Nuclear Energy: Balancing Benefits and Risks
2007

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NUCLEAR ENERGY AT A CROSSROADS

According to a prevailing belief, humanity confronts two stark risks: catastrophes caused by climate change and annihilation by nuclear war. This assessment has recently led an increasing number of policymakers, pundits, businesspeople, and environmentalists to advocate a major expansion of nuclear energy, which emits very few greenhouse gases into the atmosphere. Because fossil fuels are used to mine and enrich uranium, the nuclear fuel cycle releases carbon dioxide and other greenhouse gases. However, nuclear reactors themselves do not emit greenhouse gases while generating electricity. Summing up the total energy use associated with nuclear power production, only a small fraction of the energy expended results in greenhouse gas emissions. While acknowledging the connection between nuclear fuel making and nuclear bomb building, nuclear power proponents suggest that nuclear proliferation and terrorism risks are readily manageable. Consequently, some of these advocates favor the use of subsidies to stimulate substantial growth of nuclear power.

This conventional wisdom possesses some truth, but it oversells the contribution nuclear energy can make to reduce global warming and strengthen energy security while downplaying the dangers associated with this energy source. To realistically address global warming, the nuclear industry would have to expand at such a rapid rate as to pose serious concerns for how the industry would ensure an adequate supply of reasonably inexpensive reactor-grade construction materials, well-trained technicians, and rigorous safety and security measures.

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To reduce the deleterious effects of climate change, the world will need to dramatically increase the use of low- and no-carbon emission energy sources as well as promote far greater use of energy efficiencies. Nuclear will undoubtedly be part of this mix, but the policy question is: How much can and should it contribute to energy needs? This benefit needs to be weighed against the entire costs and risks of nuclear power production.

In addition to substantial capital costs for construction of power plants, nuclear energy includes significant external costs: applying safeguards to sensitive activities such as fuel making, securing nuclear facilities against terrorist attacks, decommissioning reactors, storing highly radioactive waste, and paying for insurance to cover the costs of an accident. Another important policy question is: How much of these external costs should be paid for by the industry versus governments? A related question is: If all energy sectors identified and paid for most, if not all, of their external costs, including greenhouse gas emissions, how would the nuclear sector fare on this level playing field that refrained from further government subsidies?

NUCLEAR ENERGY'S ROLE IN STRENGTHENING U.S. ENERGY SECURITY

Nuclear power can provide greater energy security by reducing reliance on fossil fuels acquired from unstable regions. In recent years, the United States imported about two- thirds of its oil and one-fifth of its natural gas.[i] Most of the oil the United States uses fuels transportation needs with only a small portion (about 3 percent) used for generating electricity. Electricity generation from all sources comprises about 40 percent of total U.S. energy consumption. Of this total, nuclear comprises only about 8 percent. Currently, nuclear power, which solely generates electricity, offers some relief in use of foreign sources of oil and natural gas and could, over the long term (many decades), power cars and trucks through production of hydrogen for fuel cells or electricity for plug-in hybrid vehicles. But at least over the next few decades, a substantial growth in nuclear energy use will not wean the United States off foreign sources of oil.

Unlike oil, natural gas provides a significant portion (16 percent) of U.S. electricity production as well as heating for homes and businesses. Rising natural gas prices, however, have sparked recent corporate interest in nuclear power. If natural gas prices remain at the currently high levels for many years, nuclear power could offer a more favorable business investment. But historically, natural gas prices have fluctuated, and the presently high prices could fall, undermining support for a growth of nuclear energy.

In the electricity production sector, nuclear power plants' operating costs compete favorably with coal, natural gas, hydro, oil, geothermal, wind, and solar energy sources, but its capital costs have difficulty competing against them. Presently, according to the Energy Information Administration, the United States produces 52 percent of its electricity from coal-fired plants, 21 percent from nuclear power plants, 16 percent from natural gas, 7 percent from hydro, 3 percent from oil, and 1 percent from geothermal, wind, and solar combined.[ii] Thus, the vast majority of U.S. electricity comes from three sources: coal, nuclear, and natural gas. Tables 1 and 2, based on two recent authoritative studies, show the estimated costs of these electricity sources. Coal remains a relatively cheap fuel, and capital costs for coal-fired plants are considerably less than for nuclear plants. The United States is the Saudi Arabia of coal reserves; thus, the use of coal helps reduce dependence on foreign sources of oil and natural gas in the electricity production sector. Without restrictions imposed on greenhouse gas emissions, coal wins out over nuclear in terms of financial costs.

Economics is a major factor influencing the growth of nuclear energy. As an industry official recently said, "Nuclear energy is a business, not a religion." Despite the passions both for and against continued or expanded use of this energy source, business decisions will mainly determine whether use of nuclear-generated electricity will rise or fall.

The long lead time for, and large uncertainties in, nuclear reactor construction and licensing have stymied growth in the industry in the United States. American utilities have not ordered a nuclear reactor since 1978, and that order was subsequently canceled. The last completed reactor in the United States was the Tennessee Valley Authority's Watts Bar 1, which was ordered in 1970 and began operation in 1996.

Despite the lack of reactor orders, the contribution of nuclear-generated electricity has increased in recent years in the United States. During the past decade, average operating costs have decreased, and time needed for refueling outages has shortened, allowing nuclear power plants to operate longer at full capacity or, in industry terms, "increasing the load factor." (The load factor in the United States increased from 65 percent in the 1980s to 90 percent by 2002.) Moreover, several nuclear plants have received licenses to increase their power ratings, again permitting production of more electricity.

Table 1: Cost of Electricity Estimated by the MIT and University of Chicago Studies		
	MIT Report (2003)	University of Chicago Report (2004)
Electricity Generation Type	*Cost (cents per kWh)*	
Coal	4.2	3.3 to 4.1
Natural Gas (Combined Cycle Gas Technology)	3.8 to 5.6	3.5 to 4.5
Nuclear	6.7	6.2

Table 2: Comparison of Assumptions in the MIT and University of Chicago Studies						
	MIT Report (2003)			University of Chicago Report (2004)		
Electricity Generation Type	*Overnight Capital Cost ($ per kW)*	*Lead Time for Construction (years)*	*Effective Interest Rate*	*Overnight Capital Cost ($ per kW)*	*Lead Time for Construction (years)*	*Effective Interest Rate*
Coal	1,300	4	9.6	1,182 to 1,430	4	9.5
Natural Gas	500	2	9.6	500 to 700	3	9.5
Nuclear	2,000	5	11.5	1,200 to 1,800	7	12.5

Sources: These tables are adapted from Brice Smith, "Insurmountable Risks: Can Nuclear Power Solve the Global Warming Problem?" *Science for Democratic Action*, August 2006, p. 7.

U.S. NUCLEAR ENERGY AS A CONTRIBUTION TO REDUCING GLOBAL WARMING

As the damaging consequences of climate change increase, more and more countries, including the United States, will consider financially supporting the expansion of nuclear energy use, which emits very few greenhouse gases into the atmosphere. The 1992 Framework

Convention on Climate Change commits the United States and other countries to reduce greenhouse gases, such as carbon dioxide, in the atmosphere to prevent "dangerous anthropogenic interference with the climate system." In February 2007, the Intergovernmental Panel on Climate Change, which includes about 2,500 of the world's top climate scientists, assessed a "very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming."[iii] While there are large uncertainties regarding the predicted amounts of warming and the severity of the climatic effects by the end of the century, there is no doubt that the massive amounts of greenhouse gases already in the atmosphere will continue to alter the climate across the globe for many decades to come.

The George W. Bush administration opposed mandatory greenhouse gas reduction programs. Nonetheless, in the 2007 State of the Union address, President George W. Bush acknowledged the need to confront the "serious challenge of global climate change." In recent years, some senators and representatives have proposed legislation that would implement greenhouse gas reduction programs. But the proposals have yet to pass either house of Congress. In 2003, the first proposal failed by a 55 to 43 vote in the Senate. In 2005, during debate on the Energy Policy Act, another proposal was defeated in the Senate by 60 to 38 votes. Both proposals would have enacted a tradable permit program.

An alternative approach is a carbon tax, which many economists favor. While many representatives and senators have opposed taxing carbon emissions, such a tax might win over enough political support if it were revenue neutral. Proceeds from the tax could be used to alleviate the financial burden on poor citizens and to stimulate research in innovative energy technologies.

Despite the failed efforts to pass the emission reduction legislation, in 2005 the Senate passed a Sense of the Senate resolution on climate change. The resolution finds that (1) greenhouse gases are increasing and raising average global temperatures, (2) a mounting scientific consensus concludes that human activity has significantly caused the increase in greenhouse gases, and (3) mandatory steps will be needed to slow or stop the growth in greenhouse gas emissions. The resolution calls on Congress to enact a comprehensive national program using market-based mechanisms to slow, stop, and reverse the growth of greenhouse gas emissions. Moreover, the resolution expresses the view that such a program should not significantly harm the American economy and should encourage comparable efforts by other countries that contribute to global emissions and are major trading partners of the United States.

The particular price set for carbon emissions would signal to the market whether a specific no- or low-carbon-emitting energy source is favored with respect to high-carbon- emitting energy sources. A high initial carbon price could hurt the coal industry, which would lobby against such an initiative. On the other hand, gradually ramping up the price in a predictable way over several years could provide long-term incentive for development of coal-fired power plants that employ carbon sequestration as well as for nuclear power plants.

The United States would not stand alone if it imposed costs on greenhouse gas emissions. In the past two years, the European Union started a carbon trading scheme and plans to continue developing it. California has indicated interest in joining the European carbon trading system. Several other U.S. states are also exploring ways to reduce greenhouse gas emissions. Conceivably, the United States could use the North American Free Trade Agreement to bring Canada and Mexico into a regional system to control carbon emissions. Concerned that a complicated patchwork is emerging, an increasing number of leading national and multinational corporations have expressed interest in the federal government creating a regulatory standard for controlling these emissions.

To reduce the deleterious effects of climate change, the United States will need to increase use of all low- and no-carbon emission energy sources as well as promote greater use of energy efficiency. But given the current U.S. energy sources and patterns of use, nuclear energy alone does not provide a solution for at least the next few decades for significantly reducing the U.S. contribution to global warming. However, setting a price on carbon emissions through a cap-and-trade system or a carbon tax could make nuclear energy economically competitive with coal and natural gas, potentially stimulating some growth in nuclear reactor construction.

GLOBAL NUCLEAR ENERGY USE AND ITS ROLE IN REDUCING GLOBAL WARMING

Nuclear energy provides about 16 percent of the globe's electricity. In comparison, fossil fuels, which contribute to global warming through emissions of greenhouse gases, generate about 66 percent of the world's electricity. Global electricity demand is projected to double by 2030 and triple by 2050, based on business-as-usual usage. Much of this demand growth will occur in the developing world. Decisions leaders make today about where to invest in various energy sources will have a lasting effect because the life of most power plants extends beyond forty years.

How much could global nuclear energy consumption grow over the next four decades? A 2003 Massachusetts Institute of Technology study posited a base growth scenario of one thousand gigawatts of nuclear capacity by 2050.[iv] (A one-gigawatt nuclear reactor can power a U.S. city containing about a half-million people, comparable to the size of Washington, DC.) In comparison, today the world has about 370 gigawatts of installed nuclear capacity. The almost threefold increase in nuclear power by 2050 would only increase the global proportion of nuclear energy use from 16 percent to about 20 percent because of the projected increased demands for electricity. As a consequence, this modest increase in contribution from nuclear energy alone would not decrease the emissions of greenhouse gases. In the absence of regulating carbon, reducing energy demand, and expanding no- and low-carbon energy sources, those emissions would increase because of greater use of fossil fuels to meet the projected demand for electricity as well as heating and transportation fuels.

How much nuclear energy would be needed to maintain global carbon dioxide emissions at the year 2000 level? Reaching this goal might head off many of the damaging consequences of climate change. The Institute for Energy and Environmental Research (IEER) has recently estimated that this scenario would require between 1,900 and 3,300 gigawatts of nuclear capacity depending on differing projections of alternative energy usage and adoption of energy efficiencies.[v] Under this very ambitious scenario, each new reactor would have to come online at a rate of less than one per week over the next four decades. As a practical matter, building reactors at this rapid pace would initially tend to drive up unit costs and, thus, scare off investors. For example, there are currently only a few companies in the world that can make reactor-quality steel, concrete, and other vital parts. Moreover, a rush to build would aggravate existing shortages of skilled workers to construct the reactors, qualified engineers to run the power plants, and inspectors to ensure safe operations.

In contrast to the IEER study, Stephen W. Pacala and Robert Socolow of Princeton University have proposed a more realistic, but still ambitious, plan for stabilizing greenhouse gas emissions.[vi] They have identified fifteen energy technology wedges. (They used the term "wedge" because of the wedge or triangular shape of the reduction in greenhouse gas emissions plotted over time.) Each wedge technology, if fully employed, would reduce carbon emissions by a billion tons per year by 2050. According to the Princeton study, employing seven of these wedges in equal proportions would stabilize greenhouse gas emissions at the current level. Each wedge would contribute a relatively modest contribution to reducing greenhouse gas emissions.

Although Pacala and Socolow's study remains neutral about the growth of nuclear energy, they include it as an option among their fifteen energy wedges. The nuclear wedge would include seven hundred gigawatts or about seven hundred large commercial reactors in addition to the current nuclear-generated electricity. Adding this amount to the 370 gigawatts presently used would roughly equal the MIT base growth scenario. Because almost all of the current reactor fleet would require replacement by mid-century, the Princeton and MIT growth scenarios would require about two new reactors to come online every month over the next forty years. Thus, these growth scenarios would pose quite significant challenges.

In the foreseeable future, nuclear energy is not a major part of the solution to further countering global warming or energy insecurity. Expanding nuclear energy use to make a relatively modest contribution to combating climate change would require constructing nuclear plants at a rate so rapid as to create shortages in building materials, trained personnel, and safety controls. Furthermore, while the nuclear industry is only structured to produce electricity, the existing abundant and cheap fossil fuels provide readily usable energy for electricity, heating, and transportation needs.

SAFETY AND TERRORISM CONCERNS

According to a nuclear safety aphorism, "An accident anywhere is an accident everywhere." As with the 1979 Three Mile Island accident and the 1986 Chernobyl accident, a future major nuclear power plant accident could have a chilling effect on the growth of the industry or sustained operation of the current fleet of reactors. Similarly, a terrorist attack on any reactor could have a stifling effect on continued use or potential growth of nuclear energy in many countries. Thus, regardless of nuclear expansion in America, the United States has a vested interest in working bilaterally and multilaterally to strengthen international nuclear safety and security standards.

Whether the United States builds new commercial nuclear reactors, many countries are already doing so. The location of these reactors matters. Countries with mature power programs would tend to operate reactors in a safer and more secure manner than countries with little or no experience in commercial nuclear energy. However, even in nuclear-experienced countries, safety and security risks could increase if reactors are extended beyond their design life or if operators became complacent about providing for adequate security to account for terrorist attacks[vii].

Safety as well as reliable and cost-effective consumer access to electricity depends on the electrical distribution grid. The grid in the United States and other countries is not well equipped to meet growing demand for electricity.[viii] Even if the United States had no nuclear plants, it would benefit from investing in revitalized electrical grids. Such an investment would also enhance reactor safety by ensuring more reliable access to outside sources of power in the event of a forced shutdown of or an accident at a nuclear power plant.

The United States has been a leader in improving the safety of nuclear plant operations. For instance, U.S. nuclear engineers, working with their counterparts in other countries, created the World Association of Nuclear Operators (WANO) after the 1986 Chernobyl accident. Headquartered in Atlanta, WANO serves as a nongovernmental organization that conducts confidential peer reviews of nuclear power plant safety around the world. The Nuclear Regulatory Commission's Office of International Programs has provided regulatory assistance to several countries. Also, the U.S. Department of Energy and the State Department have drawn on their technical talent to assist reactor safety programs in Eastern Europe and the former Soviet Union. The International Atomic Energy Agency also has programs to improve the safety and security of nuclear facilities, but it lacks adequate resources to educate regulatory officials and nuclear plant operators in the numerous countries that may develop nuclear power programs.

The United States has taken steps to improve the security of nuclear power plants against terrorist attack or sabotage. Soon after the September 11, 2001, terrorist attacks, the U.S. Nuclear Regulatory Commission launched a top-to-bottom review of security procedures and requirements. Despite these updated security requirements, some independent groups continue to express concern about security vulnerabilities at U.S. nuclear power plants.

In part to address such concerns, Congress placed statutory requirements for nuclear plant security in the Energy Policy Act of 2005. In particular, the act requires that each nuclear plant conduct force-on-force exercises at least once every three years, which is the NRC's current policy. The act also calls for the exercises to simulate threats in the design-basis-threat (DBT) and for the NRC "to mitigate any potential conflict of interest that could influence the results of a force-on-force exercise, as the Commission determines to be necessary and appropriate." In addition, the act requires the NRC to revise the DBT at least every eighteen months, factoring in all conceivable modes of attack, including use of multiple teams of attackers, several plant employees aiding the attackers, and large explosives. The new law also includes requirements to fingerprint and conduct background checks of plant personnel and for the NRC to consult with the Department of Homeland Security about the vulnerability of proposed nuclear facilities to terrorist attack.

Until June 2006, private citizens and nongovernmental organizations were stymied in post-9/11 attempts to challenge the government and industry about security concerns at U.S. nuclear power plants. At that time, the Ninth Circuit Court of Appeals ruled that the NRC violated the National Environmental Policy Act (NEPA) by not reviewing the vulnerability of a proposed spent nuclear fuel facility at the Diablo Canyon nuclear plant in California. The NRC rejected the security review under NEPA in part because it believed that security is already carefully evaluated outside of environmental legal requirements. In January, the U.S. Supreme Court declined to hear an appeal by the owner of the California power plant. The outcome of this legal case could affect investment decisions for building American nuclear power plants in the future.

The nuclear industry has a vested interest in ensuring the safe and secure operation of nuclear power plants. It should devote a commensurate amount of safety and security resources to meet the projected growing demands for nuclear energy and should fund efforts to develop the best regulatory practices throughout the world. This proposed initiative for industry would draw on the precedent established by WANO in improving safety. The nuclear industry should factor these safety and security costs into the total operational costs of nuclear power plants. Because the electrical distribution grid connects a variety of electricity production sources, including nuclear, the U.S. government should invest adequate resources to ensure an effective grid similar to government's role in investing in the development of the superhighway system and the Internet.

RADIOACTIVE WASTE DISPOSAL

More than fifty years of commercial nuclear energy use has left the world with a legacy of tens of thousands of tons of highly radioactive waste that will last for tens of thousands of years. If nuclear power production expands substantially in the coming decades, the amount of waste requiring safe and secure disposal will also significantly increase. Although several countries are exploring various long-term disposal options, no country has begun to store waste from commercial power plants in permanent repositories. Industry officials generally believe that further growth of nuclear energy depends on establishing these repositories.

Countries that have derived benefits from nuclear-generated electricity have an obligation to future generations to safely and securely dispose of nuclear waste. In the United States, the government is legally bound to remove this waste from reactor sites and store it in permanent repositories. Delays in storing spent nuclear fuel in a permanent repository have already resulted in lawsuits with financial penalties.

Yucca Mountain in Nevada, the site slated for a permanent geologic repository, has not received approval to store this waste. Even if the license application is approved within the next few years, the Department of Energy does not anticipate starting to store waste there until 2017, and, more realistically, not before 2020. Meanwhile, spent fuel is accumulating in pools at nuclear power plants, increasing the risk of radioactive release from sabotage or attack at these facilities. A recent U.S. National Academy of Sciences study has concluded that "successful terrorist attacks on spent fuel pools, though difficult, are possible." Zirconium cladding provides a protective barrier around the spent fuel, but the cladding could catch fire under some attack scenarios. According to the National Academy study, "If an attack leads to a propagating zirconium cladding fire, it could result in the release of large amounts of radioactive materials." In considering alternative storage options, the study assessed, "Dry cask storage has inherent security advantages over spent fuel storage, but it can only be used to store older spent fuel."[ix] Removal of older spent fuel would also relieve overcrowded conditions in many spent fuel pools, thus decreasing safety and security risks of the remaining spent fuel in the pools. While some plants have begun using dry cask storage on-site to relieve the storage burden on spent fuel pools, most plants have not.

Hardened on-site storage of dry spent fuel casks would reduce the risk of attack or sabotage. Spent fuel could be moved to dry cask storage after cooling for five years in pools. Estimates are that dry cask storage can safely and securely store spent fuel for up to one hundred years. Although a lack of a permanent repository in the coming years would not derail the potential for a major expansion of nuclear energy in the United States, financial and legal commitments argue for proceeding as soon as possible with opening up a permanent repository.

Assuming that Yucca Mountain is eventually approved for waste storage, continued spent fuel production in the next few years will exceed the current storage limits based on current legal restrictions. According to some technical analyses, the current legislative limit of 77,000 metric tons appears arbitrary. For example, Secretary of Energy Samuel W. Bodman has requested that the allowed storage capacity be determined by the physical capacity of the mountain, estimated to exceed 120,000 metric tons of waste. In addition, according to an Electric Power Research Institute study, Yucca Mountain could hold at least four times the legislative limit and possibly nine times that limit, allowing that site to store "all the waste from the existing U.S. nuclear power plants, but also waste produced from a significantly expanded U.S. nuclear power plant fleet for at least several decades."[x] But opposition to using or expanding use of the proposed repository in Nevada, a state that has never had a commercial nuclear power plant, could well demand that the United States establish more than one repository.

The waste storage problem in the United States is manageable. The United States should pursue a dual-track approach: commit to developing a consensus and then opening up a permanent repository and in parallel store as much spent fuel as possible in dry casks that are hardened against attack at existing reactor sites. The combination of interim storage and commitment to a permanent repository would provide the assurances needed by the public and the investment community for continued use of nuclear power.

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[ii] Energy Information Agency, "Country Analysis Brief: United States, Electricity," November 2005. http://www.eia.doe.gov/emeu/cabs/Usa/Electricity.html.

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[iv] "The Future of Nuclear Power," Massachusetts Institute of Technology, 2003.

[v] Brice Smith, *Insurmountable Risks: The Dangers of Using Nuclear Power to Combat Global Climate Change* (IEER Press, 2006).

[vi] S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technology," *Science*, 305, August 13, 2004, pp. 968–72, as quoted in William Sweet, *Kicking the Carbon Habit: Global Warming and the Case for Renewable and Nuclear Energy* (New York: Columbia University Press, 2006), pp. 150–51.

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[ix] Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, National Research Council, *Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report* (Washington, DC: National Academy of Sciences Press, 2006), p. 3.

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