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HYDROGEN PRODUCTION FROM NUCLEAR SOURCES

An Interactive Qualifying Project Report

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by

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Abstract

Global energy consumption will surpass oil production and alternative methods must be established before the situation escalates. Utilizing nuclear power to produce hydrogen is a viable solution to this problem. The methods of electrolysis and steam reforming are used to extract the hydrogen molecules. These methods can be accomplished at a nuclear site of varying sizes depending on the needs of the community. Compressed hydrogen gas offers the simplest and least expensive method for onboard storage of hydrogen. Carbon fiber storage tanks are currently under development to enhance the safety and reliability of hydrogen transportation and containment. Research shows that the general populace would not mind an increase in the production of nuclear power plants once they were informed of the energy issues. In contrast, the location of these power plants to the individual had an adverse affect on their decision. The further away from their hometown the nuclear site was the more the individual was open to the idea. Survey results indicated that hometown, county and state locations were acceptable with varying degrees of skepticism.

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1. Introduction

Nuclear Power is the use of regulated nuclear reactions transferred into a useful energy form, for example propulsion, heat and the generation of electricity. Nuclear energy requires a fissile material with a natural rate of radioactive decay that is accelerated in a controlled chain reaction that creates heat to drive a steam turbine. This is then used for mechanical work and also to generate electricity. The United States, France, and Japan are the top 3 nations with the most nuclear reactors worldwide as of December 31, 2005, as shown in Figure 1.

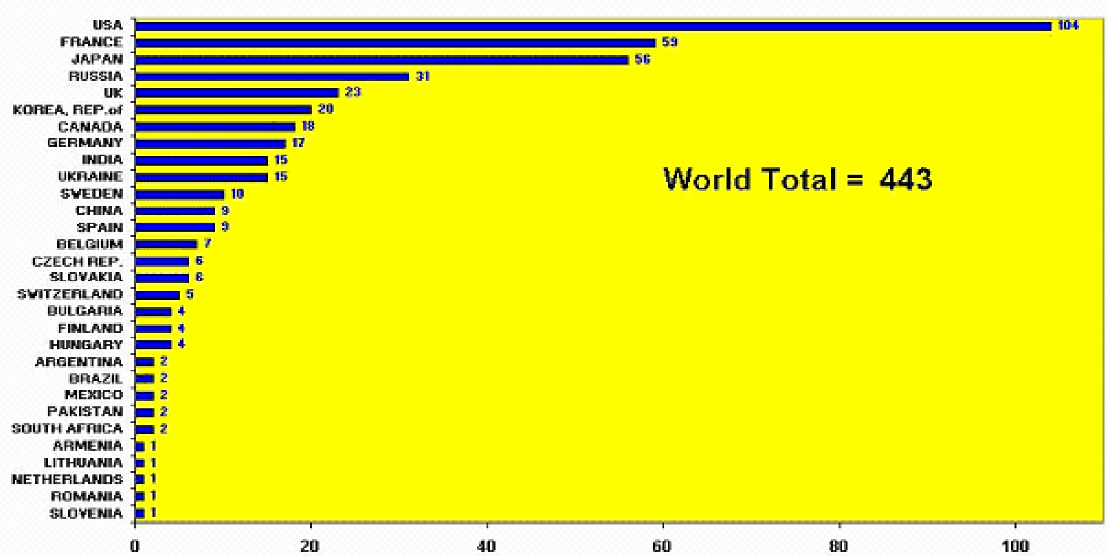


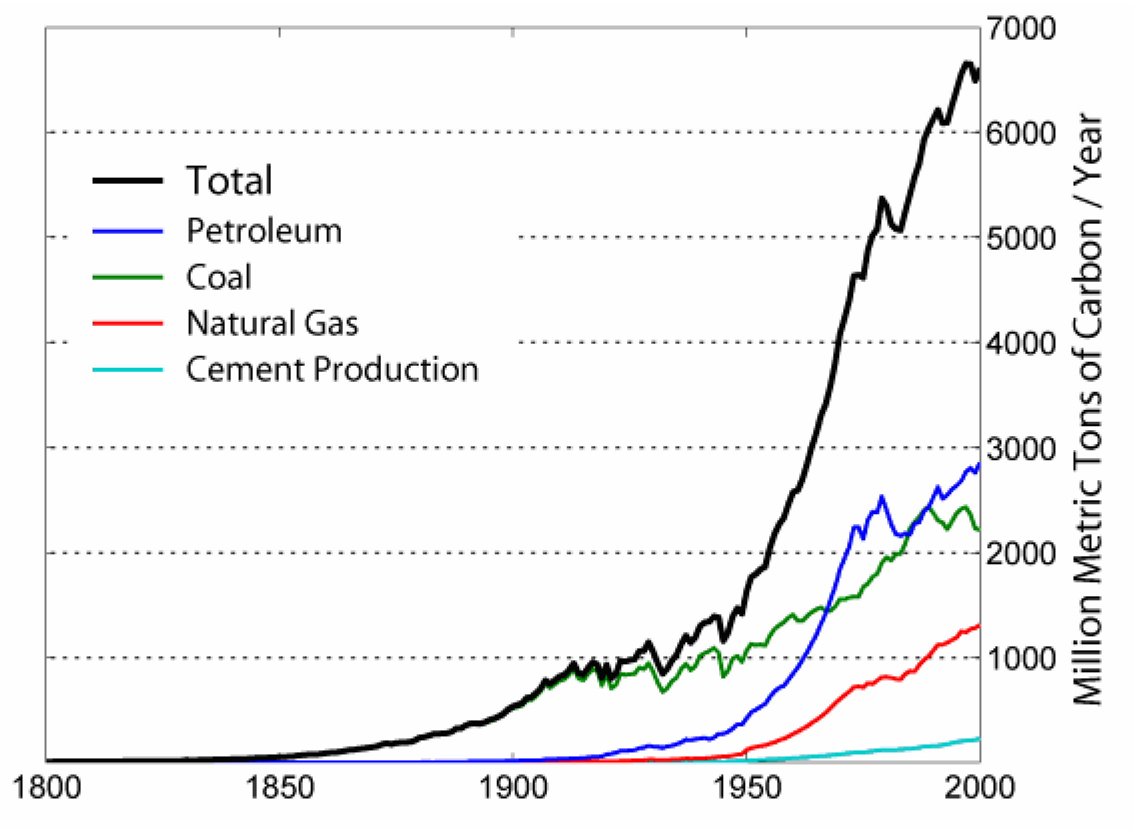
Figure 1: Number of Reactors in Operation Worldwide *(1)*
(as of 31 of December 2005)

Nuclear Power use has been deemed controversial for a number of reasons. It has the potential for radioactive contamination, the problem of storing radioactive waste for indefinite periods, and the risk of a growth of nuclear weapons that could get into the hands of terrorists. These risks can be further reduced by new technology in the reactors.

New Nuclear Power plants were at a decline after the 1979 Three Mile Island reactor had a partial core meltdown. Presently, nuclear power has renewed interest from national governments and the public. Research is being done for increasing the safety, the use of nuclear fusion, and uses of producing hydrogen. Due to this, reactors are under construction and new reactor types are being planned.

Fossil fuels are natural resources made up of hydrocarbons, for example oil and coal. These fuels are also known as mineral fuels. The use of fossil fuels has increased in the 20 and 21 centuries due to the worldwide industrial modernizations and technology advances. However, continued fossil fuel reliance may be in danger. Fossil fuel reserves are found concentrated in only a few regions around the world, in areas with low economic growth. Oil is a finite source and is predicted to peak in the early 21st century by Marion King Hubbert and other experts. The increasing use of fossil fuels has caused environmental commotion, because of its large emissions of $C0_2$ causing global warming. These emission of $C0_2$ from fossil fuels have been at an increase over the past 200 years, see Figure 2.

Figure 2: Global Fossil Carbon Emissions (2)



These issues have called for research to find new alternative energy sources that meet the demands for the higher living standards, less pollution, and that decrease or end the use of fossil fuels. (1) According to the Department of Energy, in 1999, the U.S. consumed approximately 993 million tons of coal, 21,694 billion cubic feet of natural gas, and 7.125 billion barrels of oil. With a consumption rate this high, the transition to alternative energy sources should produce liquid fuels that can be compatible with existing systems and equipment. This is due to the fact that there are huge fleets of vehicles, trains, planes, ships and other equipment with lifetimes of 15-30 years that cannot be discarded overnight. The substitute must have a process that can be produced on a large scale, millions to 10 millions of barrels per day worldwide. The substitute must also be energy efficient outputting greater than 50% of the energy input. (2)

Extensive research is being done on the use of hydrogen as an alternative fuel. Hydrogen is a gas at room temperature, with a density of 0.899g/l. The air is 14.4 times denser than hydrogen is. Hydrogen has the highest energy to weight ratio of all fuels, requiring 2.8 kg of gasoline to equal 1 kg of hydrogen. Hydrogen is colorless, odorless, and nontoxic, but it is also easily flammable. However, due to its low density it will disperse quickly unless in a confined area, which could lead to problems because of its high burning velocity and its invisible flame when it burns in daylight. Hydrogen is a clean fuel though and has very low or negligible emissions of $C0_2$ when combusted. Therefore, many believe in a hydrogen economy. Some areas of current hydrogen production research are electrolysis of water by nuclear power, reforming, photoelectrical, photobiological, and thermal dissociation(3).

The objectives of this study were to determine if hydrogen production via nuclear power plants could someday replace fossil fuels. If this were, in fact, a possibility we also wanted to determine if the public would accept nuclear power plants in their area.

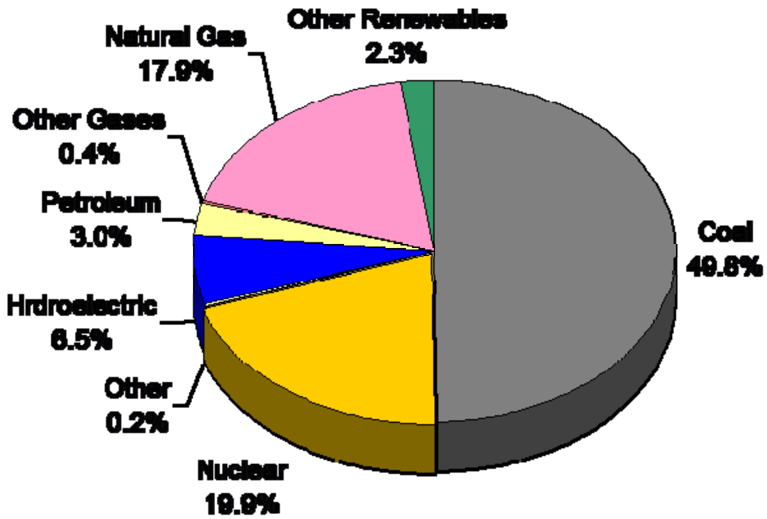
2. Suitable Energy Sources

To clarify the necessity of new energy sources, it is important to examine the different forms of energy that the public relies on. Oil and gasoline are among the most popular and demanding sources of energy, but there are other forms like nuclear, solar, coal, natural gas and many more that encompass a large portion of the energy demands. The issue at hand is that the majority of these energy wells are not renewable and without immediate intervention these wells will dry up. This would result in exponential inflation of energy prices and eventual extinction of non-renewable energy sources(4).

2.1 Fossil Fuels

Fossil fuels are an enormous contributor of energy to the world. Fossil fuels were formed from the fossilized remains of dead plants and animals millions of years ago. These fuels are considered non-renewable meaning once that they are depleted we will have to rely on different sources of energy. As seen in the chart below coal, natural gas and petroleum, clearly make-up over two thirds of the energy industry.

Figure 3: U.S. Electric Power Industry Net Generation from 2004 (5)



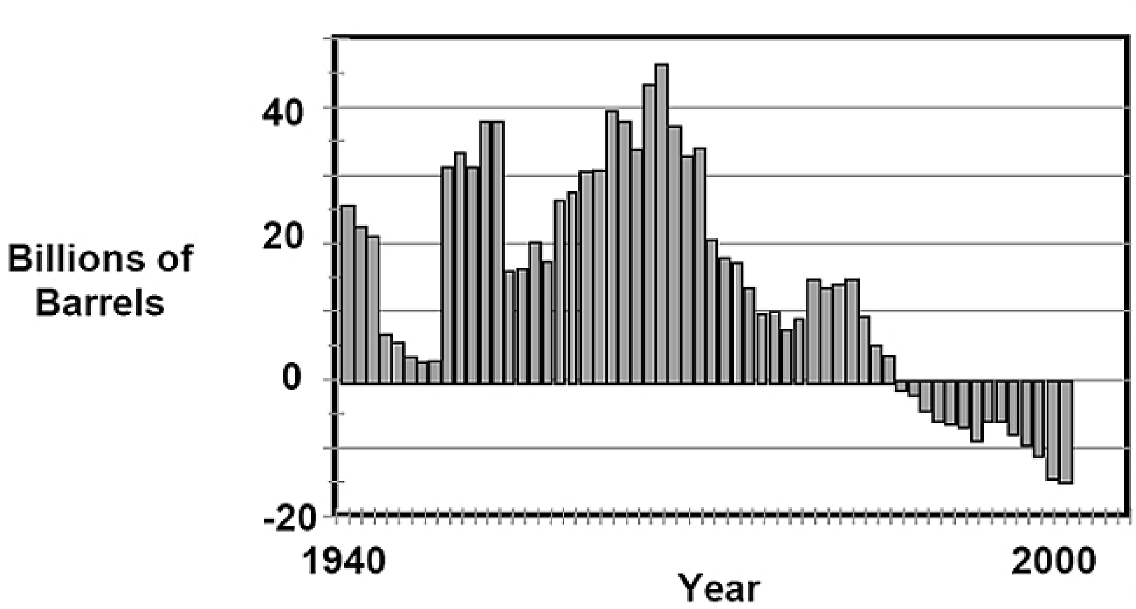
The methodology of energy production entails burning of these fossil fuels in a chemical combustion that can be harnessed and utilized in different ways. These fuels are a complex mixture of hydrocarbons that all produce the same products when they are burned. Hydrocarbons are different compositions of Carbon, C, and Hydrogen, H. An example of this composition would be, a common natural gas, Propane, C_3H_8, which is a hydrocarbon and react it with oxygen, (burn it). The chemical reaction is:

$$2C_3H_8 + 10O_2 \rightarrow 8H_2O + 6CO_2$$

This reaction is 2 molecules of propane reacting with 10 molecules of oxygen to form 8 molecules of water and 6 molecules of carbon dioxide. This ideal reaction is the average molecular occurrence due to simplistic assumptions. There are other molecules present in this reaction but this is the overall stoichiometry.

The most skeptical experts agree that within 20 years the worlds oil wells will peak. This concept of peaking indicates the oil reserves maximum production rate. The figure below represents the net difference between annual world oil production and annual consumption. In other words, we are consuming more than we are producing.

Figure 4: Net World Oil Production and Annual Consumption (4)



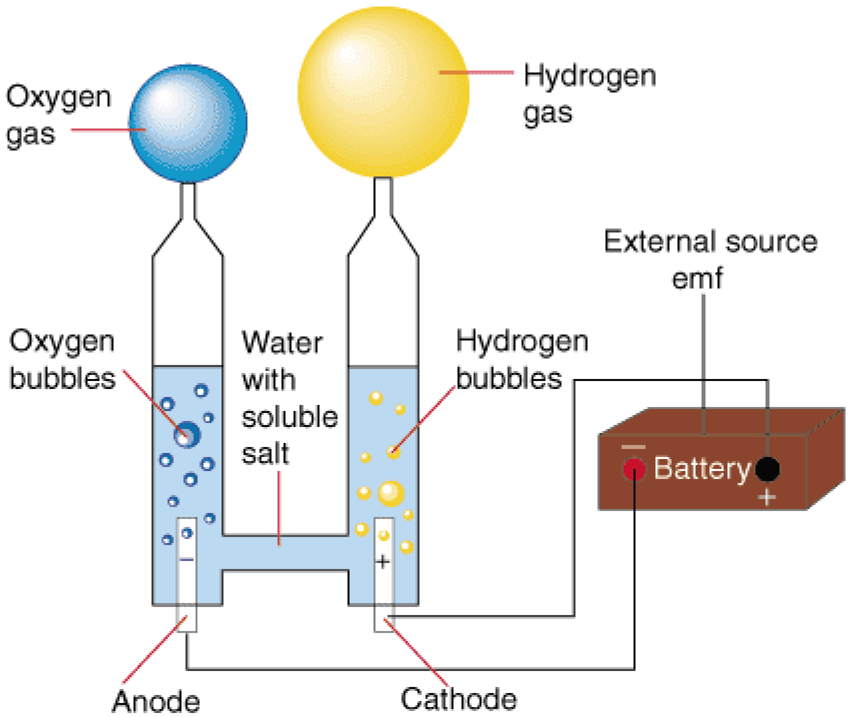
The issue that concerns most scientists is the dramatic depletion of these resources and what the impact will be on the future. These natural resources are exponentially depleting as a direct result of population growth. What are the options to divert this potentially disastrous phenomenon?

2.2 Hydrogen Production

There are many ways to produce hydrogen, but the most popular ways are electrolysis and steam reforming. The hydrogen atom consists of one electron and one proton. Stars and therefore the Sun are made up primarily of hydrogen gas, H_2. Unlike fossil fuels, hydrogen is a renewable energy source. For fossil fuels like coal, energy is harnessed by initiating a chemical reaction that produces energy and then turned into electricity. Electricity is then transferred to homes to give you light, hot water and other necessities. Electricity is called an energy carrier which means simply, a way of transferring energy from one place to another. Hydrogen is also an energy carrier that could replace electricity.

Improving hydrogen production is the first step into building a hydrogen economy. The goal is to increase production efficiency, replace the dependence on nonrenewable energy sources, and to lower environmentally degrading emissions. Hydrogen is very abundant naturally in different forms, but it is wanted in its diatomic form, which does not occur naturally on earth so it therefore must be produced(6). One of the most common ways of producing hydrogen is electrolysis of water. The reaction looks like this:

Figure 5: Diagram of Electrolysis of Water (7)

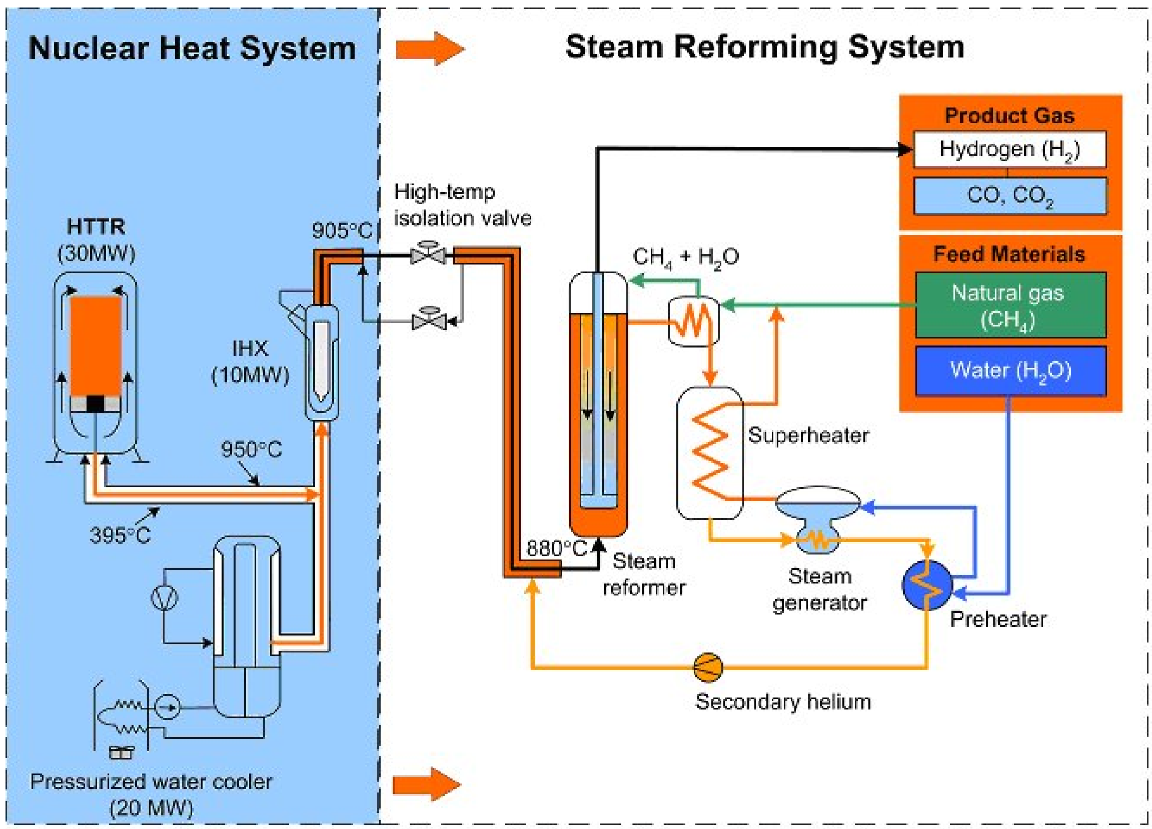


This example illustrated the usage of a low voltage power source coupled with a solution of salt water. Using platinum electrodes and the salt in the water acting as the bridge, hydrogen gas will bubble at the cathode and oxygen will react at the anode. This electrolysis process of one mole of water produces one mole of hydrogen and one-half mole of oxygen or ($2H_2O \rightarrow 2H_2 + O_2$).

A detailed analysis of this process utilizes thermodynamic properties of the system. The First Law of Thermodynamic is then change in internal energy, ΔU is equal to the heat, Q, added to the system minus the work, W, done by the system. This reaction is to take place at a standard atmospheric pressure of one atmosphere and at room temperature, 298 K. The process must provide the energy for the dissociation plus the energy to expand the produced gases. Work is defined as W = PΔV, where P is the pressure and ΔV is the change in volume. The heat added to the system is the change in enthalpy, H. Water has an enthalpy of 285.83 kJ and the work done by the system is 3.72kJ, therefore the change in internal energy is 282.1 kJ(7).

Steam reforming is the process of combining steam, at a temperature of between 700 and 1100 °C, and some type of gas in a reactor with a catalyst at a specific pressure.

Figure 6: Diagram of Steam Reforming (8)



Natural gas, which is composed mostly of methane (CH_4), is an example of this method. The methane in the natural gas reacts with water vapor to form carbon monoxide and hydrogen gases: $CH_4 + H_2O \Rightarrow CO + 3H_2$

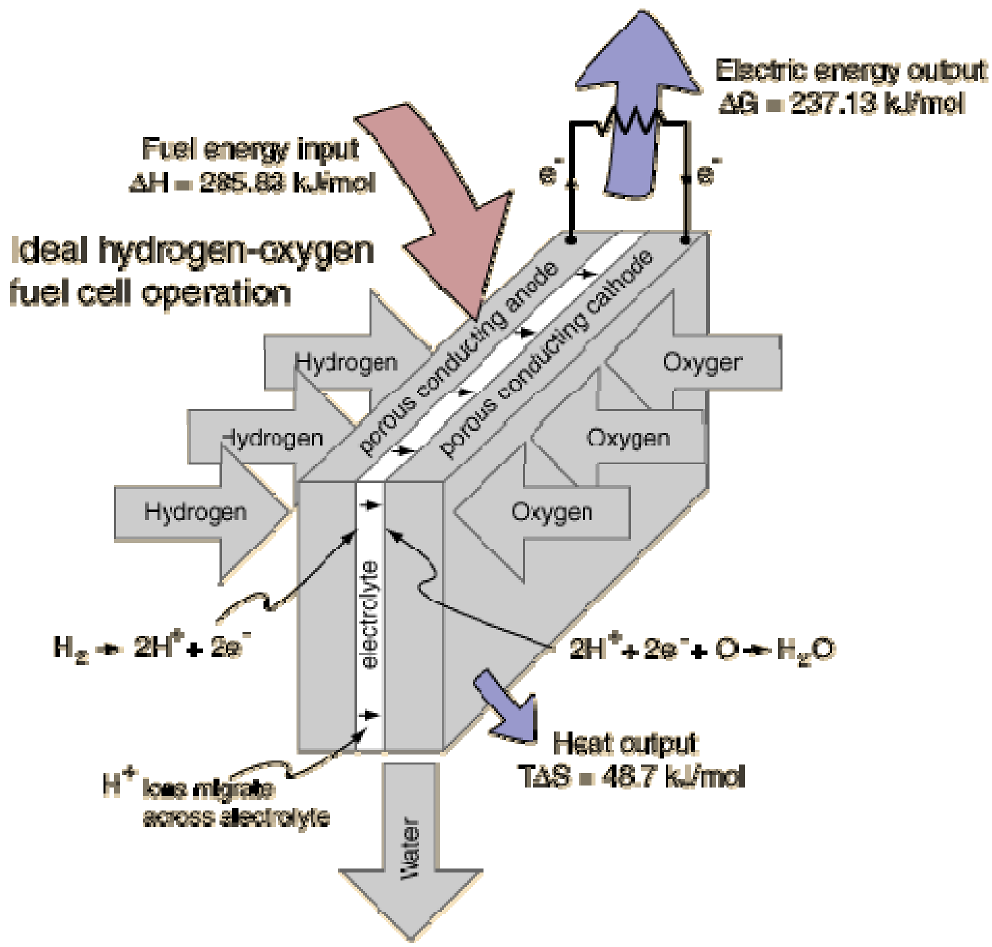
The water vapor splits into hydrogen gas and oxygen, the oxygen combining with the CO to form CO_2: $H_2O + CO \Rightarrow CO_2 + H_2$**.**

These reactions are not perfect and some methanol or natural gas and carbon monoxide traverse through without reacting. These are burned in the presence of a catalyst, with a little air to supply oxygen. This converts most of the remaining CO to CO_2, and the remaining methanol to CO_2 and water. Various other devices may be used to clean up any other pollutants, such as sulfur, that may be in the exhaust stream. It is important to eliminate the carbon monoxide from the exhaust stream for many reasons. Most importantly, if the CO passes through the fuel cell, the performance and life of the fuel cell are reduced. Another reason is that it is a regulated pollutant, so cars are only allowed to produce small amounts of it(8).

2.3 Hydrogen as a Fuel Source

A fuel cell is almost the exact reciprocal of electrolysis process. Hydrogen and oxygen are combined in a fuel cell to produce energy. This chemical reaction produces the electrical voltage to an external source as seen below:

Figure 7: Fuel Cell (9)



This process utilizes a catalyst which is a special material that facilitates the reaction of oxygen and hydrogen. It is sometimes made of platinum powder very thinly coated onto carbon paper or cloth. The catalyst is rough and porous so that the maximum surface area of the platinum can be exposed to the hydrogen or oxygen.

The figure above shows the pressurized hydrogen gas (H_2) entering the fuel cell on the anode side. By means of pressure the hydrogen gas is forced through.. When a hydrogen molecule comes in contact with the platinum on the catalyst, it splits into two hydrogen ions and two electrons. The electrons are conducted through the anode, where they make their way through the external circuit doing work on the system and return to the cathode side of the fuel cell. This work done on the system could power a light bulb or even turn the motor of a car.

On the cathode side of the fuel cell, oxygen gas is being forced through the catalyst, where it forms two oxygen atoms. Each of these atoms has a strong negative charge. This negative charge attracts the two hydrogen ions through the membrane, where they combine with an oxygen atom and two of the electrons from the external circuit to form a water molecule(9).

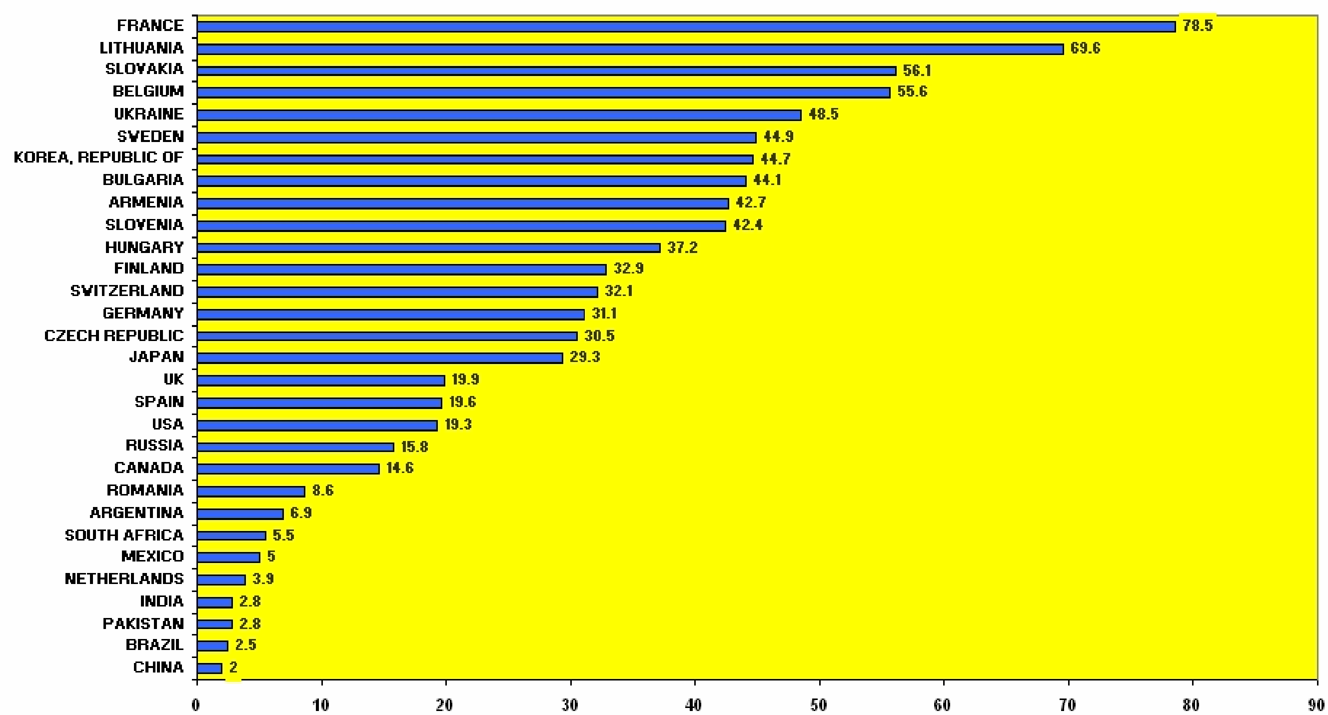
The reaction in a single fuel cell produces only about 0.7 volts. To increase the voltage output, many separate fuel cells must be combined to form a fuel-cell stack. Depending on the size of the stack and the supply of hydrogen provided, many different tasks could be accomplished with fuel cells(10).

2.4 Nuclear Energy

Nuclear Energy is the fission of uranium, plutonium or thorium or the fusion of hydrogen into helium. Uranium is an abundant element that occurs naturally in the earth's crust. This is because uranium is originally formed in stars and when old stars exploded, the dust from shattered stars combined together to form our planet. Uranium's most common isotope is U-238. U-238 makes up 99 percent of the uranium on the planet. U-235 makes up 0.7 percent. U-234 is even less and is formed by the decay of U-238. U-235 is useful for nuclear power. It has the ability to undergo induced fission. This means, if a free neutron were to run into a U-235 nucleus, the nucleus would absorb the neutron without hesitation, become unstable and split immediately. The decay of one U-235 atom produces 200 MeV. In order to use uranium in a nuclear reactor, the sample of uranium must be enriched. Enriched uranium contains 2 to 3 percent U-235. A nuclear reactor runs on at least 3% enriched uranium. The core of a 1,000 megawatt (MW) nuclear reactor contains about 75 tons of enriched uranium. A coolant, usually water, is pumped through the reactor and carries away the heat produced from the nuclear fission. The resulting super-heated steam is used to drive a steam turbine electric generator. Some of the U-238 isotope in the fuel is turned into plutonium in the reactor core. The main plutonium isotope is also fissile and it yields about one third of the energy in a typical nuclear reactor. The fissioning of uranium is used as a source of heat in a nuclear power station in the same way that the burning of coal, gas or oil is used as a source of heat in a fossil fuel power plant, producing about 7 billion kilowatt-hours (kWh) of electricity per year. To maintain efficient nuclear reactor performance, one-third of the spent fuel is removed every year and replaced with fresh fuel.

Nuclear Energy is a dependable provider of electricity. As of April 2006, this energy was being used in 30 countries worldwide in 443 different nuclear plants providing 16 percent of the world's electricity. As of 2005, France was the leaders in producing the highest percentage of their electricity with nuclear power with 78.5 percent, followed by Lithuania and Slovakia with 69.6 and 56.1 percent respectively. Seen below is a figure listing nations producing a high percentage of its electricity with nuclear power.

Figure 8: Nuclear Share in Electricity Generation in 2005 *(1)*

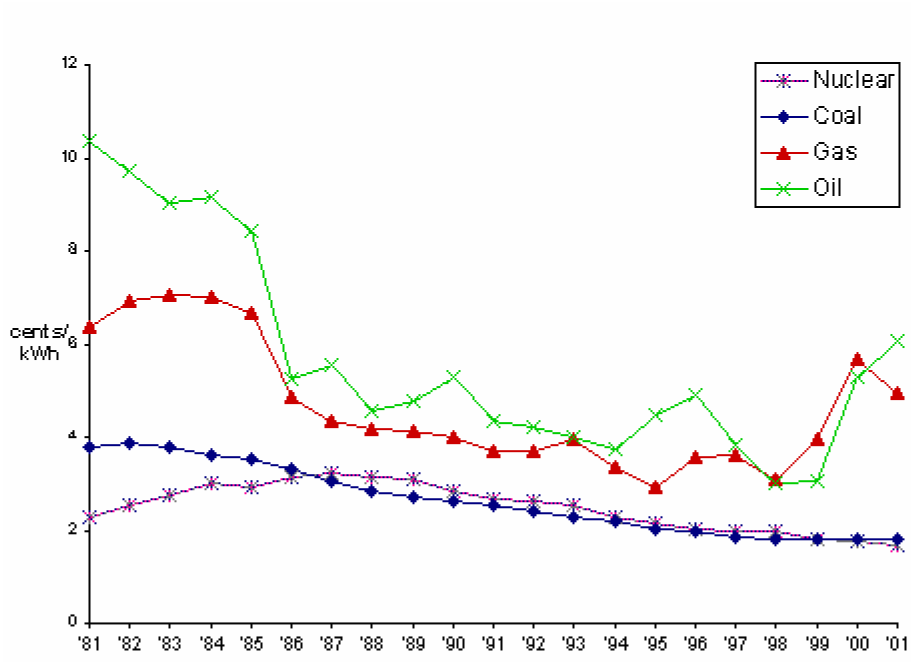


In the United States, nuclear power plants, the second largest source of electricity in the US, produce 20 percent of the nation's electricity. Today, there are 103 commercial nuclear power plants in the United States, located in 31 states different states, producing electricity. Each one is licensed to operate for 40 years, when this time is up they have an option to renew for an additional 20. On average these power plants are 24 years of age.

The 103 nuclear power plants in 2005 produced 782 billion kilowatt-hours of electricity. As of 2003, 5 states, Connecticut, Illinois, New Jersey, South Carolina, and Vermont, received over half of its electricity from nuclear energy. Vermont received the greatest percentage of electricity, 74 percent. The percentage of electricity produced compared to the total potential electricity is called capacity factor. This measures the power plants reliability. On average in the United States, the capacity factor for nuclear plants was 89.6 percent in 2005, compared to coal at 72.6 percent, natural gas at 15.6 to 37.7 percent, heavy oil steam turbine at 29.8 percent, hydro at 29.3 percent, wind at 26.8 percent solar at 18.8 percent and geothermal at 75.5 percent.

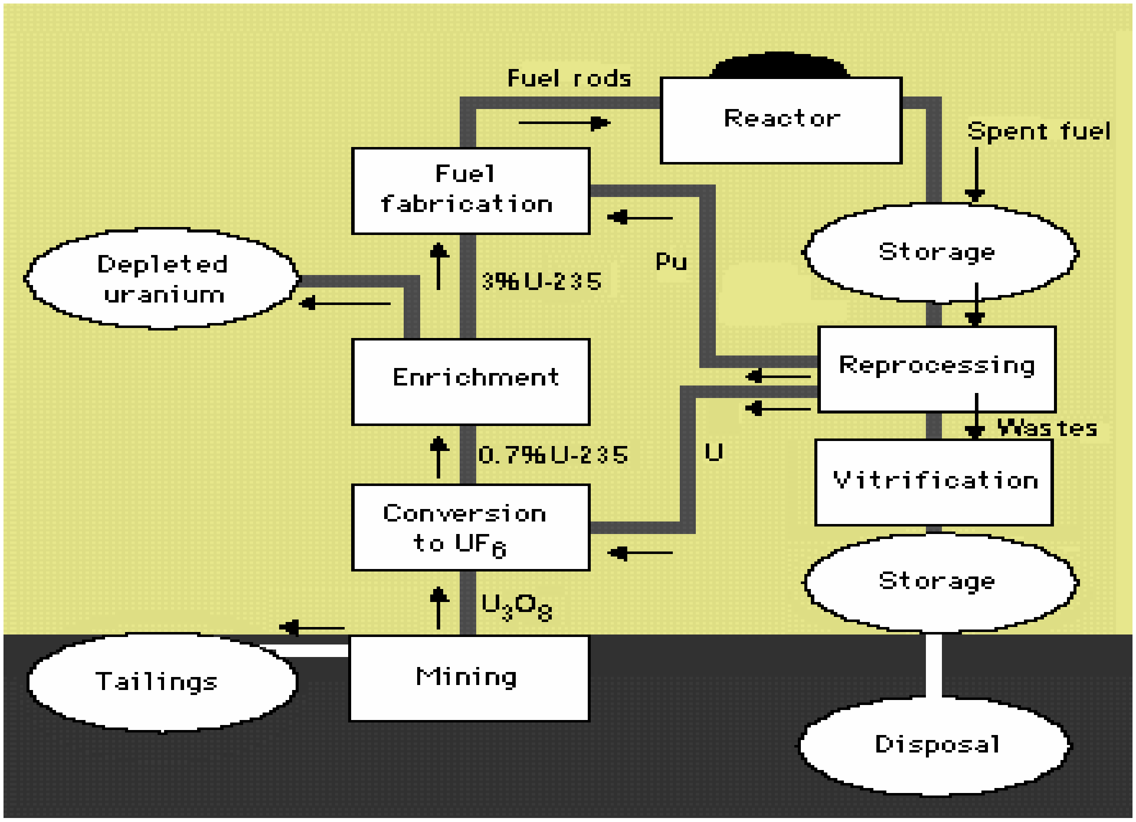
Nuclear energy is an economical energy source. In 2004, the average electricity production cost was 1.68 cents per kilowatt-hour for nuclear power plants. For coal, it was 1.90 cents, for oil, it was 5.39 cents, and for gas, it was 5.87 cents. The energy in one uranium fuel pellet, which is about 7 grams, is approximately equal to 17,000 cubic feet of natural gas, 1,780 pounds of coal, or 149 gallons of oil. Nuclear power plants are expensive to build though. However, uranium is low in cost and less sensitive to price increases, so running uranium powered plants would be cheaper and easier to run than to run a gas or coal powered plant, which has high unstable prices(11), as seen in Figure 9.

Figure 9: US Electricity Production Costs (11)



Nuclear power plants are environmentally friendly and safe. Nuclear energy is the world's largest source of emission free energy. They emit no controlled air pollutants, such as sulfur and particulates, or greenhouse gases. During the fuel cycle shown below,

Figure 10: Fuel Cycle of Nuclear Power Plants (12)



the small volume of waste by-products created is carefully contained, packaged and safely stored. Waste is categorized as low, intermediate, and high level wastes by the amount of radiation they give off. Low level waste is produced at all stages of the fuel cycle, intermediate level waste is produced during reactor operation and by reprocessing, and high level waste is waste containing fission products from reprocessing, which is mainly the used fuel itself. The longer a waste product is stored the better, with time the waste's radioactivity becomes less and less. Water released from a nuclear power plant contains no harmful pollutants and also meets regulatory standards for temperature, which protects the aquatic life(12). Also, in the United States, the nuclear energy industry has ranked among the safest places to work. In 2005, they had an a 0.24 per 200,000 worker-hours, accident rate, which tracks the number of accidents that result in lost work time, restricted work, or fatalities. Also, the radiation emitted from a power plant is miniscule. Radiation is measured in rem, it takes in account type of radiation and the amount deposited in body tissues. On average in the United States, the average person receives 360 millirem of radiation per year; 300 millirem coming from natural sources and 60 millirem coming from manmade sources. Radiation comes from many sources, 40 millirem from food and water inside the body 40 millirem, 200 millirem from the air in the form of radon, 40 millirem from a medical X-ray, 1 millirem from airlines for every 1,000 miles flown, 1-2 millirem from watching TV, 7 millirem from living in a stone, brick, or concrete building, 0.03 millirem from living within 50 miles of a coal fueled power plant, and 0.009 millirem from living within 50 miles of a nuclear power plant. This being stated the amount of radiation you would receive in a year from living next door to a nuclear power plant would be less than you would receive in one round-trip flight from New York to Los Angeles. Also, the amount of radiation exposure that you get from a single diagnostic medical x-ray could be compared to living near a nuclear power plant for over 2,000 years(13).

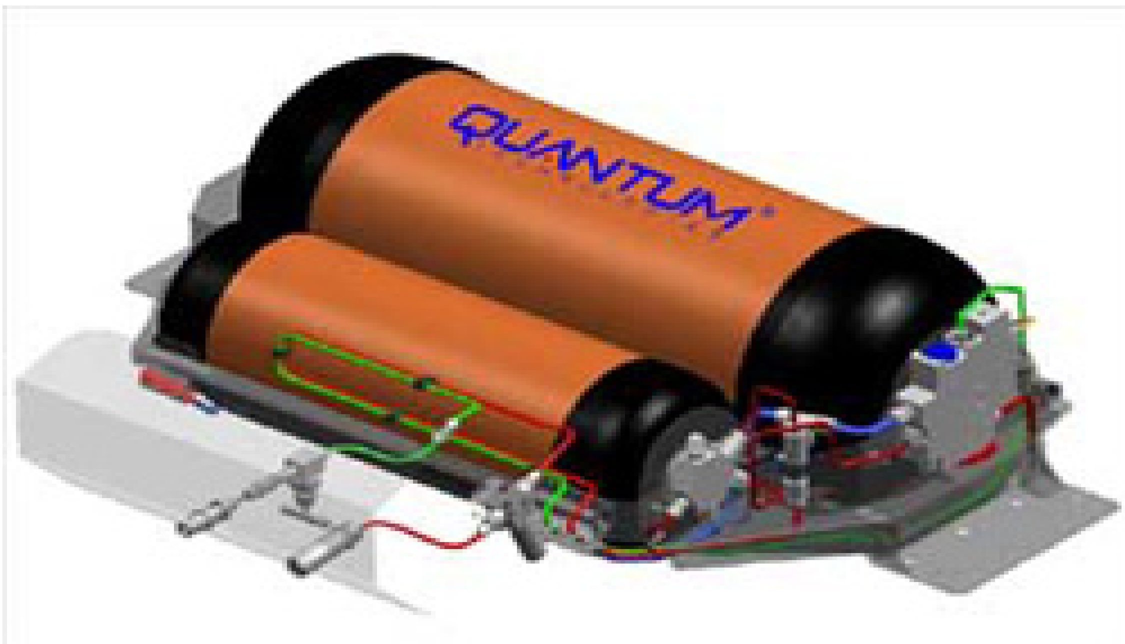
2.4.1 Hydrogen Production

Hydrogen is a clean energy carrier. It must be produced because it is not found abundant in its diatomic form. Thermochemical processes can be used to produce hydrogen from biomass and from fossil fuels. Hydrogen can also be produced electrolytically from power generated by sunlight, wind, and nuclear energy. Presently, 95 percent of all hydrogen production is through steam reforming of natural gas, which is non-nuclear. This method generates $C0_2$. Two other methods are the electrolysis of water and the direct splitting of a water molecule into hydrogen and oxygen through a high temperature thermochemical process both can be done through the use of nuclear energy(14). For the high temperature thermochemical process, a temperature range of 750 to 1000 degrees Centigrade is required. However, at 1000 degrees centigrade the conversion efficiency is three times as great as at 750 degrees centigrade. In order for this process to become large scale, a transportation system or pipeline network to carry the hydrogen from the plant to its users would be necessary. Using nuclear energy to produce hydrogen as a fuel is the most environmentally favorable method, since it will reduce $C0_2$ emissions and it produces no pollutants or greenhouse gases. Experts calculate that 240 gigawatts of electricity generated, which is about one half of the current United States generating capacity, would be needed to manufacture hydrogen by electrolysis to power all transportation vehicles in the United States. This power output is approximately 52 power plants. Compared to other energy sources, about 640,000 windmills would be needed, occupying an area of 71,000 square miles(15). Three potentially suitable reactor concepts have been identified, the high temperature gas cooled reactor (HTGR), the advanced high temperature reactor (AHTR), and the Lead cooled fast reactor. Only the HTGR is well developed enough to move forward with. It will operate at 950 plus Centigrade temperatures. It uses either a pebble bed or hexagonal fuel block type. The AHTR is similar to the HTGR, but runs at low pressure. Its reactor uses a coated particle graphite matrix fuel with molten fluoride salt as a primary coolant. The lead cooled fast reactor operates at lower temperature than the HTGR. The best developed it the Russian BREST reactor, which runs at 540 degrees Centigrade. If each were a 600 MWt module, it would produce about 200 tonnes of hydrogen per day, which is enough to meet the current industrial demand for hydrogen(13).

2.4.2 Methods of Transportation and Storage

The storage and transportation of hydrogen is one of big obstacles that must be overcome in order to obtain a hydrogen economy. Primary methods for storing hydrogen are compressed gas, liquefied hydrogen, metal hydride, and carbon-based systems. These technologies are important to the creating a hydrogen economy since hydrogen is an energy carrier. Thus, it must be stored and transported in order to be used. Hydrogen gas has a high energy density per weight, but poor energy denisity per volume compared to hydrocarbons. This is one of the problems with onboard hydrogen storage(16). According to the National Renewable Energy Laboratory, they found that compressed hydrogen gas offers the simplest and least expensive method for onboard storage of hydrogen. It uses technology similar to that of storing natural gases, using stainless steel, aluminum, or composite cylinders as storing containers. Increasing the pressure would allow you to store more hydrogen, but the storage costs would increase due to the material and design enhancements that ensure tank integrity.(17) To improve the high costs, a reduction in the cost of producing high-pressure hydrogen and improved efficiencies must be further researched. Carbon fiber reinforced 5000-psi and 10,000-psi compressed hydrogen tanks are currently under development by Quantum Technologies and others. These tanks are

Figure 11: Example of a Quantum Technologies Hydrogen Tank (17)



already in use in prototype hydrogen powered vehicles. The tanks contain an inner liner that is a high molecular weight polymer that serves as a hydrogen gas permeation barrier. A carbon fiber-epoxy resin composite shell covers the liner and works as the gas pressure load-bearing component of the tank. On the very outside is an outer shell is placed to protect the tank from impact and damage. The tank has a pressure regulator inside the tank and also a gas temperature sensor to help with the gas filling process. Two approaches are being researched to increase the gravimetric and volumetric storage capacities of compressed gas tanks from their current levels. The first approach uses cryo-compressed tanks, due to the fact that at a fixed pressure and volume gas tanks volumetric capacity increases as the tank temperature decreases. The other approach involves the development of conformable tanks in order to take maximum advantage of vehicle space. The compressed hydrogen tanks of 5000-psi and 10,000-psi have been certified by ISO 11439 (Europe), NGV-2 (USA), and Reijikijun Betten (Iceland) standards and approved by TUV (Germany) and The High-Pressure Gas Safety Institute of Japan. Tanks have been demonstrated in several prototype fuel vehicles and are commercially available. The 10,000-psi tanks have demonstrated a 2.35 safety factor, which meets the requirements of the European Integrated Hydrogen Project(17).

Liquid hydrogen tanks for storing hydrogen improve the energy density of the hydrogen stored. However, hydrogen has a critical temperature of 33K, thus hydrogen can only be a gas at atmospheric conditions. This causes problems with efficiently storing hydrogen as a liquid. This makes the requirements for hydrogen liquefaction, volume, weight, and tank cost not cost or energy effective.

Carbon nanotubes are being researched for on board storage of hydrogen. The research is in its very early stages however. The carbon nanotubes are microscopic carbon tubes synthesized in the laboratory that absorb hydrogen. Initial research shows a high hydrogen storage density, higher than solid hydrogen. This research shows promise because of the low cost of carbon materials(18).

Metal hydrides have the potential for reversible on-board hydrogen storage and release at low temperatures and pressures. The complex metal hydride alanate (AlH_4) has the potential for higher gravimetric hydrogen capacities than simple metal hydrides.

Alanates store and release hydrogen reversibly when catalyzed with titanium dopants, according to this two-step reaction.

$$NaAlH_4 = 1/3\ Na_3AlH_6 + 2/3Al + H_2$$

$$Na_3AlH_6 = 3NaH + Al + 3/2H_2$$

The first reaction is thermodynamically favorable at 1 atm pressure and above 33 degrees Celsius and can release 3.7 % weight hydrogen. The second reaction takes place over 110 degrees Celsius and can release 1.8 % weight hydrogen. However, the release kinetics is too slow for vehicular applications. They also have a low hydrogen capacity and high costs, which are issues being researched that need to be approved upon with metal hydrides now. The goal for the future is to achieve on board storage systems with 2 kWh/kg (6 wt%), 1.5 kWh/L, and $4/kWh by 2010 and develop and verify on-board hydrogen storage systems achieving 3 kWh/kg (9 wt%), 2.7 kWh/L, and $2/kWh by 2015. These storage challenges must meet vehicular constraints of weight, volume, efficiency, safety, and cost. The systems must also be durable with a lifetime of about 1500 cycles. Non-transportation storage is less restricted. Energy efficiency is an issue for hydrogen storage methods. For example, the energy for compressions. Refueling times are lengthy and a time of three minutes or less needs to be developed for refueling times(19).

3. Methodology

Nuclear power plants have inflicted fear into many people after disasters such as the Three Mile Island and Chernobyl accidents. They are also thought to be environmentally unfriendly. Nuclear Power reactors have been further developed and the safety regulations have improved as well. A survey was conducted to see how people felt about new nuclear power plants being built in location to their homes and also if their opinions would be any different if they were informed of the new generation power plant technology. So, two different types of groups were used as the subjects surveyed. One was the control group, which was just ordinary people, and the other group had the variable of reading our handout that contained information about the next generation power plants, which can be found in the appendix along with the survey. The survey and handout was looked over and approved by Elise Weaver, an assistant professor at Worcester Polytechnic Institute with a Ph. D in Social and Health Sciences. The survey was conducted at the Auburn Mall located at 385 Southbridge Street Auburn, MA 01501 on April 8th of 2006. The survey was conducted by the both of us at the entrances of the mall. A total of 64 people were surveyed, 32 for each group. For the control group, 18 of the subjects surveyed were male and 14 were female. For the group with the variable, which read the handout, 15 of the subjects surveyed were male and 17 were female. The age ranges of those surveyed were approximately between 20 and 60.

4. Results

The results of the survey showed that informing the public of improved technology in next generation power plants opened their opinions to building new power plants. However, the location of these power plants in vicinity to the subject affected that decision. The further away from the hometown of the subject the more open the subject was for a new power plant being built there. Figures 12-17 show the results of the survey. Type 1 is the control group, the ones who didn't read the handout and type 2 is the group that did read the handout. Answers were on a scale from 1-5. 1 was strongly agree, 2 was agree, 3 was no opinion, 4 was disagree, and 5 was strongly disagree. The first question asked the subjects if they would feel comfortable with a next generation power plant built in their town. The results to this question were mixed reactions. However, Type 1 showed a 3:11 ratio and Type 2 showed a 5:2 ratio for those in favor to those not in favor of the building of a new power plant in their hometown. The second question was asked the subjects if they would feel comfortable with a next generation power plant built in their county. The answers for both groups were more in favor of a new power plant being built in their county than in their hometown. Type 1 showed a 5:6 ratio and Type 2 showed a 29:1 ratio for those in favor to those against the building of a new power plant. The third question asked the subjects if they would feel comfortable with a next generation power plant built in their state. This was the most favorable situation for both groups over the previous two situations. Type 1 had a 4:1 ratio for those in favor to those against a new power plant being built, and Type 2 had no opposing votes for a power plant being built. As seen from the results, Type 2 has a substantial percentage more in favor for each question. This survey demonstrated that people correctly informed about the new nuclear power plants will be more open to the building of these plants. However, the building of these plants was less favorable as the blue prints for these plans are closer to the subject's hometown as seen from question 3 compared to question 1 from both groups. The fourth question in this survey was an optional question. It asked the subject if they felt uncomfortable with the idea of new power plants, what reasons were holding them back. Most subjects ignored this part of this survey. The responses to this question from Type 1 were:

- "environmental concerns"
- "I don't want to be exposed to elevated radiation and if something goes wrong I don't want to be nearby"
- "I would be worried about any effects on the environment,"
- "Not particularly uncomfortable,"
- "I don't feel nuclear power is a real danger,"
- "They are unpredictable,"
- "My town is not big enough for a reactor facility,"
- "Could be dangerous,"
- "Radiation and the environment,"
- "I would be worried about a power plant disaster"

Type 2 subject's responses were:

- "I would agree to it as long as they are safe for users, the community, and the environment"
- "the environment"
- "radiation"

- “I would be concerned about the environment”

The majority of the responses came from those surveyed in the Type 1 group, again supporting that most people aren’t informed correctly of the new technology next generation power plants have to offer. The people that read the handout fit into two categories. Either they briefly read the paragraph and hurried on to complete the survey, or they read the survey and had follow up questions. On average the people who read the paragraph took 30 seconds. There was a direct correlation to the amount of time they spent reading the survey to their responses to the questionnaire. If the individual briefly read the information then their responses were not in favor of nuclear power plant production. If they read the paragraph and asked subsequent questions, then obviously they were more informed and considered power plant production in their vicinity not a major issue.

4.1 Survey Graphs

Figure 12: Question 1 for Control Group

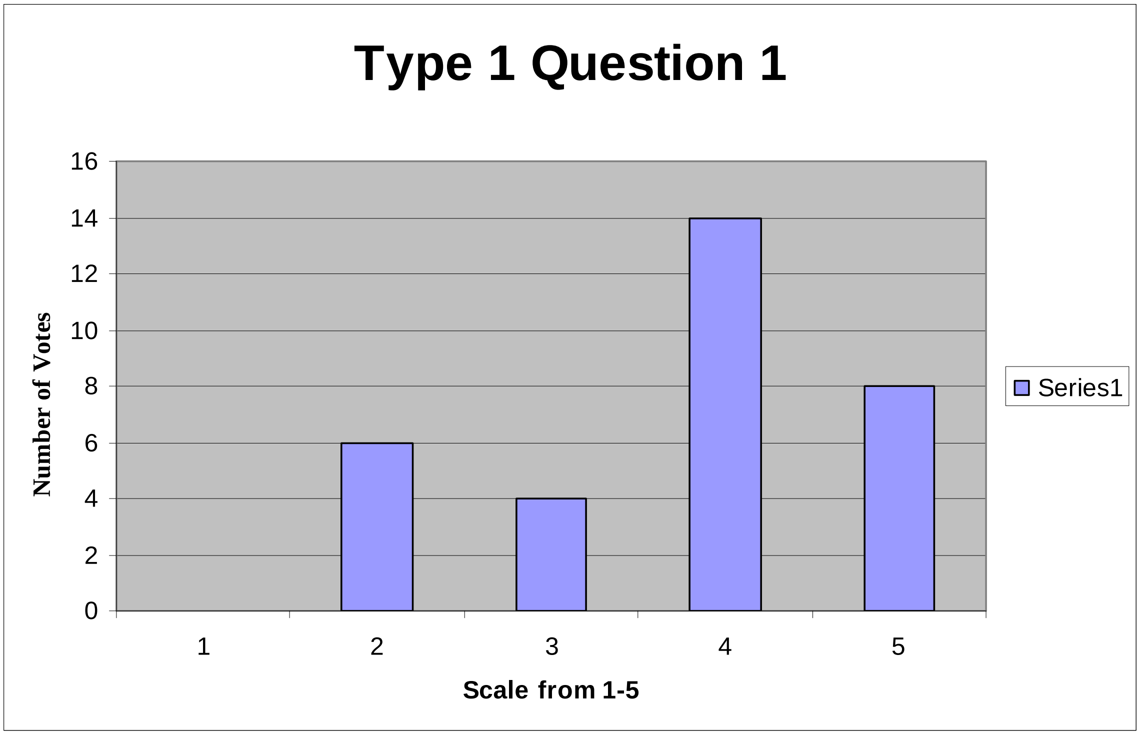


Figure 13: Question 1 for Variable Group

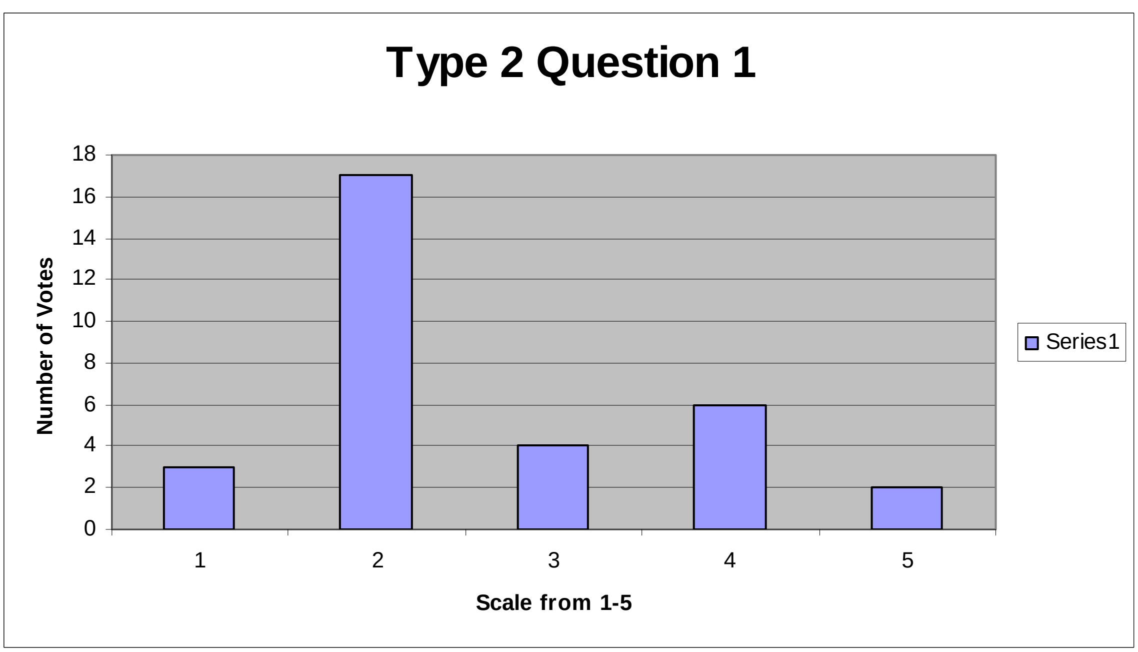


Figure 14: Question 2 for Control Group

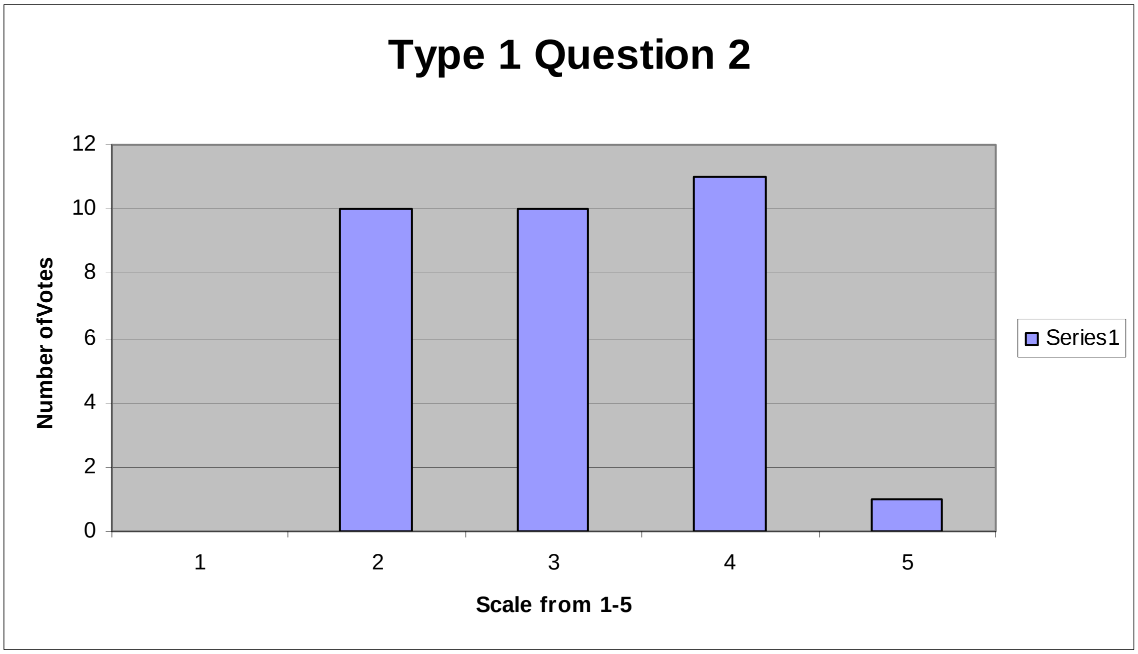


Figure 15: Question 2 for Variable Group

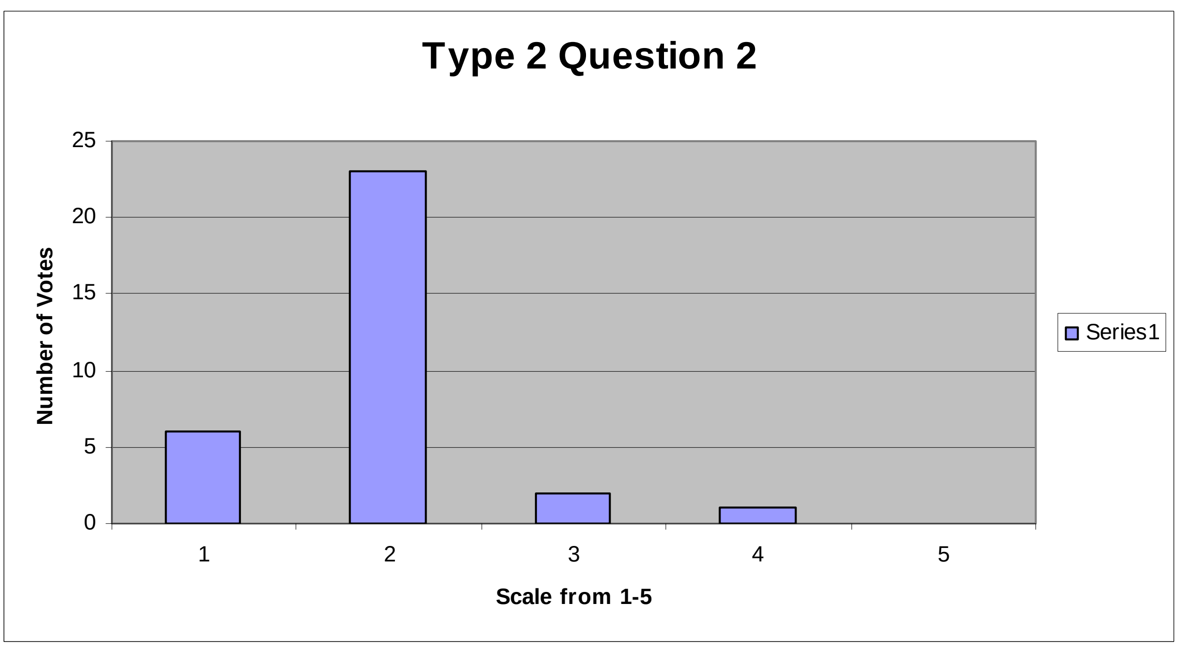


Figure 16: Question 3 for Control Group

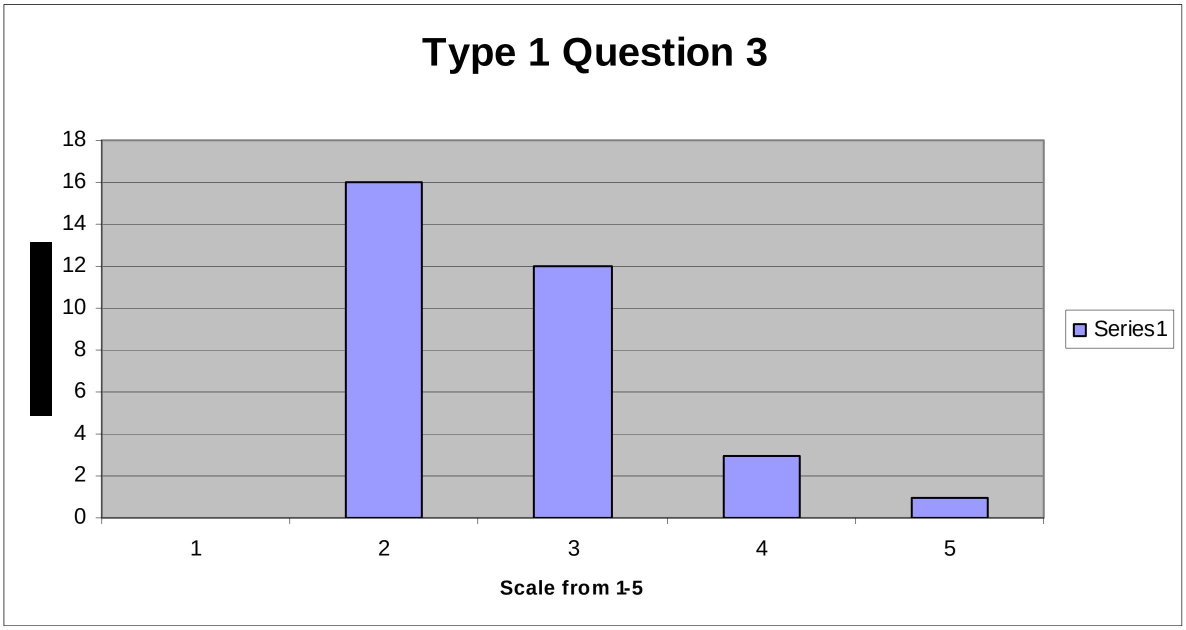
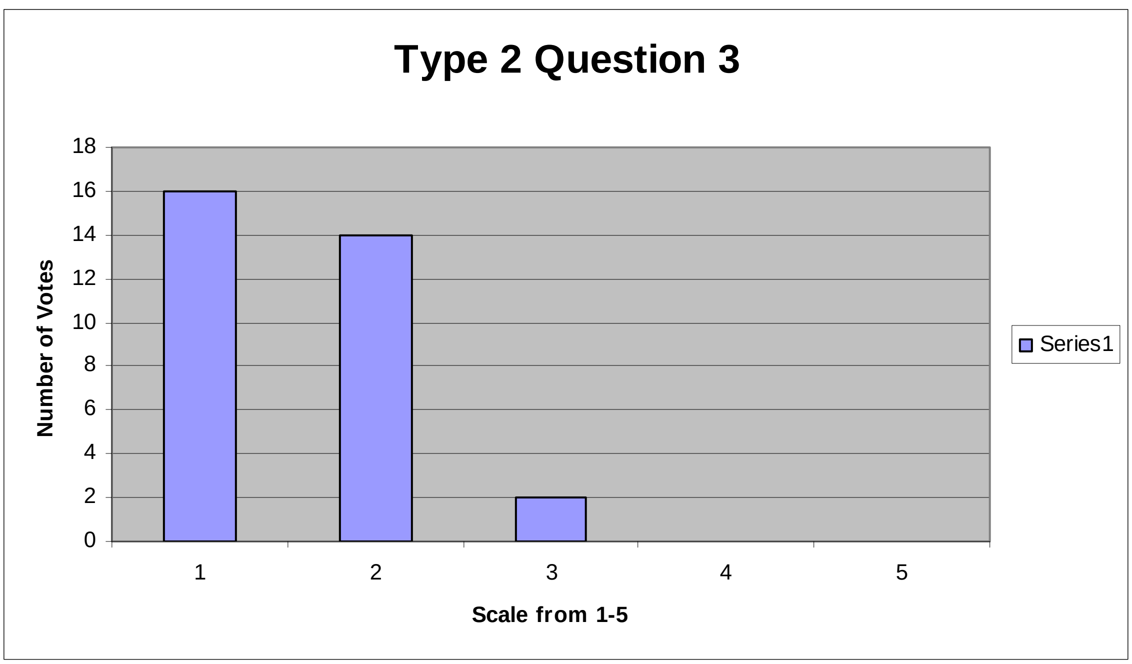


Figure 17: Question 3 for Variable Group



5. Discussion

The controversy surrounding nuclear power plants with regards to safety and reliability have made it difficult to support more production and development of these plants. As seen in the survey that was issued, when people are informed of these new technologies they open up to the idea of a hydrogen economy based on nuclear power. Their main fears were radiation, meltdowns, and environmental dangers. Concerns with radioactive contamination and other such risks can be reduced by the improvements made in the next generation power plants. However, even when informed of these new technologies, people are still doubtful about the next generation power plants being built by their homes. As the distance from people's homes increases, so does their willingness for more plants to be built.

Electrolysis and steam reforming within these nuclear plants is a possible solution to the eventual energy crisis. Unlike fossil fuels, hydrogen is a renewable energy source. To build a hydrogen economy there must be improvement in the areas of hydrogen production efficiency, public's dependences on fossil fuels and lower pollutants. Diatomic hydrogen does not occur naturally on earth so it therefore must be produced. Electrolysis of water produces hydrogen with a low voltage power source coupled with a solution of salt water. This method has proven very reliable in production of hydrogen and therefore the most common. Steam reforming is the process of combining steam at high temperatures and some type of gas in a reactor with a catalyst. This reaction is not perfect and gas and carbon monoxide traverse through without reacting. Although these gasses are burned in the presence of the catalyst steam reforming also has proven most reliable.

Once the hydrogen is harvested, a fuel cell is applied to combine hydrogen and oxygen into energy. This reaction in a single fuel cell produces about 0.7 volts. To increase the voltage output, many separate fuel cells must be combined to form a fuel-cell stack. Depending on the size of the stack and the supply of hydrogen provided, many different tasks could be accomplished with fuel cells.

It is our belief that the public needs a slow integration of nuclear power plant production. The public is just not ready to live in a town with a nuclear plant in their backyard. If these plants were in an isolated area beyond the town/city where the effects of a meltdown would not reach the citizens, the idea would become more agreeable. Even after reading the new technology concerning plant safety, 32% of the public still said they didn't want a plant in the area. It is our belief that in order to clear the public's prejudices, new generation plants need to be constructed in each state. By limiting the number of power plant construction to only one per state, the public can view the results and become accustom to them. However, by having only one plant in each state will by no means solve the energy problem, but it will allow a slow integration of nuclear energy.

6. Appendix

A.1 Survey Questions

<u>Survey Questions</u>

For the following statement please fill in the circle that best describes your opinion.

1) If a next generation power plant were to be built in my **town** to replace gasoline, I would feel comfortable.

O Strongly Agree
O Agree
O No Opinion
O Disagree
O Strongly Disagree

2) If a next generation power plant were to be built in my **county** to replace gasoline, I would feel comfortable.

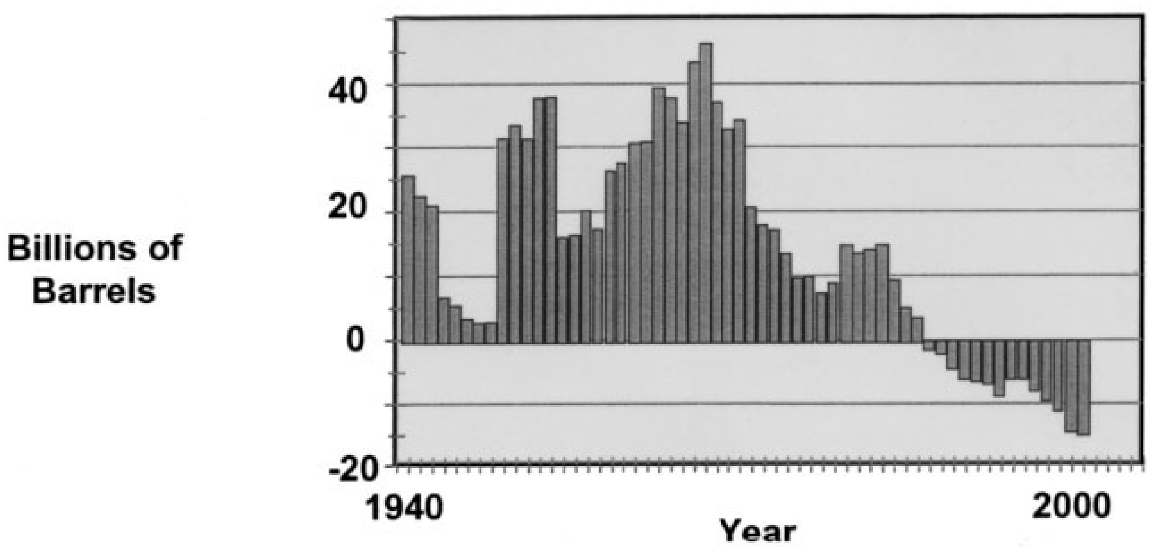
O Strongly Agree
O Agree
O No Opinion
O Disagree
O Strongly Disagree

3) If a next generation power plant were to be built in my **state** to replace gasoline, I would feel comfortable.

O Strongly Agree
O Agree
O No Opinion
O Disagree
O Strongly Disagree

4) If you felt uncomfortable with the construction of a nearby next generation power plant, briefly list your reasons why.

A.2 Survey Handout



Difference between annual world oil reserves additions and annual consumption—1940–2000

Experts have predicted that the world oil will peak in less than 25 years(4). With the human population growing and the world oil declining, new sources of energy must be developed. A possible sustainable energy source is nuclear power, using "Heavy-Metal" fission reactors that operate at higher temperatures than water-cooled reactors because they utilize liquid metal as a cooling reagent. Each of these reactors will be able to supply electricity for more than 900,000 US homes(20). Reactors of this type will negate the environmental issues of toxic waste due to their ability to consume its own waste as well as waste from other reactors.

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