NUCLEAR ENERGY IN SWEDEN: WILL THE NUCLEAR PHASEOUT FIZZLE OUT?

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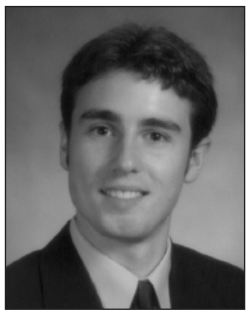

Introduction

Sweden has long stood as a beacon of environmentalism to Europe and the world. A nation rich with vast tracts of unspoiled forests and pristine waterways, it has invested countless resources to uphold rigorous environmental standards which add significantly to its quality of life. Likewise, Sweden has committed itself to sound environmental practices on the global stage. As a signing member of the Kyoto Protocol to counter the effects of global warming, the nation has pledged to curb emissions of greenhouse-causing carbon dioxide gas to pre-1990 levels; today, Sweden's consumption of fossil fuels is one of the lowest in the EU. A nationwide focus on non-carbon electricity generation has aided in accomplishing this goal, as less than seven percent of Sweden's electricity is currently provided by carbon-based fuel sources such as fossil fuels. (Nordhaus) Hydroelectric and nuclear power supply the vast majority of the country's electricity needs, with each comprising nearly half of the total production.

Given these statistics, it would appear that energy issues in Sweden are well under control. In reality, however, Sweden is currently facing a complicated energy dilemma. In a national referendum held in 1980, 76 percent of Swedes voiced a desire to end the nation's dependence on nuclear power. Ever since, Sweden has been planning to gradually phase out nuclear power and search for alternative clean energy sources. Looking back, this decision appears to have been based largely on social fears, cultural attitudes and political agendas. The referendum occurred at a time when little was known about the greenhouse effect of carbon dioxide. The science and economics of today do little to justify eliminating an energy source that has, for nearly four decades, proven to be safe, clean and economical. Although progress to phase out nuclear power has thus far consisted of much talk and little action, Sweden still appears intent on an eventual discontinuation of nuclear power generation. Unfortunately, Sweden's search for alternate energy sources, even when combined with rigorous conservation measures, has met with only limited success. Regarding nuclear power's abundant market share and an ever-increasing demand for electricity, no source of renewable energy currently exists in Sweden that can entirely replace the existing nuclear power capacity. Invariably, a phasing-out of nuclear power would necessitate an increased reliance upon fossil fuels. With global warming now at the forefront of the world environmental agenda, Sweden must reexamine its decision. All energy production carries an environmental consequence: nuclear power produces radioactive waste and the less tangible fear of a catastrophic accident, while the combustion of fossil fuels results in air pollution and global warming. Sweden must now decide which of these is the lesser of the two evils.

The implications of Sweden's ultimate decision are profound and many. On a national scale, a transition to a fossil-fuel-based power supply could increase both industrial and domestic electricity costs, as well as increase Sweden's dependence on foreign energy. An increasingly integrated European energy market means that Sweden's decision will carry continent-wide ramifications as well. Globally, Sweden's decision could represent a symbolic step forward or backward in combating global warming.

History and Growth of Sweden's Electric Power Infrastructure

Throughout the first half of the twentieth century, electricity in Sweden was provided almost exclusively by hydroelectric power plants constructed along the nation's rivers. The terrain in northern and central Sweden consists of rolling hills which slope gently from the mountains along the Norwegian border westward toward the Baltic Sea. Rivers in this region flow from west to east and are fed by storms which carry abundant moisture inland from the Atlantic Ocean. This ideal natural combination of terrain and climate made hydroelectricity an obvious power supply choice. Not only was power generation inexpensive, but harmful environmental effects such as pollutants or waste were nonexistent.

By the mid-1950s, Sweden's hydroelectric power infrastructure had been expanded to what is almost its current capacity. Though not all of Sweden's river systems had been exploited, it was decided that the majority of yet-untapped rivers should remain free-flowing for environmental reasons. Despite providing clean and renewable energy, hydroelectric dams hinder fish migration and disrupt the overall ecological balance of a river basin. Four major river systems were designated as protected from further hydroelectric development. (Lofstedt, p. 1)

It was during the 1950s that Sweden initiated its nuclear power program. Following the "Atoms for Peace" conference held in Geneva in 1955, Sweden decided to use nuclear power as a means of achieving national self-sufficiency in energy production. Sweden's first two nuclear plants, Marviken and Ågesta, were heavy-water reactors. Due to a combination of factors, including technical problems, cost overruns, and the use of low-grade domestic uranium ores, neither plant was ever successful. Marviken was never put into operation, while Ågesta never became profitable and was shut down after just ten years of production. (Nordhaus, pp. 14-15)

Nuclear power only became successful in the mid-1960s, when the safer, more efficient light-water reactor technology came into use. The Swedish government collaborated with the domestic power equipment manufacturer ASEA and several American companies to implement the new technology, and in 1972 the first of Sweden's modern nuclear power plants was opened in Oskarshamn. Between 1972 and 1985, a total of twelve nuclear power generators were constructed: four at the Ringhals plant, three at Oskarshamn, three at Forsmark, and two at Bäresback. (Nordhaus, p. 16) Nine of the twelve units are boiling-water-reactors, while the remaining three, at Ringhals, are pressurized cold-water-reactors. Individual reactor outputs range from 600 to 1200 megawatts for a total power production of 96 terawatt-hours per year (1 tWh = 10^9 kWh). (Uranium Information Centre Ltd. [UIC])

Together, nuclear and hydroelectric power currently account for 93 percent of Sweden's total electricity production, with hydroelectric comprising 48 percent and nuclear 46 percent. (Bergman, p. 151) Renewable energy sources such as wind power, solar power and biofuels provide an additional six percent. Biofuels, which consist largely of waste wood products derived from Sweden's extensive paper and pulp industry, make up the majority of this category. Fossil fuels as a whole provide only a fraction of a percent of Sweden's total electricity production.

The extent to which Sweden has decreased its reliance upon fossil fuels since the 1970s is truly remarkable, and is likely a direct result of the advent of nuclear power. Between the years 1955 and 1970, oil consumption for all energy needs, including electricity, heating and transportation, more than doubled, increasing from 32 to 76 tWh per year. Beginning in 1973, the year after Sweden's first nuclear reactors came online, oil use began to decrease. A reduced dependence on foreign, largely Middle Eastern, oil allowed Sweden to ride out the oil shock of the 1970s with minimal impact. By the mid-1980s, oil consumption had fallen below pre-1955 levels, and in 2001 it accounted for a mere 19 tWh per year. (Royal Swedish Academy...[IVA], p. 55) Most of this oil is consumed by the transportation sector in the form of petroleum. As a result, oil still represents a substantial component of Sweden's total *energy* budget. In terms of *electricity*, however, Sweden's dependence on fossil fuels has become almost negligible.

The 1980 Referendum

The nuclear power program in Sweden had barely gotten off the ground when opposition began in the mid-1970s. Starting in 1972, the Center Party adopted a platform that nuclear power was both "dangerous" and "immoral" (Lofstedt, p. 1) due to an inherent risk of disaster and inability to dispose of nuclear waste. This stance proved popular with both rural voters and the environmentally-minded urban middle class, and by 1976 the Center Party had gained control of Parliament.

Afraid of losing further power to the Center Party, it was the Social Democrats who proposed the nuclear power referendum of 1980. Held in March of that year, the non-binding referendum included the following three alternatives:

1. Continue construction of plants currently being built; phase out all plants at the end of their useful lifetimes, approximately 2010. Allow no new construction.
2. Same as Option 1, but phaseout contingent upon first securing replacement power sources.
3. Cease construction of unfinished plants. Phase out all plants by 1990.

The results of the referendum were as follows: Alternative 1 received 18.9 percent of the vote, while alternatives 2 and 3 received 39.1 percent and 38.7 percent, respectively. It is of note that 3.3 percent of voting Swedes cast blank ballots, and only 76 percent of eligible voters participated in the referendum. (Nordhaus, p. 35) Additionally, none of the three options allowed for the expansion of the nuclear power system. This fact alone would seem to invalidate the referendum results for lack of a "pro-nuclear" alternative. Despite limited choices and a clearly undecided electorate, the Swedish government accepted the referendum as a moral mandate to plan for an eventual phasing out of nuclear power as an energy source.

Progress towards fulfilling the results of the referendum has been painfully slow and riddled with controversy. New energy bills passed in 1991 and 1997 have voiced continued intentions for a nuclear phaseout but have also emphasized the importance of curbing greenhouse gas emissions. In 1993 the independent Energy Commission was created to study the effects of a nuclear phaseout. The Commission determined that it might be feasible to close up to four of Sweden's twelve nuclear power reactors by the year 2010, but that the closure of all reactors would carry "grave repercussions" for Sweden's economy. (Lofstedt, p. 2)

After months of delay, the first successful closure of a nuclear reactor finally took place at the Bärseback 1 reactor in southern Sweden in November of 1999. The Danish government had been placing political pressure on the Bärseback reactors because of their proximity to the Danish capital of Copenhagen, which lay just across the Öresund from the nuclear facility. The Swedish government favored the choice because the plant's relatively small 600 MW size would make acquiring replacement power comparatively easy, relative to the shutdown of one of Sweden's larger plants. The Swedish government was forced to compensate Sydkraft, Bärseback's private owner, by granting it partial ownership of the Ringhals plants and allowing power production at these plants to be increased. Following the closure of Bärseback 1, Bärseback 2 was scheduled for closure first in July 2001, and later by December 2003. These two dates have since come and gone, and Bärseback 2 remains in full operation. Sydkraft would like to see operation of the plant continue through 2017. (Lofstedt, p. 2)

The extent to which public opinion on the nuclear power issue has changed over the past two decades is astonishing. The most recent poll, conducted in December 2003, found that the top environmental priorities of Swedes included curbing greenhouse gas emissions (74 percent of voters) and protecting unspoiled rivers from further hydroelectric development (15 percent). Only 7 percent considered the nuclear power issue a top concern. If a new referendum were to be held today, only 14 percent of Swedes would continue to favor a nuclear phaseout. In total, 84 percent of Swedes could be considered "pro-nuclear"; their stances on the issue are as follows:

- Thirty-three percent support continuing operation of existent nuclear plants to the end of their useful lives.
- Another 33 percent support continuing operation plus performing retrofitting and upgrades to extend the lives of existing plants.
- Eighteen percent support expanding Sweden's nuclear power infrastructure by constructing additional nuclear facilities. (UIC)

Economic Trends in Energy Consumption

Due to a unique combination of climate, industrial presence and government regulatory policy, energy consumption trends in Sweden differ considerably from those of other developed nations. Compared with Europe and other industrialized nations, Sweden's overall energy consumption per capita is actually one of the highest in the world, with consumption exceeding 16,000 kWh per person per year. By contrast, the OECD average is less than 8,000 kWh, and the EU average is just over 6,000 kWh. (Bergman, p. 132) Sweden's large energy requirements are largely the result of three factors: A northern climate means that much electricity is required to provide light and heat during Sweden's long dark winters. Energy-intensive industries provide the backbone of Sweden's industrial sector. Finally, a sparsely-populated, broad geographic expanse results in large energy requirements for the transportation sector.

A reliable supply of inexpensive power has been the operational basis for many of Sweden's most important national industries. Industries such as forestry, paper and pulp processing, and mining make use of Sweden's abundant natural resources, but processing requires large amounts of electricity to create a finished product. These industries are invaluable to Sweden in terms of both economic production and employment. Together, such industry produces $48.5 billion per year, or 30 percent of Sweden's gross domestic product. ("Sweden in Figures…," p. 64) At the same time, they provide nearly one million jobs. ("Sweden in Figures…," p. 58) These industries find a competitive advantage in Sweden, thanks to affordable electricity rates provided by cheap and abundant hydroelectric and nuclear power. They pay an affordable 3.5 cents per kilowatt-hour for electricity (in 1993 U.S. dollars), one of the lowest rates in the EU. By comparison, industrial pre-tax electricity rates in France, Germany, and the U.K. are 5.5, 8.3 and 6.7 cents per kilowatt-hour, respectively. (Nordhaus, p. 29) Sweden nurtures these prized industries further by levying no tax on industrial electrical consumption of any kind. Energy derived from biofuels actually receives a 25 percent subsidy. (BioFinance) This subsidy largely benefits paper producers, who, through the processing and combustion of their own waste, have created a practically self-sustaining energy cycle.

In the residential and commercial sectors, Sweden has encouraged conservation practices through higher prices as its primary means of regulation. Consumers pay a significantly higher rate for their electricity at 5.5 cents per kilowatt-hour. In addition, they are charged an energy tax which brings the final cost of electricity closer to 8.2 cents per kilowatt-hour. Although this tax rate is high in comparison to other EU nations, the final cost of electricity to Swedish homes and businesses still remains far below what residents of France, Germany, Italy, or the U.K. might expect to pay. In these nations, electricity costs range from 11 to 17 cents per kilowatt-hour. (Nordhaus, p. 29)

Sweden and Europe: Trading Electricity

Over the past decade, many of the electrical utilities in Sweden and throughout Europe have become privatized and deregulated, and the European power grid has become increasingly interconnected. As nations begin to import or export larger and larger shares of electricity, the effects of market forces on electricity production are becoming more pronounced. As a result of its efficient system of hydroelectric and nuclear power production, Sweden became a net electricity exporter during the 1990s. By 1998 Sweden was exporting 10.7 tWh of electricity, or about 7 percent of its total generation. (Bergman, p. 151) The closure of Bärseback 1 in 1999, however, left Sweden with an approximately 4 tWh energy deficit, and it became necessary to import electricity to make up the difference. Economically, Sweden was hurt because it was forced to pay higher market prices for energy it could produce more cheaply and efficiently on its own. Perhaps the greater irony, however, is the harsh environmental reality of the situation: Sweden is now paying to import electricity produced at coal-fired power plants in Denmark or newly constructed nuclear plants in Finland. (Lofstedt, p. 3) Sweden's push to phase out nuclear power at home is directly responsible for increased use of fossil and nuclear fuels by its European neighbors. Because Sweden's national carbon budget does not include emissions on electricity produced abroad, the nuclear phaseout still looks good on paper. Dirtier air in southern Sweden and accelerating global warming, however, offer a harsher reality.

Nuclear Waste

Despite economic and environmental statistics which seem to favor nuclear power production, several key arguments against it still exist. In recent times, the most significant of these has been the lack of a reliable means of disposal for high-level radioactive waste generated during power production. An ongoing effort to create a permanent waste repository, however, should help ensure that this criticism becomes dispelled. The Swedish Nuclear Fuel and Waste Management Company, or SKB (Svensk Kärnbränslehantering AB), has been contracted by the government to spearhead this effort. A private company, the SKB manages the disposal of all nuclear-type waste ranging from medical and industrial refuse to spent nuclear fuel. (SKB)

The operation of Sweden's nuclear reactors produces over 200 tons of high-level radioactive waste per year. Waste from all nuclear power facilities is transported by sea to the Oskarshamns power station on Sweden's southeast coast. Here, a storage facility known as the CLAB provides intermediate-term storage. At the CLAB, high-level reactor waste is stored in underground pools for a period of 30 to 40 years. During this period, the waste is allowed to shed initially high levels of heat produced as a result of the radioactive decay process. The CLAB, which has the capacity to hold up to 5,000 tons of nuclear waste, is expected to be filled by the end of 2004. A second cavern of pools, currently under construction, should add an additional 3,000 ton storage capacity to the facility, extending its useful life to 2010. (SKB)

SKB is currently making plans for the long-term permanent storage of nuclear waste in deep underground repositories. In such facilities, high-level waste will be stored at depths ranging from 500 to 1000 meters. Waste will be encapsulated in copper cylinders and placed in caverns carved from the nearly two-billion-year-old granite bedrock. A bentonite clay lining would ensure that waste would remain isolated from groundwater flowing through fractures in the rock. (SKB)

Two potential sites for the final repository are currently being explored: one is located on the Simpevarp Peninsula near the Oskarshamns nuclear plants, and the second is located near the Forsmark nuclear facility in Uppsala County, north of Stockholm. Initial site investigations, which began in 1999, have involved test drilling, environmental impact assessments, and consultation with local citizens and municipalities. Site conditions appear promising, being described as "meet[ing] the regulatory authorities' safety requirements with ample margin" in SKB's SR-97 safety assessment. The report goes on to say: "It is completely feasible to build a safe deep repository on these sites." (SKB) Initial investigations should be concluded by the end of 2004, and complete site investigations and construction lasting 6 to 10 years will commence thereafter. The completed repository should be ready to begin accepting waste by the early 2010s. (SKB)

Nuclear Safety

Like nuclear waste disposal, nuclear safety is another issue which prompts many Swedes to question the prudence of nuclear power. At the time of the 1980 Referendum, concerns regarding the overall safety of nuclear power were likely a leading factor prompting Swedes to favor a nuclear phaseout. The nuclear power industry was relatively young at the time, and the near-meltdown at Three Mile Island in the U.S. which had occurred less than a year earlier made many wonder whether a potentially catastrophic accident could occur at one of Sweden's nuclear plants.

The following decades, however, have proven the performance of Sweden's nuclear reactors to be enviably safe. None of Sweden's nuclear plants has ever experienced a severe core melt, and the SKI — Sweden's nuclear regulatory agency — estimates that the probability of such an event is less than one in 100,000. In terms of routine operation, collective radiation exposures from Swedish plants average 40 percent less than the world average. (Nordhaus, p. 97) The greatest nuclear threat that Sweden faces likely comes from plants operating in neighboring countries. Several Chernobyl-class graphite reactors, such as the Ignalina plant in nearby Lithuania, are still operating in former Soviet-bloc states. (Lofstedt, p. 5) These plants are inherently less safe than those built using Swedish technology, and fallout from a disaster at one of these plants could easily impact Sweden. Ironically, if Sweden is to continue phasing out nuclear power, it will likely begin importing electricity produced in part by these potentially dangerous foreign facilities to meet its domestic power needs.

Alternative Energy Outlook

If Sweden follows through with a phaseout of nuclear power, alternative non-carbon sources of energy must be researched, developed and implemented if Sweden is to meet its present and future power needs. In its 2003 Energy Foresight Report, the Royal Academy of Engineers (IVA) paints a picture of Swedish society in the year 2050. In this idealistic scenario, solar power and the hydrogen fuel cell have become the basis for providing electricity to power everything from industry to residences to transportation. By this time, solar fuel cells are forecast to have undergone enough technological improvement such that their cost and production make them practical for widespread use. Not only would the solar cells provide a substantial share of traditional electricity, but energy produced would be used to create hydrogen fuel by electrolyzing water. Hydrogen fuel cells could then be used to power vehicles, eliminating the need for fossil fuels in the transportation sector as well. Other renewable energy forms based on natural ecocycles, including hydroelectric, wind and biofuels, would play an important role by helping to meet the remainder of electrical demand. (IVA)

Such an outlook appears idealistic to say the least. Even if the technological advances of the next 45 years are sufficient to make such a scenario plausible, however, implementing such a system will require a major overhaul in technology and infrastructure at all levels of Swedish society. Nonetheless, advances are well under way in several key areas which the Academy considers "bridges" to this self-sustaining energy system of the future. Specifically, researchers are concentrating on biofuels, wind power and natural gas. (IVA)

Biofuels are currently the most widely-used alternative fuel sources in Sweden. The majority of biofuels today are wood-based, derived primarily from waste created as a byproduct of the forestry and paper industries. The waste is processed into combustible pellets which can be burned in a controlled fashion to obtain energy. This natural fuel source is consumed at a variety of levels. On the small scale, the wooden pellets can be burned in woodstoves at private residences to provide heat to homes and businesses; this practice is common in rural areas. In more urbanized zones, the fuel is combusted en masse at a CHP (Combined Heat and Power) thermal power plant. Not only does the plant generate electricity through use of a steam turbine, but the resultant hot water is pumped through homes and buildings to create blocks of district heating. In this way, it is estimated that biofuels provide Sweden with as much as 92 tWh of energy per year, a quantity of energy nearly 30 percent greater than the amount of electricity produced by either nuclear or hydroelectric power. (Bergman, p. 148) Recent work in genetic engineering has created prospects for fast growing, high-fiber varieties of plants which could be cultivated and harvested for the specific purpose of combustion as biofuels. Additional advances in the use of organically derived methanol and ethanol as biofuels in the transportation sector also hold future promise. (IVA, p. 8)

It is of note that the combustion of biofuels does produce carbon dioxide gas. Such emissions, however, are reabsorbed when new forests are replanted to replace harvested trees. Thus, the system is in equilibrium, and there is no net increase of carbon dioxide in the atmosphere. Combustion of fossil fuels, on the other hand, releases geologically "old" carbon sequestered hundreds of millions of years ago and confined in rock layers deep below the earth.

Wind power in Sweden contributes a mere 0.3 percent of Sweden's total annual electricity generation. (Bergman, p. 151) Compared to neighboring nations such as Denmark, which receives 12 percent of its annual production from wind power, this number is rather small. (Helby) Nevertheless, the wind power industry in Sweden is expanding. In the past seven years, the number of wind turbines in Sweden has more than doubled, from 300 in 1996 to 631 in 2003. Due to increases in the size and efficiency of new turbines, electrical output during this same period more than tripled from 0.15 to 0.50 tWh of electricity per year. The Swedish government has established the goal of implementing 10 tWh of annual wind power generation capacity by the year 2015. (Lund) Despite its appeal as a clean and renewable energy source, wind power carries several drawbacks. Accounting for capital costs, wind power is 10 to 30 percent more expensive to produce than traditional thermal power. (Helby) Therefore, it must depend on subsidies from the Swedish government to maintain its economic viability. An additional drawback of wind turbines is their tendency to spoil the aesthetics of scenic mountainous or coastal landscapes. Unfortunately, some of the windiest regions of Sweden are also the most valued as natural or recreational havens, causing wind turbines to draw public opposition. (Lofstedt, p. 4)

Despite being a fossil fuel, natural gas holds great promise as a "bridge" fuel to carry Sweden into the solar-hydrogen era. Natural gas is clean-burning when compared to oil or coal, and its market price makes it competitive with nuclear and hydroelectric power. Natural gas also has the advantage that it can be burned in smaller scale CHP plants close to population centers, thus eliminating long electric transmission distances and simultaneously fueling district heating blocks. Sweden currently obtains approximately 9 tWh of energy per year from the combustion of natural gas. (Bergman, p. 148) This figure is expected to increase dramatically beginning in 2008 or 2009, upon the completion of the Mid-Nordic Gas Pipeline. Once completed, the pipeline will run from the Norwegian offshore oil fields, across central Sweden, beneath the Baltic Sea and across Finland to the Russian border. Although Sweden itself has no gas reserves, the pipeline will supply Sweden with natural gas extracted from both Norwegian and Russian fields. (Guomundsson)

The greatest disadvantage of natural gas as an energy source is the carbon dioxide which results from the combustion process. In a standard power plant, this gas would be released into the atmosphere, where it would contribute to global warming. New sequestration technology, however, allows carbon dioxide emissions to be separated, captured and stored. Carbon dioxide is then injected deep underground for permanent storage in appropriate geologic formations. Carbon dioxide injection is currently being practiced in Sweden on a limited basis. Over the past ten years, the cost of this procedure has decreased dramatically, from nearly €100 per ton to less than €30 per ton. Further technological improvements could decrease the cost even further. (IVA, p. 15)

A second disadvantage of natural gas is its finite supply. Because natural gas is a non-renewable resource, supplies will eventually dwindle and its use will become less economical. When this occurs, however, it is thought that the transition to a hydrogen-based fuel cycle will be well underway. The existent gas infrastructure could then be converted to a hydrogen distribution system with relative ease.

Conclusions

The time has come for Sweden to seriously reevaluate its decision to phase out domestic nuclear power production. The scientific discoveries and technological advances of the past twenty-four years have largely discredited any argument for the elimination of nuclear power. As an energy source, nuclear energy has continually proven to be reliable, safe and economically sound. Even nuclear waste, which many considered to be the final unresolved drawback of nuclear energy generation, will soon find a permanent home in deep geologic repositories. As nations across Europe continue to expand their nuclear power capacity, Sweden should see that a nuclear phaseout is, in today's world, a clear step backwards.

In the years since 1980, the greenhouse effect has taken center-stage as the most pressing environmental issue faced by today's society. Swedes have recognized this fact, and Sweden as a nation has made great strides in reducing greenhouse gas emissions. Sweden deserves commendation for its energy conservation measures, as well as research and development of alternative and renewable fuel sources. Such measures, however, can only carry Sweden's energy supply so far.

Sweden now finds itself at a crossroads. The nation needs affordable and reliable energy to grow and prosper, but is nuclear power or fossil fuel the lesser of the two evils? Sweden must look beyond history, politics and a thickening veil of carbon-dioxide to see that nuclear power is clearly the better choice.

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