United States of America:
Energy Policy for the 21st Century and Beyond

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INTRODUCTION

In recent years, energy consumption has been an increasing concern in America. From increasingly frequent power outages California, to an alarming rise in pollution. In this policy we will describe our needs, nuclear history, other systems similar to our goal, and discuss more energy options in addition to the explanation of our plan and its benefits. This policy's goal is to establish an electrical energy policy that is environmentally friendly, economically sound, and has long-term sustainability based primarily on nuclear power.

FUTURE AND CURRENT NEEDS

Currently, there are many problems with the United States' energy policy. In recent years, power outages – especially in California – have been increasing in severity, showing a growing imbalance of the supply and demand ratio. This is perhaps the most obvious result of not having enough power to disperse. Aside from the inconveniences of power outages, 20% of recently polled businesses have moved out or have considered moving out of Californian because of the energy hassles. Thus, aside from affecting one's home and personal necessities, the outages are bad for business and raise the risk of hindering economic growth and development in those areas. The inconsistency of America's power grid is also a key issue here. If all of the continental United States were on one power grid, energy could be easily transferred and shared between different regions. If America used one power grid, the energy problems in California could be greatly alleviated, and maybe prevented permanently. The fossil fuels we use now do not supply us with enough energy to live in the lifestyle much of America has gotten used to, and they also pollute the environment. The air, water, and land pollution are growing concerns amongst environmentalists and laymen alike, though many people cannot get behind a cause they can't see, therefore much of the environmental damage has gone unnoticed and unspoken out for. To help correct these issues and improve the country's efficiency, we need to develop a long term energy source, a reliable and well thought out energy policy centering around a single power grid. This plan would keep pollution to a minimum, produce and optimum amount of energy, making more than enough to go around, and a plan that will survive for decades to come. Plans have been written before, but to be modern, one has to adapt to the times as well as pick the best choice, which is not necessarily the most high-tech.

THE FRENCH PLAN

The French, after World War II, hoped to regain their spot as a world power after an embarrassing time of occupation. With the dropping of the atom bombs in Hiroshima and Nagasaki, they realized the future of technology lay in nuclear energy. It held such power, the essence of modern technology; what would bring France together as a country.

Their first few plans consisted of isolated systems on different power grids for each region, they soon discovered this was a poor plan. A mulit-grid plan would cut-off one region from another. Region A would not know how it affected or was being affected by region B. They quickly moved on to a plan that looked at the whole picture, rather than just remote aspects. Early plans were centered around quality, whereas later plans around quality and quantity of energy and life. To incorporate all aspects of life into planning this dramatic change of energy source, modernization commissions were formed in focus group like atmospheres for each region of France to determine how a nuclear plant should be incorporated and integrated into each region.

To start, sociologists would study a region's statistics such as agriculture, economy, politics and other demographics and come up with as close to a homogeneous system as possible, but usually leading to a few broad heterogeneous systems. The French felt that by incorporating every aspect of life into this new policy, they could gain public support as well as make the transition easier and more comfortable for their citizens. Once these systems were studied thoroughly, the modernization commissions took over and looked into the ways in which nuclear power could be incorporated into specific areas. To include everyone in these decisions, people from all careers on the spectrum were chosen to be on the commissions, everyone from artists and writers to union leaders to architects and urban planners. Together, they were able to look at the large picture of nuclear power on many different levels.

The Science Behind It

At the same time, nuclear experts were developing ways to create safer nuclear power. A major concern for the French was to develop a method uniquely French way of producing nuclear power. This would boost the people's sense of patriotism and also let the world know of France's power in the new geopolitical world. They decided on using a gas cooled, graphite moderated system. In this type of reactor, blocks of extremely pure graphite are used to control the nuclear pile, while a flow of helium cools the pile and extracts energy. With this new power system, France could produce enough power to fulfill their energy needs, and they also planned on supplying energy to French speaking countries in Africa. African colonies loyal to France could provide Uranium (U) and oil to fuel the reactors and other things that require oil to run. Thus, not only would France be making enough power for themselves, but also providing other European and third world countries with cheap and efficient energy.

Thinking Long-Term

Beauty and coordination were highlights in France's big picture plan. They found ways to make the reactors blend in well with the natural landscape as well as keeping costs down. They also took the opportunity to see past the short-term benefits and potential squabbling amongst transportation departments and turned toward a long-term plan that coordinated different systems of travel, to make ease of transportation optimum.

In the 1960's, however, Americans introduced light water reactors (LWR), which were more efficient than France's gas graphite systems. During a time when technology was tied very closely with politics, a tough and controversial decision came into play: should France go with the better American LWRs, or stay with the graphite reactors? The Commission of Atomic Energy (CEA), centered more around politics, wanted the French system, whereas the Electricite de France (EDF) wanted to implement LWRs because they saw the benefits both economically and technologically of using them. Eventually a committee was formed by both the EDF and the CEA to research the economics behind the decision. In the end, LWRs were chosen because even though graphite reactors would have been French, light water reactors were cheaper in the long run. As a response to implementing American systems, the LWRs were later modified to have a French influence in the design.

Waste

The French National Agency for radioactive waste management (ANDRA) keeps tabs on the waste produced by Frances nuclear power plants. There are many places and ways to dispose of nuclear waste. There are treatment facilities to melt contaminated scrap metal and an incinerator for solid and liquid wastes, currently there is a research program studying the use of clay and granite for the purpose of containing high level and intermediate level waste underground.

America and the French Plan

Currently, there are 59 operational nuclear power plants in France, a country the size of Texas. In a country the size of the United States, and with terrain as different from deserts in Arizona, to busy downtown areas like New York City, the French plan could be used, but needs to be "Americanized." Nuclear energy should be used where possible, appropriately and in harmony with its surroundings. As far as pride goes, few things within the past 20 years have made Americans as patriotic as September 11^{th}, and even then it seemed to be a passing fad. For the French plan to work, Americans would have to get behind and support it. This involves education and convincing Not in My Backyard (NIMBY) proponents that nuclear energy is good if used correctly. Also, different states need to work together to study the effects of and on different regional areas as well as see past the short term. This plan might be better implemented on a state-to-state basis, a more manageable level, but with that brings an onslaught of political uproar. For this plan to work, politicians, educators and scientists alike must work together for the long term good of America.

NATIONAL ELECTRICAL ENERGY POLICY PROPOSAL

This proposed national electrical energy policy is intended to be a sustainable long-term energy solution to the current problems raised above. One of the main goals of this policy is to significantly reduce the dependence on fossil fuel based electrical power sources over the next few decades while improving the national electrical energy infrastructure.

There are three major components of this proposal: The first component is a revitalization of the current nuclear power generation establishment, to increase electrical production and decrease nuclear waste. The second component is an expansion of the power distribution infrastructure, specifically high-tension electrical transmission lines. The last component is a massive public education and relations push.

Nuclear power generation plan

The nation's currently operating 104 electric power generation plants are mostly light water reactors (LWRs). Almost all of these plants were completed prior to 1981 using the technology available at the time. Since then there have been massive technology improvements, especially in the area of instrumentation and control (I&C). These improvements increase the safety and operating efficiency of nuclear power plants when applied. Due to deregulation and increased competition for power, the national average up-time for nuclear power plants has increased to 92% from the mid 80s. Many companies have opted to spend the money to install these new I&C systems along with making other improvements along the way. In most cases, plants can be up-rated to produce more power than they were originally designed for. National electric companies have also purchased multiple nuclear power plants, consolidating knowledge and standardizing operating procedures. However these companies have been met with legal problems with transferring the decommissioning funds set aside for when the plants are taken out of service at the end of their operational lives.

Most current nuclear reactors are reaching an age where they need to be relicensed for continued operation. There is nothing unsafe or wrong with these plants, but current regulation requires relicensing by the NRC, which is currently a long and arduous process. Current licensing issues also a problem for building new reactors extending construction times to upwards of fourteen years. Companies are now looking at creating standardized pre-approved designs to streamline the licensing and building process.

- We recommend the NRC streamline its process of licensing current and new nuclear power plants while maintaining sharp watch over safety and environmental protection.

- We recommend that both federal and state governments provide incentives in some form to nuclear power plants that install new instrumentation and control systems or new safety measures.

The most significant problem with either new or current LWRs is the production of high-level nuclear waste in the form of spent fuel rods. These fuel rods still contain a significant portion of unburned uranium (U) fuel along with a significant proportion of plutonium (Pu), where only about 3.5% of the fuel rod is fission products. Currently, the used fuel rods are stored mostly on-sight at each reactor and not reused. According to the Energy Information Administration, the United States has stockpiled 38413.7 metric tonnes of spent nuclear fuel from 1968 to 1998. Just recently federal government approved the Yucca Mountain underground storage facility for nuclear wastes in Nevada. However, there is no way for Yucca Mountain to possibly contain all this waste, including at least 340 metric tonnes of plutonium. Furthermore, if we began burring such high level waste, we would have to guarantee its security and isolation from the environment for over 10,000 years, which is impossible.

There are a number of countries that have invested in nuclear fuel reprocessing and have been successful. A fuel reprocessing plant uses chemical and mechanical means to separate the components of used fuel rods. The unused uranium fuel can make new fuel rods that can be fed back into the LWRs. The remaining fission products and the plutonium can then be dealt with separately. The new technologies, especially those dealing with automation, have significantly increased the safety and reliability of new fuel reprocessing systems. Fuel reprocessing in the United States was banned by executive order in 1977 for fear of nuclear proliferation because reprocessing separates out plutonium. However, the ban was lifted in the early 80s when it was realized that the benefits of fuel reprocessing outweighed the risk of nuclear proliferation. It is unfortunate that because of the ban and the falling support of nuclear power in the 1980s that reprocessing was not ever implemented in the United States. Still, adopting a nationwide spent fuel reprocessing program would create significant mass of plutonium and other separated fission products.

The transportation of spent nuclear fuel and materials to the reprocessing plants has caused some fears in the general public. However, the issue has already been addressed by the National Spent Nuclear Fuel Program (NSNFP) under the Department of Energy. The NSNFP has developed and tested numerous transportation casks that can withstand severe mechanical shock. These were to be used to transport spent nuclear fuel by rail to underground repositories such as the Yucca Mountain site. In this case, the same transport infrastructure can be used to transport waste to the reprocessing facilities and return new fuel rods.

There needs to be a solution to both the need for electrical power generation and elimination of plutonium fuel material. The answer is in a high temperature gas cooled reactor using a “pebble bed” style fuel source; a pebble bed modular reactor (PBMR). The PBMR uses extremely high temperature helium gas as both a moderator and as a heat transfer medium. The “pebble bed” refers to the way in which the fuel is loaded into the reactor. Unlike LWRs, where fuel is contained in long metal tubes, a pebble bed style reactor is loaded with millions of 60mm ceramic spheres that contain a small granule of nuclear fuel at the center. Each sphere is perfectly inert, entirely self contained and almost impossible to break open once formed. This type of PBMR can be fueled with the plutonium from the fuel reprocessing operations. Unlike the LWRs, it has a 90% burn up rate of plutonium-239. The remaining fuel and waste is sealed within the fuel pellets. These reactors are can be build modularly in small units and have very high power generation efficiency. Furthermore, if the production of the fuel pellets is integrated into the waste reprocessing system, there is virtually no chance for nuclear proliferation. The PBMR can even use weapons grade plutonium from the decommissioning and disarming of nuclear bombs. The other benefit of PMBR systems is their decreased complexity and increased safety. It is not possible for a PBMR to melt-down because as the temperature increases the output of the nuclear fission decreases.

- We recommend that federal and state governments, under the direction of the Office of Civilian Radioactive Waste Management, begin a nationwide nuclear spent fuel reprocessing program for all spent uranium fuels. As part of this process, separated plutonium would be formed into ceramic fuel pellets suitable for use in high temperature gas cooled reactors.

Transportation of hazardous materials is to be carried out using existing infrastructure as outlined by the National Spent Nuclear Fuel Program.

- We recommend a significant number of high temperature gas cooled pebble bed style reactors be built for the purposes of generating electrical energy and destroying plutonium fuel from LWR waste and weapons material.

Even with fuel reprocessing and PBMRs, a significant amount of high-level nuclear waste is created. This is waste that would have to be buried in a geological waste repository for thousands of years due to its radioactive half-life, although there would no longer be the need to worry about future nuclear weapons threats. This waste, in addition to being radioactive and biologically toxic, will give off significant heat over its half-life as the radioactive isotopes decay and release heat. However, if the waste is placed into a particle accelerator and bombarded with particles, the radioactive decay can be forced. In this manner, the radioactive waste material can be transmuted into medium and low half-life products while giving off significant energy in the form of heat. This excess heat can be used to generate the electricity needed to run the particle accelerator. The transmuted waste is still radioactive but would only need to be isolated for about one hundred years, which is far less than the 10,000 years needed by the current waste disposal policy. The system could power itself while at the same time significantly reducing waste heat being put into the geological repository. Furthermore, the waste would be of much less volume and mass, and could be packed closer together because it would no longer be fissile.

- We recommend that the United States construct particle accelerators for the nullification and transmutation of nuclear high-level waste into lower grade waste while generating the electricity required to power itself.
- We recommend that the United States consolidate, encapsulate and store remaining transmuted nuclear waste materials in geological repositories like those at Yucca Mountain.

Other technologies exist for nuclear power generation. One technology type, the breeder reactor, is very efficient when properly designed. It can extend useful operating life of a given supply of fuel by up to thirty times. In the past, breeder reactors have had some problems with operation and they are difficult and expensive to build. Unlike PMBRs, Breeder reactors must be built as one large unit; they currently aren't built as small modular units.

Another very important technology is fusion. Work is currently underway to make fusion a viable and competitive power generation option. Fusion offers a potentially unlimited source of energy that could also be absolutely zero emissions with the right technology. At the moment, fusion is not a mature technology but it is important to support work that would lead to widespread use of fusion for power generation.

- We recommend that the United States, both in the public and private sectors, continue to fund research and set up new research into long term energy generation solutions using breeder reactors and fusion technology

There are significant benefits to using renewable energy sources. Hydroelectric and geothermal energy options are very limited and have already been exploited for the most part. In these cases, the only option is to attempt to increase the plant operating efficiency. Other renewable energy sources, such as wind and solar, are still available across the country, but their use is very dependent on location and available space and conditions. Renewable energy sources are not inherently environmentally friendly either. For example, hydroelectric power usually damages the local ecology, and solar power requires highly polluting semiconductor processing plants. In any case, the local conditions determine if a specific renewable energy option is economically and environmentally practical.

There are also situations where a nuclear plant might not be practically possible for various reasons. A high-efficiency fossil fuel electrical plant might be an acceptable option in some cases, even though it is not viable as a long-term sustainable energy source. Consuming fossil fuel, even if not in combustion, still produces the same pollutants that enter the environment if not in the air then in the ground or water. However, before the public becomes fully supportive of the directives outlined in this proposal, there will be some instances where fossil fuel plants would be best.

- We recommend renewable, environmentally benign energy sources be utilized where appropriate and reasonable determined on a per site basis by local authorities and businesses.
- We recommend research into non-nuclear sustainable energy sources continue to be funded and encouraged by both public and private institutions and corporations.
- We recommend that construction of fossil fuel based energy generation plants be discouraged except in those instances where use of fossil fuels shows a significant advantage over the new nuclear and renewable energy sources, or where construction has already begun.

National Electric Distribution Infrastructure

Solving the issue of electricity generation does not resolve problems with electrical energy distribution. Currently, North America is segmented into four integrated transmission grids. These grids are currently very near capacity and their interconnection is rather limited. Furthermore, there are bottleneck issues within each grid causing inefficient and even impossible power transfer between locals. The effects of this are especially felt right now in California and New York. The cause of these bottlenecks is partly infrastructure and partly regulation. Power shortages and even blackouts can be caused not by a need for more power generation, but more power distribution. The limits imposed by the current power grid infrastructure drive prices up and power reliability down. What is needed is an open fully national electric grid.

The standard technology for electric transmission lines is high-voltage high-tension copper or aluminum wires. The problem with this system is that these metals, although good conductors, still have resistance. Resistance in the transmission lines causes losses and reduced transmission efficiency that forces power plants to be nearby the point of use. When extra power is needed from other plants on the grid, electricity is wasted overcoming the resistance of the transmission lines. In some places where the bottlenecks are really bad, it can be impossible to send power some places because of the resistance. Superconductors can be used in order to overcome the resistance of standard metals. Superconductors work at very low temperatures, hundreds of degrees below freezing, and are made of unique materials. When cooled to the proper temperature, a superconducting wire will have virtually no resistance. When applied to a national electric grid, superconductors would fantastically improve capacity and quality of power transmission. However, because superconductors do require to be chilled, they currently are best suited for very high capacity runs (like those between a power plant and a city). As the technology matures, superconductors could be applied to wider and wider applications.

One prominent researcher and respected college in nuclear power engineering, Dr. Chauncey Starr, proposed a long term, sustainable solution called the “SuperGrid.” The basic idea of the SuperGrid is to build many nuclear power plants that produce more power than is needed locally. These power plants can be located far away from where the power is to be used because they are connected together and to the end users with high capacity superconducting transmission lines. A hydrogen generating station at each nuclear power plant creates liquid hydrogen that is used to cool the superconducting wires. As a benefit of the system, the hydrogen can be tapped from the SuperGrid and used to power transportation or local electricity generation. In this manner, the SuperGrid generates and distributes both electrical power and hydrogen fuel across the country with very little waste. Such a SuperGrid would be able to not only free us from the dependency on fossil fuels for electricity, but also free us from international oil used to power the transportation industry.

- We recommend that the Department of Energy work with the states and independent power producers to unify, upgrade and expand the four electric grids in the United States to form one coherent national electric grid. We also recommend that regulation of the national electric grid be standardized and updated to reflect our current and future energy needs.
- We recommend that the national electric grid make use of superconducting transmission lines as it becomes practical, starting with major metropolitan areas and moving outward.
- We recommend that the Department of Energy look into implementing a nation wide SuperGrid plan similar to the one described by Dr. Chauncey Starr.

Public Education

It is important to recognize the concerns the public may have about nuclear issues, as this plan advocates a significant increase in the use of new nuclear technology. During the 1960s and 1970s there were a number of minor accidents along with growing concerns about the environment and spiraling regulation costs that caused almost a backlash by the public and government officials. This caused a resurgence in fossil fuel use, opposite the goals of nuclear power. Current concerns about nuclear power are mostly caused by the fear of the unknown. New technologies and policies are significantly different, safer and cleaner than the first generation of nuclear power plants. However, the public has not been made aware of this. Little effort has gone into educating the public about nuclear technology.

An integral part of our energy policy is to inform the public about the truths of nuclear power and clear up some of the myth regarding the subject. For instance, very few people know that the NRC makes daily safety and compliance inspections at each an every nuclear plant around the country. To start, we plan to integrate nuclear education into the classroom as part of public school curricula. Nuclear power plants would open up for visiting days and give tours, explaining how the plant works, how radiation effects a person, and some benefits of radiation, such as irradiation of food, to children as young as in primary school. In secondary school curricula, more nuclear science would be taught; a furthering of what they had learned in primary school. This curriculum would include basic physic and chemistry behind the nuclear process, with its aim of getting people more interested and aware of nuclear science. College should also start recruiting nuclear engineers at the high school level, offering scholarships and other incentives to invoke further interest in pursuing the field, which will lead to more research, and thus a growth cycle of research and development will be formed. An educational system that promotes nuclear energy will in turn perpetuate a society that supports nuclear energy.

Outside of the school system, this policy plans to launch a massive public relations campaign promoting truth and dispelling the myths of nuclear energy. Television ads, bus ads and billboards, and door-to-door information in pre-election boosts are just a taste of the nationwide pro-nuke campaign. Similar to the Truth ads regarding cigarette smoking, the nuclear campaign would let the public know what is really going on inside the great steam stacks. By increasing general knowledge and understanding of nuclear technology, misconceptions and fears can be alleviated.

- We recommend the Department of Energy, industry leaders, and academic leaders being a positive public relations and public education campaign on the benefits and safety of nuclear technology as utilized in this proposal.
- We recommend the Department of Education look into school curriculum to see if changes can be made to increase interest in and preparation for a career in engineering and the sciences.
- We recommend that state and federal governments encourage colleges and universities to recruit and expand their programs in engineering and the sciences in order to promote understanding and careers in those fields.

Economic and Environmental Impacts

Switching to a nuclear society would bring many benefits to the economy. Research committees would have to be set up to look into the qualifications of different regions to host plants, engineers would be busy researching developing safer and more efficient nuclear energy, thousands of plants would be made to build the actual plants, while many more created to maintain and operate each plant. International independency on fossil fuels would also be obtained. No longer would America have to rely on oil from the middle east, instead we could create, use, and dispose of our own energy to be used in transportation, housing, commercial industry, and much more. Finally America would have a low-cost, high-stability power supply, which boosts peoples buying confidence, which in turn boosts the economy.

The policy outlined here will make a significant impact on the environment. By eventually eliminating fossil fuels as a source of electric power generation, direct air, water and land pollution can be virtually eliminated. Even technologies such as “Clean Coal” still produce hundreds of tonnes of solid waste slag and carbon dioxide because they are based on a fossil fuel resource. The entire supply and waste chain for the system proposed here is completely closed with the exception of the small-scale mining of uranium. The waste management system proposed here using particle accelerator transmutation reduces the half-life of radioactive isotopes in waste by over 100 times along with decreasing the intensity of the radiation. Any remaining wastes, buried in geological containment facilities, would be sealed away and completely degraded within a couple of hundred years. With the new technologies and waste management techniques, there is an extremely low risk of contamination. This is important in the long-term as there is no way to predict the geological, social and political conditions of geological waste repositories tens of thousands of years from now as would be required by current policy.

Of course, the national electrical energy policy is a delicate issue that hinges not only on necessity, economics, environmental issues, and public opinion, but also on political will. The current fossil fuel industry is enormous and has significant lobbying power. In the Presidents own national energy policy, the observation that nuclear energy is the desirable choice is repeated over and over but is always followed by a statement promoting fossil fuels and ignoring the need for nuclear power plants. Other than the pollution caused by using fossil fuels, there is nothing wrong with the industry. However, fossil fuels are a non-sustainable energy and given the significant advantages it is important to move towards a newer, progressive, and sustainable electrical energy policy.

- We recommend that this plan be put into action as fast as possible to the betterment of the United States, its citizens, its economy and the environment.

Appendix A: Sources of electrical energy

Fossil Fuels

About 65% of electricity generation worldwide involves burning fossil fuels, principally coal, then natural gas and oil. Fossil fuel plants are the bulk of construction of new generating capacity, and energy companies seem firmly committed to using more fossil fuel in the future. There are several upsides to using fossil fuels. The cost of building a coal-burning plant is lower than any equivalent. There is a good distribution structure for fossil fuels, and significant domestic supplies of coal and natural gas. New technologies have been able to reduce hazardous emissions from combustion and improve the efficiency of power generation. These have led to long term energy plans based on coal.

The detractions to fossil fuel usage are almost too numerous to list. From an economic standpoint, while capital investment is lower, the price of fuel is a significant share of the cost of generating electricity. Natural gas plants, favored for their low emissions and utility in urban areas, are subject to an extremely volatile and expensive fuel market. Fossil fuel plants are notorious for causing environmental problems, especially air pollution. No matter what plans are proposed to capture CO_2 and convert it to solid or liquid forms, fossil fuel combustion produces prodigious quantities of the gas. Combustion also produces very large quantities of NO_2 and NO, which lead to acid rain. Finally, to silence any critics of nuclear power, burning coal releases several **tons** of uranium into the air and the slag heaps each year.

Renewable Sources

Renewable energy sources ideally are the most ideal of any power supply. They have no fuel costs and no emissions (but may have high implementation and maintenance cost). They ultimately rely on capturing potential energy from the sun, or gravity, or the Earth’s core. Their greatest weakness is that they are severely limited by geography. Some regions of the earth are simply unsuitable for any form of renewable energy capture. These sources can be divided broadly into low and high density sources. Low density sources such as photovoltaic solar and wind power require large amounts of surface area. High density sources such as hydroelectric and geothermal are concentrated at certain favorable locations.

Hydroelectric power is currently a major source of energy, providing more than nuclear on a worldwide basis. Hydroelectric stations have typically been immense installations, occupying vast areas with lakes. All of the readily available sites for hydroelectric power have been utilized. In the future, hydroelectric power may be feasible to implement as small to micro sized plants, generating between 10 MW and 100kW of electricity. These smaller plants would have a much smaller environmental impact than the massive public works projects operated now. Hydroelectric plants have been constructed largely by government agencies due to the cost and scale of construction. Privatized energy companies are not willing to spend as much on capital investments, making small hydroelectric stations more feasible. Geothermal energy, another high density source, is of small importance. There are even fewer locations amenable to geothermal power generation, and the power output of any station is small in comparison to other sources. Where geographically possible, it can be used to supplement the grid, but it cannot be used as a primary source of electricity.

Photovoltaic solar power and wind power require very large areas of favorable space to generate power. Even where open land is available, the total output is not comparable to a medium or large nuclear plant. There is a great amount of improvement to be had in the power output of these methods, and their development should be continued. At this time, they are suitable only as a supplemental source in small areas. The amount of solar energy at 60° latitude is less than half of that available at the equator. This effectively rules out solar power as a useful power supply in the northern USA.

Nuclear

Current light water reactors (LWR) are inefficient, a safety risk, and feared by the general public. Power companies do not want to build them because of the long construction time, and significant capital expense. While they do not need to be shut down before the end of their normal useful life, they are not suitable as a future power source. All of their faults can be improved on significantly.

Standard LWR designs are centered around an inherently critical nuclear pile. . A typical plant is a tremendously complex system, with miles of wiring and pipes, and thousands of valves and switches. This means that there are millions of points of failure. In the event of a catastrophe, active safety systems such as control rods and redundant cooling systems can fail to prevent an accident.

The next generation of nuclear plants will be simpler and safer. BNFL/Westinghouse has a series of Advanced Passive Light Water (AP) reactors that is currently undergoing design certification by the Nuclear Regulatory Commission. These AP plants are based off of existing PWR designs, but add an additional twenty years of design experience. Westinghouse engineers decided to simplify the power plant to make it safer, and ended up using only 20% of the piping, 30% of the wiring, 50% of the valves, and 65% of the pumps of current PWR technology. Passive safety systems make the largest impact. Instead of the mechanical power of active safety systems, passive systems rely only on natural forces such as gravity and gas pressure to bring the core to subcritical levels. The US Navy contributed some of its extensive nuclear design experience, backing up the reliability of the passive safety system. Additional design improvements include new ways to route cooling pipes that reduce the number of failure-prone welds, and a new reactor pressure vessel fabricated without longitudinal welding.

The AP series of plants are not only safer, but even more economical. The nuclear pile is constructed to handle more efficient fuel rods which can be run for longer periods of time. A longer fuel burn-out time means that a greater part of the fissionable uranium is used, and that the time spent offline refueling the plant is reduced. It has been common for nuclear power plants to take upwards of 15 years to be built. The AP600 was designed to go from groundbreaking to fuel loading in a three year construction period, and this has been achieved with the demonstration reactors. This is a huge improvement over past PWR plants, and should make the AP600 and AP1000 plants very attractive to utility companies looking for a flexible nuclear solution. The AP600 plant design, producing 600 megawatts of electricity, was approved for use by the NRC in 1999. The AP1000 plant is similar to the AP600, with a denser fuel assembly, beefier safety and cooling systems, and a nominal electricity output of 1090MW. It is currently undergoing evaluation by the NRC, and is expected to be certified in 2003.

A unique feature of nuclear power is that it can produce its own fuel. So-called 'fertile' isotopes such as Thorium-232, or even common Uranium-238 can absorb a neutron and transmute into fissile isotopes. A well-designed breeder reactor can use fuel 30 times longer than an equivalently fuelled light water reactor. However, power output from breeder reactors is typically less than from a light water reactor. Though breeder reactors were used first, they have not been used often for public electricity generation. The Fermi I plant operated for a short period of time before being shut down, but never went into commercial use. Part of this is because breeder reactors produce large amounts of plutonium, a significant weapons risk. Another reason is because the most efficient designs are cooled using liquid metallic sodium, which explodes on contact with air. Most breeders built have suffered from sodium leaks, and the problem has shut down more breeders than any other. While at some point uranium supplies will be reduced to critical levels, the price and supply of fissile uranium are not projected to impact nuclear power for centuries. When breeder technology is improved to the point where it is safe and efficient, it can be used for electricity generation.

A new approach to reactor design is the so-called "pebble bed" modular reactor (PBMR). Also known as modular helium reactors (MHR), and high temperature gas cooled reactors (HTGCR), these reactors have been developed since the 1980s, and exist across the globe as prototypes. Extensive development has been done by General Atomics in the USA, and by an international consortium based in South Africa. The key technical development with this type of reactor is the fuel elements. Instead of using metal-clad rods of uranium oxide or PuO_2 mixed with UO_2, they use ceramic composite spheres 60mm in diameter. A small grain of fuel is surrounded by layers of porous carbon, pyrolitic carbon, silicon carbide, and other ceramics. These pellets are highly corrosion resistant, durable, and self-contained. The risk of release of radioactive material is very small compared to standard fuel rods. Since the fuel is largely graphite and ceramic, not metal, it can withstand much higher temperatures, and it will not melt. The reactor core is composed of blocks of nuclear grade graphite, filled with approximately 330,000 fuel spheres, and 100,000 spheres of graphite for moderation. A feature of this design is that the reactor can be continuously refueled by adding new fuel pebbles at the top of the reactor, and releasing burnt out pebbles from the bottom of the reactor through a simple gravity feed. This eliminates the long offline period necessary to refuel a conventional PWR, increasing the efficiency of the plant. Depending on exactly how the core is configured, a PBMR can be fueled with either standard enriched uranium, or with a mixture of reprocessed PWR fuel containing up to 60% Pu-239. When used to destroy plutonium, a PBMR uses fuel elements for two to three years, burning out about 90% of the initial Pu-239. What remains is no longer suitable for manufacturing a fission bomb, and can be destroyed in an accelerator-driven modular reactor. PBMRs are designed to output between 120 and 150 MW of electricity per reactor. This figure initially seems low, but as a modular design, a typical plant would contain 3 to 5 reactors. The modular design leads to lower construction costs than even an advanced LWR, and only a two year construction time. An inherently safe design, flexible construction options, and convenient waste for disposal should make PBMRs an attractive power generation option for utilities.

Appendix B: Figures

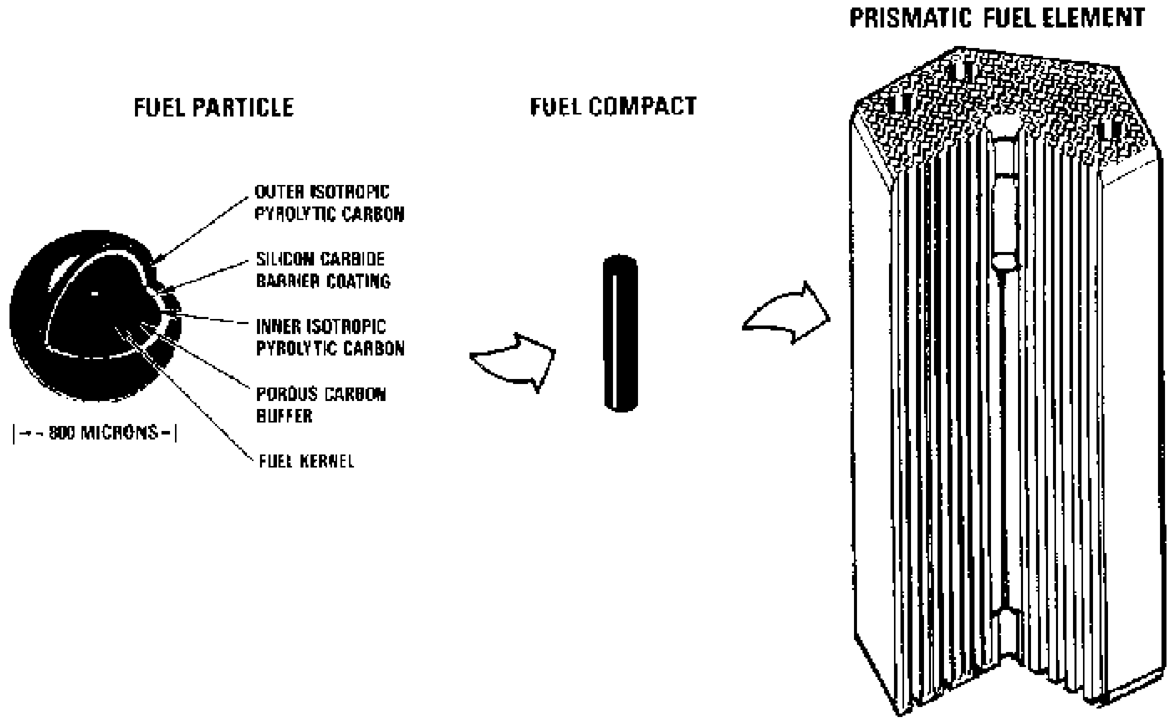

Figure 1: Components of HTGCR fuel. (Richards)

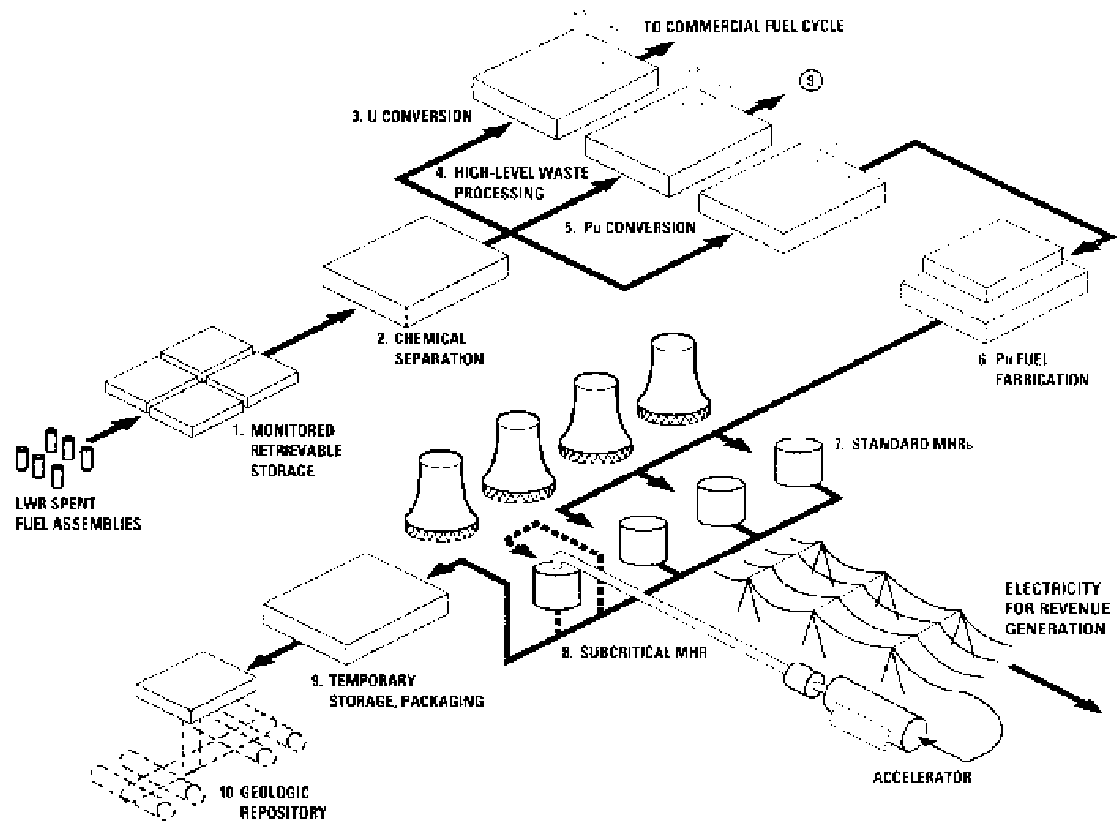

Figure 2: Nuclear Fuel Cycle as proposed: Waste from LWR is separated, reprocessed, and fabricated into HTGCR fuel elements. Pu is burnt out, then intermediate half-life isotopes are destroyed. The remaining wastes are buried. (Richards)

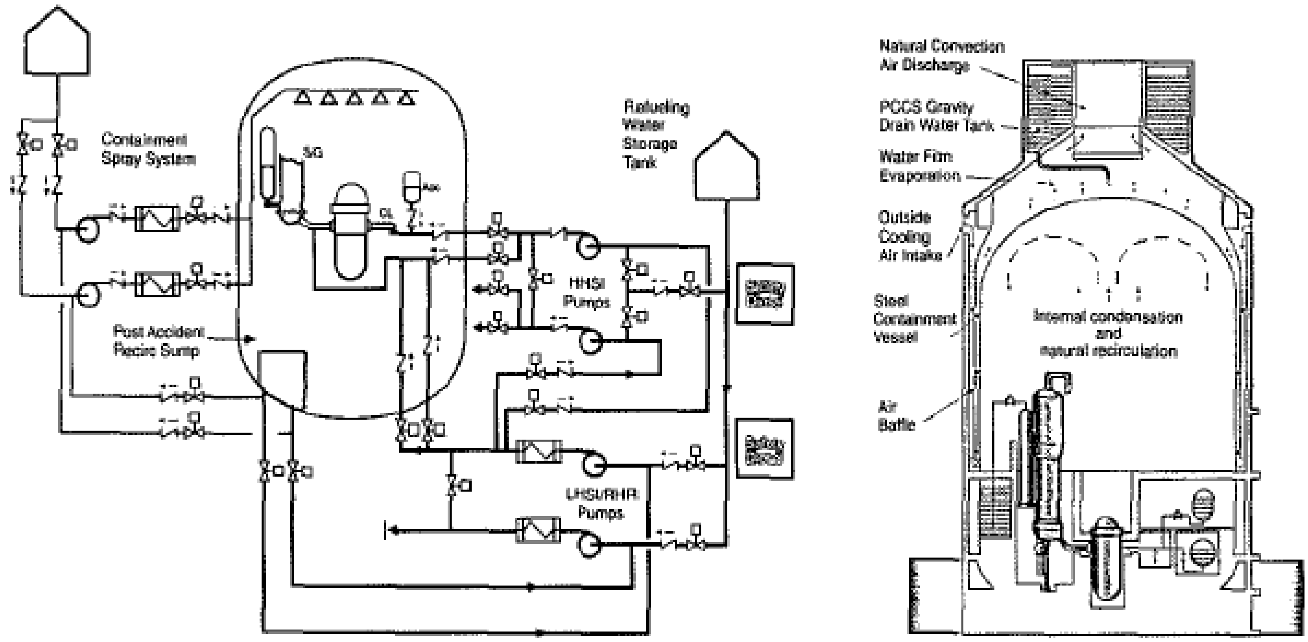

Figure 3: Simplified safety systems in the AP1000 plant. A typical PWR plant is on the left, the AP1000 is on the right. The entire external system of piping and pumps has been removed.

APPENDIX C: REFRENCES

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