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Vermont Legislative Research Shop

Nuclear Power

Nuclear power is a very important issue for the state of Vermont, as the Vermont Yankee plant in Vernon provides much of the state's energy. Nationally, the debate over global warming has spurred new interest in nuclear energy. The environmental benefit of nuclear energy is clear: nuclear reactors emit very little CO2 or greenhouse gases throughout their lifetimes. Coal power plants, on the other hand, are responsible for a third of America's total greenhouse gas emissions.[1] Unfortunately, nuclear power has other drawbacks, which include safety concerns, disposal of radioactive waste, and a lack of economic feasibility for new construction. Policy makers will have to make very difficult decisions regarding America's energy production, and each source has its own downsides. The following report will examine nuclear energy with regard to environmental benefits, safety, waste disposal, and economic feasibility.

Vermont Yankee

Vermont Yankee power plant opened in 1972, and has since provided the state with a fairly reliable and cheap source of energy. In 2003 the plant provided almost 35% of the state's power.[2] In recent years there have been a few accidents at the plant and there is widespread concern over the future of the aging plant. The license to operate the plant will expire in 2012.

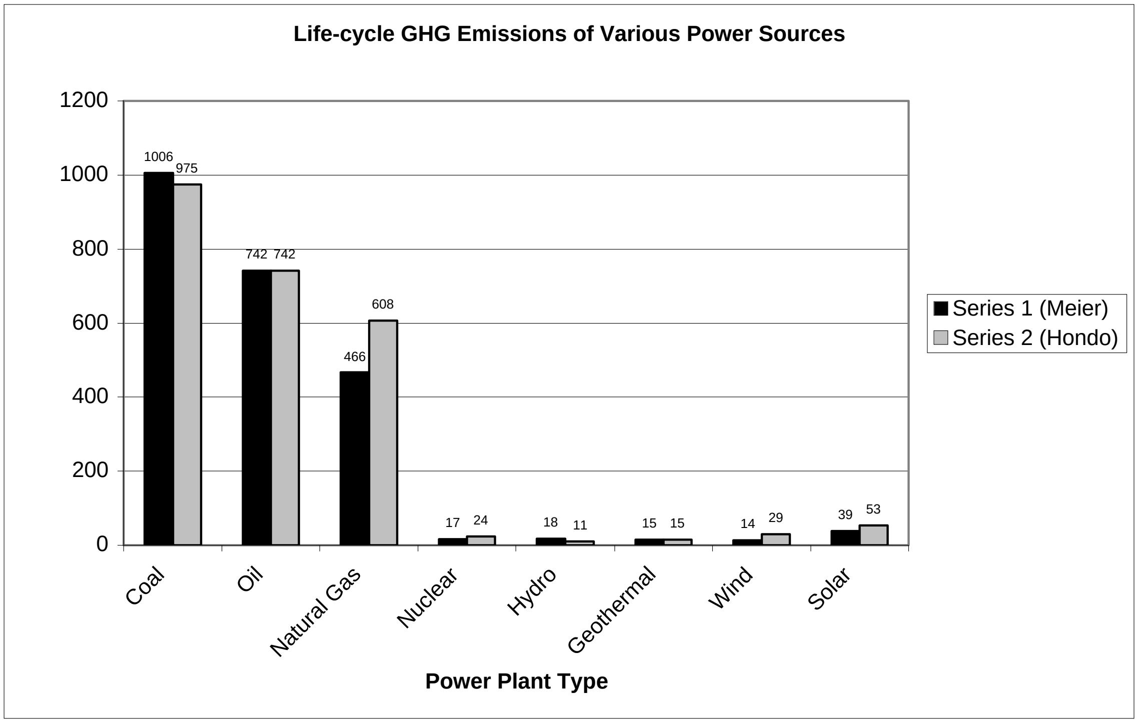
Greenhouse Gas Emissions of Common Electricity Sources

Though nuclear power is sometimes characterized as a "carbon-free" energy source, this isn't wholly accurate: greenhouse gas emissions are created during plant construction, processing of fuel, and other necessary activities which draw power from existing emissions-producing sources of energy.[3]

Below we examine two studies which take into account the amount of greenhouse gas emitted over the entire life cycle of a variety of power sources, and compare this to the estimated amount of power generated over the life cycle of these sources. This information is expressed as the mass of greenhouse gas emissions produced (measured in grams of CO2 equivalents) per unit of electricity generated (kilowatt hour). By comparing the figures for each source, we can determine which power sources produce the least amount of global-warming gases per each

[1] William Sweet, *Kicking the Carbon Habit* (New York: Colombia University Press, 2006).
[2] Vermont Department of Public Service, "Nuclear Power – Vermont Yankee," retrieved April 16, 2008 from http://publicservice.vermont.gov/electric/vermont-yankee/vermont-yankee.html.
[3] Vassilis M. Fthenakis and Hyung Chul Kim, "Greenhouse-gas emissions from solar electric- and nuclear power: A life-cycle study," *Energy Policy*, Volume 35, Issue 4, April 2007, Pages 2549-2557.

kilowatt of electricity, and therefore, which energy sources are the most environmentally efficient.[4]



In the chart above, the measure of green house gasses (GHG) in Series 1 draws on a study that collected information from a number of different studies about production technologies typically used within the U.S.[5] The measure of GHG in Series 2 draws on a study that used information on production technologies that are typically used in Japan.[6] (Note that Series 1 and Series 2 show identical values for both oil and geothermal electricity sources because they draw their information from the same source).

Despite some differences between the two studies, the results are similar and clear: nuclear energy is among a group of power sources (including hydro, geothermal, wind, and solar) which produces relatively little in the way of greenhouse gas emissions per unit of electricity generated.

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[4] A note about measurements in these studies: For the sake uniformity in comparing emissions values, greenhouse gas emissions are commonly measured in a unit called "CO2 equivalents" (CO2-eq). This unit reflects the global warming potential of all greenhouse gases measured (including CO2, if applicable), expressed as an amount of pure CO2 that would have the same magnitude of global warming potential. Hence CO2 "equivalents." Source: Paul J Meier, P. H. Wilson, Gerald L. Kulcinski, and Paul L. Denholm, "US electric industry response to carbon constraint: a life-cycle assessment of supply side alternatives," *Energy Policy*, Volume 33, Issue 9, June 2005, Pages 1099-1108.

[5] Paul J. Meier, P. H. Wilson, Gerald L. Kulcinski, Paul L. Denholm, "US electric industry response to carbon constraint: a life-cycle assessment of supply side alternatives," *Energy Policy*, Volume 33, Issue 9, June 2005, Pages 1099-1108.

[6] Hiroki Hondo, "Life cycle emission analysis of power generation systems: Japanese case," *Energy*, Volume 30, Issues 11-12, August-September 2005, pages 2042-2056.

In contrast, another group – including natural gas, oil, and coal – produces substantially more greenhouse gas emissions for the same amount of electricity.

Safety

One of the primary public concerns regarding nuclear energy is the safety of having radioactive plants close to human populations. All power plants have potential for accidents, but the potential damage from an accident at a nuclear plant is significantly higher than from other types of plants. There have been several high profile nuclear accidents over the last thirty years, but some experts and nuclear advocates maintain that safety standards have vastly improved over the years, due to improved training, computer systems, and gained experience.[7] The problem is that for the foreseeable future, safety at nuclear plants will depend to some degree on humans whose reliability, by virtue of being human, cannot always be perfect.

An MIT study on the future of nuclear energy found that thus far, the U.S. has a reactor core damage rate of 1 incident in 2679 reactor years. Projecting that the number of nuclear plants in the world will increase three-fold over the next fifty years, the study estimates (using Probabilistic Risk Assessment methods) that the number of core damage accidents world-wide would be 4 over the next fifty years, which the study deems unacceptable. The study acknowledges that this number does not account for future improvements in technology, and holds out hope that research and development will be able to get the number to below 1 accident over the next fifty years.[8]

Chernobyl and Three Mile Island

The two nuclear disasters that have captured the public imagination over the past few decades are the disasters at the Chernobyl Nuclear Plant in Ukraine, and the Three Mile Island plant in Pennsylvania. On March 28, 1979, the Three Mile Island Unit 2 plant suffered a reactor meltdown. The meltdown was the result of a series of events started by a failure in a non-nuclear part of the plant, and ultimately the accident was blamed on a mix of human error, design problems, and system failures. Nobody was injured or killed during the accident, and minimal radiation was released, but for two or so days the surrounding area was terrified by the incident. The accident caused a serious overhaul of American nuclear safety standards, and even caused some nuclear construction to halt.[9]

On April 26, 1986, one of the four reactors at Chernobyl exploded due to errors made during an experiment. The explosions released 100 times more radiation than the atomic bombs dropped on Japan during World War II, and parts of the northern hemisphere are still dealing with contamination. At least 15 people died as a direct result of the accident, but it also caused

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[7] MIT, "The Future of Nuclear Power: An Interdisciplinary MIT Study," Massachusetts Institute of Technology, 2003, retrieved April 23, 2008 from http://web.mit.edu/nuclearpower/ .

[8] MIT, "The Future of Nuclear Power: An Interdisciplinary MIT Study," Massachusetts Institute of Technology, 2003, retrieved April 23, 2008 from http://web.mit.edu/nuclearpower/.

[9] Nuclear Regulatory Commission, "Fact Sheet on Three Mile Island," February 20, 2007, retrieved April 23, 2008 from http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html.

thousands of new cancer cases. The UN Chernobyl Forum estimates that 9,000 people will eventually die of Chernobyl related cancer, while Greenpeace puts the number much higher.[10]

Terrorism

Another concern regarding nuclear safety is the potential of nuclear plants and waste storage sites as terrorist targets. One study found that U.S. nuclear facilities were not susceptible to airplane attacks such as those of September 11, 2001. It would be possible to crash a plane into a nuclear plant, but not possible to breach the containment areas that would result in massive damage to the plant, and possibly the populace.[11] Other types of terrorist attacks on nuclear plants would be possible, but one MIT study argues that plant safety considerations that take into account natural disasters (tornados, earthquakes, etc.) would also prevent terrorist attacks due to the amount of fortification that the buildings receive.[12] Obviously increasing plant security budgets would help prevent terrorist attacks on nuclear plants.

Perhaps the most vulnerable part of the U.S. nuclear infrastructure is the radioactive waste while it is being transported to storage sites. The idea of a "mobile Chernobyl" (as one website calls it) haunts the nuclear power industry, but the Department of Energy insists that transportation is quite safe. The Department has clear guidelines for transporting waste, which include contact with law enforcement officials along the routes, trained armed guards, satellite tracking, limiting of information regarding shipment, and extremely well protected containers for the waste.[13]

Economics of Nuclear Power

A main impediment to the construction of new nuclear facilities is the high up-front cost of construction. Building a new nuclear plant simply does not make economic sense for investors, who would be better off putting their money into other energy sources (such as coal and natural gas).[14]

Over the last few decades, very few nuclear plants have been constructed in the U.S. In the short-term, the rational for not building new nuclear plants is based on the fact that most regions have excess base load capacity which must be taken up before new plants are necessary. The long-term reason that no new nuclear plants have been built is that capital costs of new plants are historically high. This is because it takes a long time to build a nuclear power plant. The newest plant in the United States is the Watts Bar in Tennessee, which has been operating since 1996. The plant at Watts Bar took 23 years to complete at a cost of $6.9 billion. Regulatory

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[10] BBC News, "The Chernobyl Disaster," April 18, 2006, retrieved April 23, 2008 from http://news.bbc.co.uk/2/shared/spl/hi/guides/456900/456957/html/nn1page1.stm

[11] EPRI, "Deterring Terrorism - Aircraft Crash Impact Analyses Demonstrate Nuclear Power Plant's Structural Strength," EPRI Study, Nuclear Energy Institute website, December 2002, retrieved April 23, 2008 from www.nei.com.

[12] MIT, "The Future of Nuclear Power: An Interdisciplinary MIT Study," Massachusetts Institute of Technology, 2003, retrieved April 23, 2008 from http://web.mit.edu/nuclearpower/.

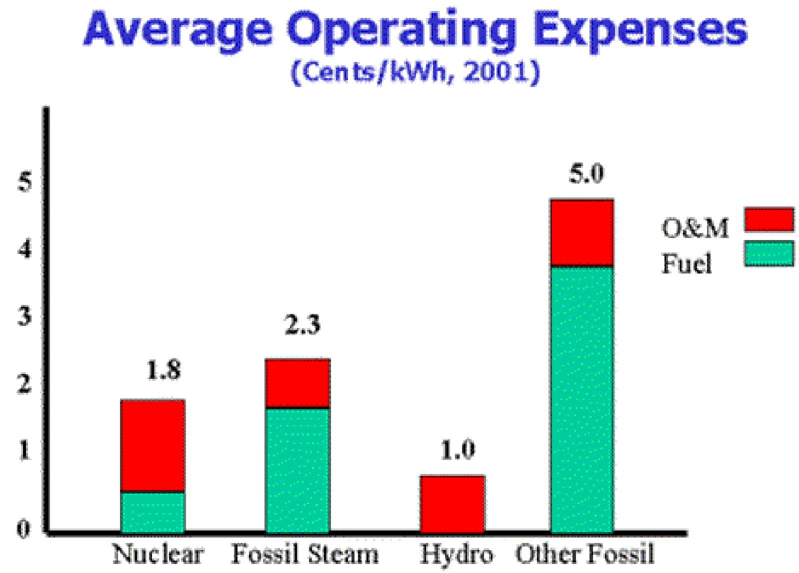
[13] Office of Civilian Radioactive Waste Management, "Transportation Security," US Department of Energy, December 2007, retrieved April 23, 2008 from http://www.ocrwm.doe.gov/transport/faq2.shtml#14.

[14] MIT, "The Future of Nuclear Power: An Interdisciplinary MIT Study," Massachusetts Institute of Technology, 2003, retrieved April 23, 2008 from http://web.mit.edu/nuclearpower

uncertainly also plays a key role, consider the example of the Shoreham plant on Long Island which was nearly finished construction when it was told it would not be able to commence operations. Many of these negative factors have been streamlined with new regulation specifications coming earlier in construction and promises of lower cost of construction.[15]

Many experts believe that the U.S. government will to introduce a tax on carbon emissions sometime in the next fifty years. If this were to happen, nuclear power would suddenly be a lot cheaper to produce than power generated from other sources, such as coal and natural gas.[16]

The following chart shows the operating costs of various power sources.



Source: Energy Information Administration, Electric Power Annual 2000

Storage of Nuclear Waste

Long-Term Storage

There is currently no perfect method for permanent disposal of spent fuel and other radioactive waste from nuclear power plants. The most popular method is geological disposal, where waste is stored deep underground and the main problem is prevent leaks. Leakage is avoided through a combination of geological and engineered barriers such as waste containers and natural rock structures. One of the main problems with this method is damage from unexpected geological

15 Energy Information Administration, "Nuclear Power: 12 percent of America's Generating Capacity, 20 percent of the Electricity," U.S. Department of Energy, (no date listed), retrieved April 28, 2008 from http://www.eia.doe.gov/cneaf/nuclear/page/analysis/nuclearpower.html

16 MIT, "The Future of Nuclear Power: An Interdisciplinary MIT Study," Massachusetts Institute of Technology, 2003, retrieved April 23, 2008 from http://web.mit.edu/nuclearpower

events such as earthquakes.[17]

The other main problem is finding somewhere to store the waste. In the 1980's the Federal Government promised nuclear power plant owners that they would soon begin to accept and dispose of waste from the plants. This has yet to happen, largely due to delays in the construction of a facility at Yucca Mountain, Nevada. The project has not received proper financing, and has been the subject of heated debate throughout the country. The facility will certainly not open until 2017, and many question whether it would be possible to open it even then. The waste is still being stored at the plants where it was generated, and the utility companies have sued successfully the government numerous times for the cost of storing the waste. One estimate says that if the facility does open in 2017, it will cost the government $7 billion in payments to the utilities.[18] The people of Nevada are generally opposed to the plan, for fear of accidents or radiation seeping out. Some people also have questioned the sites geological suitability. The problem is that the country needs somewhere to store its waste, and nobody is going to want it anywhere near their homes.[19] Government scientists insist that the project is feasible and safe, and that the natural rock walls and floors will provide an adequate barrier against possible leaks.[20]

Temporary Storage Methods

While the government struggles to find a place to permanently store the waste, plants are forced to store it onsite. The spent nuclear fuel is stored in cooling pools, which decrease the temperature of the spent fuel in a contained area away from the environment, the workers, and the public. The spent nuclear fuel produces extremely high temperatures due to radioactive decay, and for cooling pools to work properly high temperatures must be continuously constrained. To ensure this, the correct levels of air, steam, or water need to be maintained at a precise level. If these levels are disturbed, it increases and sustains the oxidation rate of the spent fuel and increases the temperature. The increase in oxidation produces higher amounts of radioactive gasses than the original spent fuel, increasing the gas pressure inside the fuel rod, and causes rupture and leakage of radioactive emissions. Regulation and oversight of this process at commercial reactor sights is necessary due to the dangerous results of an accident.[21]

To maximize storage space, plants have started utilizing the dry cask storage method. This

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[17] John M. Deutch and Ernest J. Moniz, "The Nuclear Option," *The Scientific American*, Vol. 295, Issue 3, September 2006, p. 76-83.

[18] Matthew L. Wald, "As Waste Languishes, Expense to U.S. Rises," *The New York Times*, February 17, 2008, retrieved April 28, 2008 from http://www.nytimes.com/2008/02/17/us/17nuke.html?_r=1&scp=1&sq=yucca+mountain%2C+radioactive+waste&st=nyt&oref=slogin.

[19] James Kanter, "Radioactive Nimby: No One Wants Nuclear Waste," *The New York Times*, November 7, 2007, retrieved April 28, 2008 from http://query.nytimes.com/gst/fullpage.html?res=9C0CE5DF113CF934A35752C1A9619C8B63&sec=&spon=&pagewanted=2.

[20] Office of Civilian Radioactive Waste Management, "Why do scientists think a repository will work?" US Department of Energy, (no date given), retrieved April 28, 2008 from http://www.ymp.gov/factsheets/doeymp0004.shtml.

[21] Committee on the Safety and Security of Spent Nuclear Fuel Storage, National Research Council, "Safety and Security of Commercial Spent Nuclear Fuel Storage," The National Academies Press, Washington DC, 2006.

allows for higher amounts of storage space and also provided plants with a way of transplanting their nuclear fuel waste to other locations. Even with the increased capacity space for nuclear waste at plants, more space will be needed to meet the demands of constant growing population and increased utilization of nuclear power.[22]

This report prepared by Sarah Palma, Travis Morrison and Daniel R. Woodward, with help from Kensington R. Moore under the supervision of Professor Anthony Gierzynski on April 28, 2008.

[22]Committee on the Safety and Security of Spent Nuclear Fuel Storage, National Research Council, “Safety and Security of Commercial Spent Nuclear Fuel Storage,” The National Academies Press, Washington DC, 2006