor Statistics 2008)

Table 6: Peak On-Site Labor Requirements Post-Construction

| Peak On-Site Labor Requirements Post-Construction | |
|---------------------------------------------------|-----------------------------------------|
| Personnel Description | Peak Personal for Average Nuclear Plant |
| Craft Labor | 1600 |
| Craft Supervision | 80 |
| Site Indirect Labor | 160 |
| Quality Control Inspectors | 40 |
| Vendor and Contractor Staffs | 140 |
| Managers, Engineers, and Schedulers | 100 |
| Owner's Operation and Maintenance Staff | 200 |
| Start-Up Personnel | 60 |
| Nuclear Regulatory Inspectors | 20 |
| Total | 2400 |

Sources: (U.S. Department of Energy 2005) Table 3-3.

Nuclear-Grade Material Shortage

The first step in the process of manufacturing large nuclear power plant components is the building of the forgings which encapsulate the reactor pressure vessels (RPVs) (Figure 1). A nuclear power plant can have a number of units; each unit has one RPV. Since the decline of the nuclear industry in the U.S. and Europe, Japan Steel Works (JSW) is the only company worldwide that is both capable of and actually building nuclear-grade forgings. Orders for forgings have doubled in since 2005 and slots are booked until 2010 (The Economist 2007). The limited manufacturing capacity for RPV forgings is a significant construction schedule risk and could become a project financing risk in the United States.

Numbers for the global capacity for manufacturing new nuclear power plants vary; given JSW's manufacturing capacity, the critical nuclear forgings coming out of the company limits world-wide nuclear plant construction to an estimated eight to ten nuclear plants a year (Freeman 2006). The entire manufacturing capacity of JSW is not devoted to nuclear; the company also makes forgings for non-nuclear endeavors such as petrochemical and natural gas plants.

The second step for nuclear power plant components is for a manufacturer to take the forgings for the reactor vessel head and do the precision machining, cladding, surface finish, and welds on any attachments, such as the control rod mechanism (Freeman 2006). All of the work involved with reactor vessel construction needs to be nuclear grade. While there are companies in the U.S. that are capable of medical and military nuclear machining, there is not U.S. capacity for nuclear power plant machining.

The term 'nuclear-grade' refers to a process of thorough manufacturing quality assurance for components that are critical to reactor safety. There are a limited number of certified suppliers of certain nuclear-grade components worldwide; as nuclear plant construction

increases, competition for these extremely limited resources will increase. This will extend lead times and raise component prices (Nuclear Energy Institute 2007).

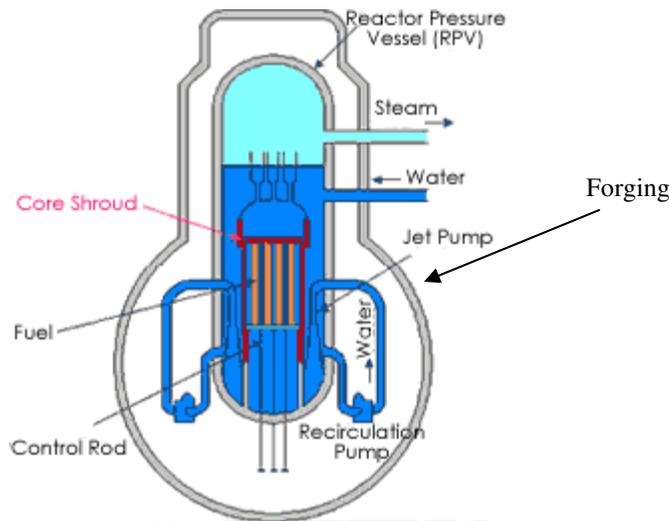
The 2005 U.S. Department of Energy study on the costs of building and operating nuclear power plants identified ultra-large nuclear-grade forgings as the first major “pinch point” that the industry will encounter before 2010 with constraints on supplies of nuclear-grade pumps, valves and heat exchangers in safety-related systems could arise in subsequent years (U.S. Department of Energy 2005). “These constraints may intensify if the manufacturing industry does not increase capacity on a schedule consistent with the nuclear industry’s needs,” the report concluded” (Nuclear Energy Institute 2007).

Once the reactor pressure vessels are obtained and put together, the remaining materials include steam turbine generators and condensers, ten pumps, 2,100 valves, and bulk nuclear-grade materials including seismic snubbers, prefabricated pipe support, cable tray, conduit, power cable, concrete, and control cable. The nuclear-gradation process of all of these components involves the heavy use of nickel, a vital metal in many industries including stainless steel production, battery production and chemical and aerospace industries (London Metal Exchange 2008).

World nickel mine production reached an all time high in 2007, with supply just meeting demand; since 1993, global stainless steel production has been growing at an average rate of 5.6 percent per year (London Metal Exchange 2008). The consumption of stainless steel in China has been vigorous since 2003, outpacing the combined use of the U.S. and Japan and causing nickel prices to reach unprecedented levels in the first half of 2007 (London Metal Exchange 2008). Prices in June of 2007 climbed to almost \$25.00 per pound, up from \$4.00 a pound in 2003 (Kitco Base Metals 2008). As of February 2008, there are thirty-four nuclear units under

construction worldwide (Table 11). Most of the construction is going on in less developed countries. There will be tremendous international competition for nuclear-grade components.

Figure 1: Reactor Pressure Vessel



Source: (Toshiba 2008).

Uranium

Nuclear power's cost advantages compared to natural gas and coal rely on the abundance of low cost uranium, or yellowcake, the raw, unrefined uranium oxide extracted from mines. In 2005, mines supplied approximately 49,000 tons of uranium oxide concentrate (U_3O_8), about 64 percent of utilities' annual requirements. The remaining balance is made up from secondary sources like stockpiled uranium held by utilities, but those stockpiles are now largely depleted (Uranium Information Centre 2008). The perception of imminent scarcity drove the spot price (or current market price) for non-contracted uranium sales to over \$138 per pound in 2007, but the price has leveled slightly to between \$70 and \$80 per pound in early. However, recent issues and changes in the uranium markets have created uncertainties around future uranium prices.

Two events in the summer of 2007 caused significant spikes in uranium prices (Figure 2).

Uranium prices, which hovered around \$30/lb in 2004 and 2005, rose sharply when flooding closed down a major Canadian mine. Cigar Lake is located on top of one of the world's largest undeveloped deposits of uranium in northern Canada. In 2007, Cameco Corp., the largest uranium producer in the world which owns the deposit, was expected to produce 18 million pounds of uranium from Cigar Lake (Humber and Donville 2007). The flood put the company three years behind schedule and set off concerns about the availability of uranium.

Following the flood, there was a speculative scramble in the commodities markets over the future price of uranium; in May of 2007 the spot price for uranium hit a high of \$138/lb in May of 2007 sending shockwaves through the industry (Mills 2007). The uranium mania that followed quintupled the share price of more than twelve mining companies worldwide (Humber and Donville 2007).

In May of 2007, an agreement between Ux Consulting Co. and the New York Mercantile Exchange, a unit of Nymex Holdings, introduced the trading of uranium futures products for the first time. Before May of 2007, uranium was sold under long and short-term contracts between end users, such as electric utility fuel managers and uranium producers (Saefong 2007). According to Kevin Bambrough, a market strategist at Sprott Asset Management, the reason for the agreement is awareness at Nymex of prospective growth in the nuclear industry (Saefong 2007). The lack of a public-trading platform for uranium has discouraged private investors in the past. However, some analysts question how successful publically traded uranium will be due to a separation of the actual metal from the trader. Unlike other commodities like gold and silver, traders of uranium don't actually take possession of the uranium, they simply own a title of it. Although uranium is a metal, Nymex is viewing it as an energy contract because the only use of commercial-grade uranium is fuel for nuclear reactors (Saefong 2007).

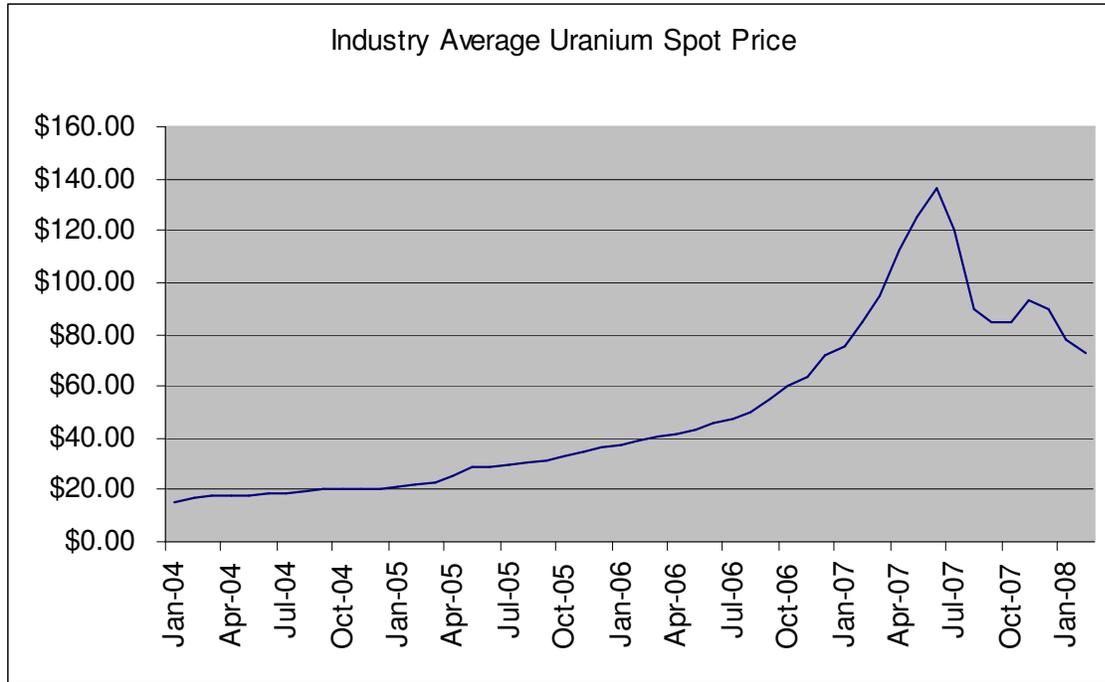
The inception of the futures contracts has so far resulted in increased volatility in the uranium price. “Whether the launch of futures contracts will be a disadvantage or advantage to the uranium market depends on who you ask” (Saefong 2007) Traders invested in uranium producers will be happy if the price of uranium continues to spike higher. On the other hand, for a utility that hasn’t taken care of the uranium it needs for a refueling, the futures contracts could be bad news (Saefong 2007). Analysts predict long-term prices of uranium to jump between \$70 and \$100 dollars per pound given the increasing international demand.

In terms of actual uranium availability in the world, present data suggests that known resources include 3 to 4 million tons of uranium (Organization for Economic Cooperation and Development (OECD) 2006). The OECD estimates that primary uranium production capabilities including existing, committed, planned and prospective production centers, recoverable at a cost of \$36/lb or less, could satisfy projected world uranium requirements until 2010 if all expansions and mine openings proceed as planned and if production is maintained at full capacity (Organization for Economic Cooperation and Development (OECD) 2006). It is unlikely that that all of the above listed projects will run at full capacity. In order for the uranium industry to keep up with increasing world demand, production capacity needs to increase. Due to long lead-times required for new uranium production (10 years or more), there is the potential for a uranium shortfall (Organization for Economic Cooperation and Development (OECD) 2006).

In terms of secondary supply streams of uranium, recycled uranium and plutonium from spent fuel, ex military weapons-grade uranium, civil stockpiles, and ex military weapons-grade plutonium are all used by utilities in Europe and Russia (Uranium Information Centre 2008). The major commercial reprocessing plants are operating in France and the United Kingdom with a total capacity of over 4000 ton of spent fuel per year (Uranium Information Centre 2008).

Recycled fuel is fabricated into fresh mixed oxide (MOX) fuel element; about 200 tons of MOX is used each year, equivalent to less than 2000 tons of U_3O_8 from mines (Uranium Information Centre 2008). The secondary uranium supply stream is not robust enough to fill in the gaps should world demand for uranium increase rapidly in the next ten years.

Figure 2: Uranium Spot Price



Source: (The Ux Consulting Company LLC 2007).

Waste Disposal

The disposal of high-level radioactive waste is the biggest long-term, scientific, political, and public opposition battle the nuclear revival faces. In addition to being the Achilles' heel of the nuclear industry, the current and future costs of the problem to the federal government are astronomical. The Department of Energy (DOE) told the nuclear industry in the 1980s that it would be responsible for disposing of high-level radioactive waste at a cost of a tenth of a cent per kWh (\$0.001); utilities were required to sign long term contracts with the DOE saying they would pay. The nuclear industry has been paying the federal government this high-level waste

fee for over twenty-five years and the High-Level Waste Fund is currently at \$21 billion with \$500 million being added annually (Davis 2007). As the High-Level Waste Fund increases steadily, so does the pressure to figure out a long-term storage solution.

The site for the nation's high-level radioactive waste, Yucca Mountain, Nevada, has been embroiled in political controversy since Congress chose it in the Nuclear Waste Policy act of 1982. DOE told the utilities it would take the waste off their hands in 1998. When that year came and went with no progress on the long-term storage front, utilities began suing DOE for storage expenses. After 60 lawsuits, the federal government has paid the utilities \$342 million and the damage number is rising (Wald 2008). If DOE began building an actual repository in Yucca Mountain today, with an optimistic opening year of 2017, DOE's liability for its failure to begin taking high-level waste from utilities would total \$7 billion (Wald 2008)

The High-Level Waste Office at the NRC is currently waiting on a licensing application from DOE to begin building a repository in Yucca Mountain. Since 1982, the only development onsite at Yucca has been an exploratory study facility (Davis 2007). The NRC is expecting an application from DOE in June of 2008, however, Edward F. Sproat III, director of the Office of Civilian Radioactive Waste Management, has been quoted as saying that that date is “ ‘clearly out the window’ ” because Congress underfinanced the effort to build the repository, among other problems (Wald 2008).

From the NRC's point of view, Yucca Mountain is not tied to the nuclear revival the agency has been gearing up for because of existing interim storage technology consisting of steel casks where the waste is surrounded by inert gas to prevent corrosion (Davis 2007). This method has been used for decades in the 120 temporary storage locations in 39 states. However, there are other opinions. Besides concerns about the long-term integrity of the dry-cask storage

technology that would be used in Yucca, the inventory of spent fuel in the United States is accumulating at the rate of 2,000 metric tons per year (Suppes and Storvick 2007).

VI. Analysis and Policy Solutions

Looking at the potential barriers to the nuclear power industry, there seem to be several key indicators that a nuclear revival can take place. The first indicator: a solution to the waste issue. Nuclear waste is the barrier that both the industry and the NRC turn to DOE to resolve. The long-term spent nuclear fuel problem is seen as DOE's problem and the issue is big enough to prevent a significant nuclear power build in the U.S. over the next thirty years.

Plans for waste disposal in almost all countries with commercial nuclear power plants are based on the placement of the waste in deep geological repositories (Sailor, Bodansky et al. 2000). Continuing litigation and uncertainty surrounding the construction of a long-term storage facility at Yucca Mountain, Nevada, makes a case for U.S. investment in chemical reprocessing. There is currently no capacity in the U.S. for reprocessing spent nuclear fuel and a significant amount of capital would be required to begin such a process. However, reducing the amount of high-level radioactive waste would both address the waste issue and the uranium volatility issue by extending the current, domestic nuclear fuel supply into future centuries. (Suppes and Storvick 2007).

The fear of nuclear weapons proliferation is a major obstacle for domestic fuel reprocessing (Suppes and Storvick 2007). The option for reprocessing spent fuel in the United States was eliminated after the signing of the nuclear nonproliferation treaty during President Carter's administration (Suppes and Storvick 2007). Although President Regan lifted the ban, President Clinton reinstated it. The PUREX process (Plutonium-Uranium Extraction), the most

commonly used reprocessing technology, removes pure plutonium from spent fuel. The fear is that reprocessing makes this material more available to terrorists.

One problem with reprocessing spent nuclear fuel in the United States is that the technology is currently more expensive than mining and enriching uranium. Even in France, where recycling technology has existed for decades, reprocessed fuel is currently 0.90¢/kWh, while new uranium fuel costs 0.68¢/kWh, not including storage costs (Suppes and Storvick 2007). Reprocessing requires expensive facilities, similar to large chemical plants, that either the public or private sector would have to develop and clear with the Nuclear Regulatory Commission (Nuclear Energy Institute 2005).

The second indicator that a nuclear revival can take place is a loosening of the international bottleneck for resources used to build plants. What many proponents of nuclear power seem to overlook is that utilities in the U.S. are competing internationally for a very small supply of nuclear-grade forgings and other restricted markets for nuclear-grade pipes and conduits. Due to the thirty year lull in nuclear power plant applications, suppliers have stopped providing components. From an industry standpoint, one solution to this problem is to work with AP1000 suppliers, like Westinghouse, to identify components way ahead of time that might be scarce and immediately put in orders (Dolan 2007). Another option is to seek out suppliers besides Japan Steel Works that make forgings, but have them develop their existing operation to nuclear grade (Dolan 2007). While this would be an expensive initial investment for a company, the pay off could be considerable in the event of a world-wide nuclear revival. The Nuclear Energy Institute, the industry's lobby group, has an effort underway to look at strategic issues concerning suppliers such as: could the U.S. make its own forgings? Is this a national policy issue?

If the demand for nuclear-grade forgings continues to rise, it is likely that the market will eventually correct for the tremendous world-wide shortage, but the timeline for such a think will be long. It is possible for additional suppliers to enter the market, but making an existing operation nuclear grade is a complex process and there are lots of manufacturing layers added in the nuclear-grad industry for safety reasons. It costs a significant amount of money to take a facility from regular grade to nuclear grade, no matter the component (Dolan 2007).

The third indicator that a nuclear revival can take place is the establishment of a carbon dioxide limiting policy in the U.S. Coal is the lowest cost option for generating electricity in the United States (Suppes and Storvick 2007). In absence of a carbon-limiting policy, new nuclear power plants need to decrease construction time by approximately 7 to 4 years to cut the energy cost difference between coal and nuclear in half (Suppes and Storvick 2007). Therefore, a piece of legislation for the purpose of putting a price on carbon emissions would indicate that a nuclear revival is possible.

As mentioned in the Background section, the implementation of a carbon tax or an equivalent “cap and trade” system would reduce the cost of nuclear power relative to fossil fuel; several recent estimates indicate that new nuclear plants could compete in the electricity market if there were a tax between \$80 and \$100 per ton of carbon placed on fossil fuels (Sailor, Bodansky et al. 2000), (Deutch 2003), (Energy Information Administration 2007). Under the assumption that the costs of carbon emissions are imposed, the following table from the MIT study illustrates the impact on the competitive costs for different power sources, for emission costs in the range of \$50 to \$200/ton of carbon (Table 7).

Table 7: Power Costs with Carbon Taxes

| Carbon Tax Cases Levelized Electricity Cost (cents/kWh) | \$50/ton C | \$100/ton C | \$200/ton C |
|------------------------------------------------------------------------|-------------------|--------------------|--------------------|
| Coal | 5.4 | 6.6 | 9.0 |
| Gas (low) | 4.3 | 4.8 | 5.9 |
| Gas (moderate) | 4.7 | 5.2 | 6.2 |
| Gas (high) | 6.1 | 6.7 | 7.7 |

Source: (Deutch 2003).

Nine bills to reduce greenhouse gas emissions in the U.S. have been introduced in the 110th Congress. One of them, the Lieberman-Warner Act, S. 2191, was reported by the Senate Committee on Environment and Public Works by an 11-8 vote in December of 2007. This proposal creates a market-based greenhouse gas reduction program that should reduce emissions to 15 percent below 2005 levels in 2020, declining steadily to 63 percent below 2005 levels in 2050 (Parker and Yacobucci 2008). The limitation scheme is an absolute cap on total emissions from all entities in the electric power, transportation, and industry sectors that release more than 10,000 metric tons of carbon dioxide equivalent per year (Parker and Yacobucci 2008). Core scenarios envisioned by S. 2191 rely heavily on nuclear power as an enabling technology and contemplate growth of the industry by 150 percent (U.S. Environmental Protection Agency 2008). Under S. 2191, there are incremental coal plant retirements in 2025 as the allowance price hits \$50/ton. In response, a considerable amount of new nuclear and renewable-energy capacity is built along with new coal with carbon-capture and storage facilities. Further action on S. 2191 is expected (Parker and Yacobucci 2008).

The fourth indicator that a nuclear revival can take place has already taken place: a government-backed solution to the financial barriers of nuclear power. Construction of the first new nuclear power plant in the U.S. is regarded as a relatively high-risk undertaking by the electric utilities and the financial community (U.S. Department of Energy 2005). The Energy

Policy Act of 2005 provides an initial government backstop during the construction and early operation phases of the first few plants. Without this subsidy, it would be extremely difficult for a utility to get a nuclear power plant off the ground simply due to the financial risks. The Department of Energy believes that once the first few projects have been successfully completed, debt investors and equity investors will be prepared to assume the risks of new nuclear construction and the Production Tax Credits will no longer be necessary. The levelized cost comparison below shows that nuclear is made competitive with coal and natural gas with the Production Tax Credit (Table 8).

Table 8: Levelized Cost Comparison with Production Tax Credit

| Levelized Cost Comparison (2005 cents per kilowatt hour*) | | | | |
|----------------------------------------------------------------------|-------------|--------------------|--------------------------|---------------------------|
| | Coal | Natural Gas | Nuclear (low) | Nuclear (high) |
| Total** | 5.71 | 5.52 | 6.11 | 6.53 |
| Production Tax Credit | 0 | 0 | 1.8 | 1.8 |
| New Total | 5.71 | 5.52 | 4.31 | 4.73 |

* Estimates taken from Energy Information Administration (2007). Annual Energy Outlook 2007. Report #: DOE/EIA-0383.

** Includes capital, O&M, fuel and transmission costs

Table 9: Policy Matrix

| | BARRIER | CURRENT SITUATION | CURRENT SOLUTION | FUTURE SOLUTION |
|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| Primary | Nuclear is not competitive with coal and natural gas | Levelized cost of nuclear is 2-3¢ more per kWh | Energy Policy Act of 2005 provides a Production Tax Credit of 1.8¢ for first 5 or 6 plants for the first 8 years of operation | Climate change legislation that limits carbon dioxide |
| | Risk-aversion among utilities to invest given historical regulatory and construction-related delays, and inherent risks of nuclear technology | Construction of a nuclear plant can last 5-6 yrs and cost \$2 - \$4 billion; in comparison, natural gas plants take 1-2 yrs and cost \$500 million | Energy Policy Act of 2005 included the renewal of the Price-Anderson Act | Construction costs may decrease over time |
| Secondary | Labor Shortage | Industry to lose 15,600 workers | Recruiting incentives | Recruiting, training, and knowledge-capture programs |
| | Nuclear-Grade Material Shortage | International bottleneck for forgings | None | Incentives for manufacturers to upgrade |
| | Uranium Supply | Uranium prices in could be volatile due to agreement between Ux Consulting and the New York Mercantile Exchange which introduced uranium futures trading in May '07 | None | U.S. investment in reprocessing technology |
| | Waste Issue | DOE application to NRC expected August 2008 for Yucca Mountain | On-site storage | U.S. investment in reprocessing technology |

VII. Conclusions.

In order for a nuclear expansion in the U.S. to be possible, the competitive posture of nuclear power needs to be improved by either the industry itself reducing construction time and capital costs, federal climate change legislation, or the continuation of subsidies akin to the Production Tax Credits of the 2005 Energy Policy Act. It is likely that the first 5 or 6 plants that receive NRC approval will be built and provided with a 1.8¢ per kilowatt hour tax credit for the first 8 years of the plants' lives. Despite secondary barriers, this government subsidy almost guarantees that 5 or 6 new nuclear plants will be built in the U.S. in the next 5 to 10 years. However, a nuclear expansion beyond this point is unlikely without solutions to the most significant secondary barriers, the international nuclear-grade material shortage, and the issue of high-level nuclear waste disposal.

An additional point about the cost of new nuclear plant construction is that the entire process is extremely uncertain since a new nuclear plant has not been built in the last 20 years. As the Hultman study points out, the historical experience of nuclear power in the U.S. suggests that "new, complex, and culturally sensitive technologies risk surprises that skew the distribution of costs beyond what might be expected in a rational world" (Hultman, Koomey et al. 2007). For example, the Olkiluoto-3 plant, currently underway in Finland, is the first nuclear plant to be ordered in Western Europe since the 1986 Chernobyl disaster. The construction project is more than 25 percent over its budget at \$4.1 billion. It is likely that a situation like this will occur in the U.S. due to inexperienced construction workers and long wait times for materials. The objective of the industry should be to reduce capital costs to competitive levels and increase building efficiency.

If it is determined by citizens and the federal government that nuclear energy should continue to play an essential role in U.S. energy policy, investments should be made by the federal government and the industry to address the nuclear-grade materials shortage and the waste issue. An international bottleneck of materials will slow a nuclear expansion. The federal government and the nuclear industry should encourage additional manufacturers to become certified to make nuclear-grade materials. Japan Steel Works, the only manufacturer of nuclear-grade forgings, cannot provide enough forgings in the next ten years to keep up with the number of plants currently planned world-wide. There is tremendous opportunity for entry into this market.

The issue of what to do with the nation's high-level radioactive waste is the biggest secondary barrier to a major nuclear expansion. The current solution, on-site storage, is a satisfactory solution for short-term nuclear construction only. While a federal investment in reprocessing technology is an expensive solution, it might be necessary if a significant nuclear expansion, beyond 5 or 6 plants, is to take place. The current policy solution to the nation's high-level nuclear waste has been at a standstill for the last twenty year and something new, like a commitment to reprocessing, is necessary.

A labor shortage is not a large enough barrier to stop an expansion of new nuclear power. Not only is the nuclear industry recruiting the next generation of nuclear power plant workers, but labor immigration, which has traditionally solved this problem during other labor shortage periods, may also relieve this challenge. The global supply of uranium is not a large enough barrier to halt a new nuclear power plant build. The spot prices will continue to be volatile since the 2007 agreement between Ux Consulting and Nymex, which introduced the trading of

uranium futures products for the first time, but uranium extraction will continue to be viable for at least the next 50 years.

A combined license (COL) is an authorization from the NRC to construct and operate a nuclear power plant at a specific site in accordance with laws and regulations (U.S Nuclear Regulatory Commission 2008). As of April 22, 2008, the NRC has received nine applications for COLs. Most of these applications are for new units in southeastern locations including Alabama, South Carolina, and Georgia. It is important to point out that the future of nuclear power in the U.S. will be different for various regions of the country; opinions about nuclear technology tend to vary by state. Another important point about these applications is that a majority of them are for adding new units to locations where a nuclear plant is already in operation (Table 12). Adding a unit to an already existing location has a greater chance of receiving NRC and public approval than a plant in a new location.

The passing of climate change legislation in the U.S. will change the economics of nuclear power. However, there is more to the expansion of nuclear power than economics. The issue of high-level nuclear waste has simply not been properly addressed by the Department of Energy. If the country intends to rely on nuclear power in the future to reduce greenhouse gas emissions and increase energy independence, then a proper solution to the waste issue must be determined and acted upon.

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IX. Appendix

Table 10: Summary of Conclusions

| | BARRIER | CONCLUSION |
|------------------|-----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Primary | Not Competitive with Coal and Gas | <ul style="list-style-type: none"> • Production Tax Credits will allow the first 5 or 6 plants to be built • Climate change legislation relying on nuclear power will force expansion • Great uncertainty surrounding future costs of new nuclear power plants |
| | Risk-aversion among utilities to invest | <ul style="list-style-type: none"> • While inherent risks in the nuclear power industry cannot be completely done away with, the Renewal of the Price-Anderson Act and a likelihood of decreasing construction costs over time decreases financial risk |
| Secondary | Labor Shortage | <ul style="list-style-type: none"> • Recruiting initiatives and training programs will fill the labor gap |
| | Nuclear-Grade Material Shortage | <ul style="list-style-type: none"> • International bottleneck will slow nuclear expansion considerably • Additional manufacturers need to become certified to make nuclear-grade materials |
| | Uranium Supply | <ul style="list-style-type: none"> • Uranium extraction will continue to be viable for at least the next 50 years |
| | Waste Issue | <ul style="list-style-type: none"> • Biggest secondary barrier to major nuclear expansion • On-site storage is a satisfactory solution for short-term nuclear construction only • U.S. investment in reprocessing technology could help; costly investment |

Table 11: Nuclear Units under Construction Worldwide

| Nuclear Units Under Construction Worldwide | | | | | |
|---------------------------------------------------|---------------------|---------------------|------------------|--------------------------------|------|
| Country | Reactor Name | Reactor Type | Total MWe | Estimated Start-up Year | |
| Argentina (1) | Atucha 2 | PHWR | 692 | NA | |
| Bulgaria (2) | Belene 1 | PWR | 953 | NA | |
| | Belene 2 | PWR | 953 | NA | |
| China (5) | Hongyanhe 1 | PWR | 1,000 | NA | |
| | Lingao 3 | PWR | 1,000 | 2010 | |
| | Lingao 4 | PWR | 1,000 | NA | |
| | Qinshan 2-3 | PWR | 610 | 2010 | |
| | Qinshan 2-4 | PWR | 610 | 2011 | |
| China, Taiwan (2) | Lungmen 1 | ABWR | 1,300 | NA | |
| | Lungmen 2 | ABWR | 1,300 | NA | |
| Finland (1) | Olkiluoto 3 | PWR | 1,600 | NA | |
| France (1) | Flamanville 3 | PWR | 1,600 | 2012 | |
| India (6) | Kaiga 4 | PHWR | 202 | 2007 | |
| | Kudankulam 1 | PWR | 917 | 2009 | |
| | Kudankulam 2 | PWR | 917 | 2009 | |
| | PFBR | FBR | 470 | NA | |
| | Rajasthan 5 | PHWR | 202 | 2007 | |
| | Rajasthan 6 | PHWR | 202 | 2007 | |
| Iran (1) | Bushehr 1 | PWR | 915 | 2007 | |
| Japan (1) | Tomari 3 | PWR | 866 | NA | |
| Pakistan (1) | Chasnupp 2 | PWR | 300 | 2011 | |
| Russia (7) | Balakovo 5 | PWR | 950 | 2010 | |
| | Beloyarsk 4 | FBR | 750 | NA | |
| | Kalinin 4 | PWR | 950 | 2010 | |
| | Kursk 5 | LWGR | 925 | 2010 | |
| | Severodvinsk 1 | PWR | 30 | NA | |
| | Severodvinsk 2 | PWR | 30 | NA | |
| | Volgodonsk 2 | PWR | 950 | 2008 | |
| | S. Korea (3) | Shin-Kori 1 | PWR | 960 | 2010 |
| | | Shin-Kori 2 | PWR | 960 | 2011 |
| Shin Wolsong 1 | | PWR | 960 | 2011 | |
| Ukraine (2) | Khmelnitski 3 | PWR | 950 | 2015 | |
| | Khmelnitski 4 | PWR | 950 | 2016 | |
| United States (1) | Watts Bar 2 | PWR | 1,165 | NA | |
| Total (34) | | | 28,139 | | |

Source: International Atomic Energy Agency PRIS database, (2007) <http://www.iaea.org/programmes/a2/index.html>.

ABWR - Advanced Boiling Light-Water-Cooled and Moderated Reactor
 FBR - Fast Breeder Reactor
 PHWR - Pressurized Heavy-Water-Moderated and Cooled Reactor
 PWR - Pressurized Light-Water-Moderated and Cooled Reactor
 LWGR - Light-Water-Cooled, Graphite-Moderated Reactor

Table 12: Expected New Nuclear Power Plant Applications

| Expected New Nuclear Power Plant Applications as of April 18, 2008 | | | | | | |
|---------------------------------------------------------------------------|---------------------------------|--------------------|---------------------------------|--------------|------------------------------------|---------------------|
| Expected Application Year | Company | Design Type | Site Under Consideration | State | Existing Plant at this site | Deregulation |
| 2007 | Duke Energy | AP1000 | William Lee Nuclear Station | SC | No | No |
| 2007 | NuStart Energy | AP1000 | Bellefonte (2 units) | AL | No | No |
| 2007 | Dominion | ESBWR | North Anna (1 unit) | VA | Yes | No |
| 2007 | NRG Energy | ABWR | South Texas Project (2 units) | TX | Yes | Yes |
| 2008 | Progress Energy | AP1000 | Harris (2 units) | NC | Yes | No |
| 2008 | Progress Energy | AP1000 | Levy County (2 units) | FL | No | No |
| 2008 | Southern Nuclear Operating Co | AP1000 | Vogtle (2 units) | GA | Yes | No |
| 2008 | South Carolina Electric and Gas | AP1000 | Summer (1 unit) | SC | Yes | No |
| 2008 | Entergy | ESBWR | River Bend (1 unit) | LA | Yes | No |
| 2008 | NuStart Energy | ESBWR | Grand Gulf (1 unit) | MS | Yes | No |
| 2008 | UNISTAR | EPR | Calvert Cliffs (1 unit) | MD | Yes | Yes |
| 2008 | PPL Generation | EPR | Berwick (1 Unit) | PA | Yes | Yes |
| 2008 | AmerenUE | EPR | Callaway (1 unit) | MO | Yes | No |
| 2008 | UNISTAR | EPR | Nine Mile Point (1 unit) | NY | Yes | Yes |
| 2008 | TXU Power US | APWR | Comanche Peak (2 units) | TX | Yes | Yes |
| 2008 | Exelon | TBD | TBD (2 units) | TX | | Yes |
| 2008 | Detroit Edison | TBD | Fermi (1 unit) | MI | Yes | Yes |
| 2008 | Amarillo Power | EPR | Vicinity of Amarillo (2 units) | TX | | Yes |
| 2008 | Alternate Energy Holdings | EPR | Bruneau (1 unit) | ID | No | No |
| 2009 | Florida Power & Light | AP1000 | Turkey Point (2 units) | FL | Yes | No |
| 2010 | Transition Power | TBD | Utah | UT | No | No |

Sources: U.S. Nuclear Regulatory Commission (2008) Expected New Nuclear Plant Applications. Available: <http://www.nrc.gov/reactors/new-licensing/new-licensing-files/expected-new-rx-applications.pdf> (U.S Nuclear Regulatory Commission 2008); Energy Information Administration (2007) Status of Electricity Restructuring by State. Available: http://www.eia.doe.gov/cneaf/electricity/page/restructuring/restructure_elect.html (Energy Information Administration 2007)