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Alternative and Renewable Energy

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<u>Alternative and Renewable Energy</u>

Interactive Qualifying Project
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Abstract

Energy, in its current state, is a finite resource that will not last for generations to come. This project investigates existing research on several renewable energy alternatives, including nuclear, hydroelectric, natural gas, biofuels, and more, as well as providing a potential method of combining solar and wind energy harvesting techniques for increased efficiency. Finally, the social effects of renewable energy on health, the environment, and politics are considered, and an outlook for the future is included.

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Executive Summary

The goal of this project is to analyze the current state of global energy resources and determine what the long term outlook for humanity is. To this end we researched the different energy sources we typically use today: natural gas, coal, oil, hydroelectric and nuclear. Once we had learned about these resources it became evident that it was unlikely any of them would last through our lifetime without causing serious damage to the environment, if they lasted at all. Nuclear fuel and coal could potentially last for quite a while yet, but have serious issues with waste disposal and pollution, natural gas burns cleaner than most fossil fuels, but it has very controversial mining techniques such as fracking associated with it. Similarly hydroelectric is effective, but can cause major environmental damage downstream of dams and oil isn't likely to last for more than 50 or so more years. This means that the alternative should be a renewable energy that doesn't produce pollutants like fossil fuels do.

For renewable energies we looked at solar power, wind power, tidal power, alcohol, and methane hydrate which is a potential source for natural gas. Of these we quickly determined that currently solar power is essentially infeasible due to the poor efficiencies of solar panels, tidal power is still developing and as such currently there aren't any generators adequate to replace conventional fuels available and their indirect costs have yet to be measured. Alcohol, similarly to solar, isn't a particularly efficient method of generating power, especially when one takes into consideration all the fossil fuels used in fertilizers and farm implements to grow crops that are then converted to alcohol. Methane hydrate, methane frozen at the bottom of the ocean, has only just started to be tapped for use and as such many of the costs of acquiring large amounts of it are unknown, on top of the normal problems with natural gas. Wind power seemed to be the most reasonable alternative power source, since it has efficiencies upwards of 50% and is fairly abundant. The issue with wind comes from people disliking how they look and setting up infrastructure to properly make use of them since they need to be placed out in open areas away from cities where the power is needed. Since none of these solutions are ideal our group decided to use a combination of them: we would place solar panels on the column of a wind turbine and use a reflective surface to refract light onto them from around the turbine's base. This would allow us to capitalize on the land and utilities we already needed for the turbine by adding the power generated by the solar panels.

Unfortunately we found that it was not effective to set up our system based on current costs of solar panels and wind turbines. We found that our alternative was a lot better if you were just going to use solar panels originally, but compared to a wind farm it was slightly more expensive per kilowatt hour. As we were looking at solar technologies, though, we found some interesting new ideas that could in the future significantly increase their efficiency and potentially make our plan feasible. For this reason we would recommend that in the future as new solar technologies become available the idea be reconsidered

as combining wind power significantly reduced the costs of solar alone and brought it that much closer to being a viable alternative.

Chapter 1: Introduction

It is public knowledge that humans depend greatly on energy to meet our basic needs of food, clothing and shelter. The degree in which energy is being consumed has increased over the last several decades which have caused our reliance on fossil fuels to increase as well. Unfortunately, fossil fuels, such as coal, gas, and oil, have many negative effects on the environment and human health. This is why this project concentrates on the importance of alternative renewable resources.

The first part of this project studied the current resources of energy and then determined an approximated date when they would be exhausted. Part of the research involved figuring out why the consumption of energy has grown and how much more it could rise in the future. Once traditional energy resources were well understood, current alternative renewable resources were examined. Things that were particularly important were the reliability of the resource, energy output, and cost. With this understanding, the last part of our project concentrated on making a wind turbine more reliable by surrounding it with solar panels. This involved understanding each of the alternative resources fairly well and how both of them combined would be more beneficial than each on their own. We also briefly examined how alternative renewable resources could affect society in the future. Lastly, a few ideas were suggested for future projects on how to make this wind-solar turbine more reliable.

As oil deposits continue to dwindle and threaten our planet with the effects of global warming as well as pose health hazards to humans, other energy sources will need to take a larger role in supplying the world's energy demand. Over the last several decades, reliance on fossil fuels has increased. Thus, this project concentrates on the importance of alternative renewable resources.

Seventy percent of the earth is covered in water, which is an abundant resource that could be used to supply a reliable form of renewable energy. The most popular and known technology is hydroelectric power which uses running water to propel turbines and create electricity. While this is reliable and clean, there are huge costs to hydroelectric dams and some environmental drawbacks.

Although not a completely clean source of energy, methane hydrate deposits, methane molecules trapped inside ice, can be converted to natural gas. These deposits are located across the world in the arctic regions and under the ocean, estimated to be around 30,000 trillion cubic feet. The potential of this amount of natural gas could allow for the dependence of oil to decrease greatly and allow for more time to further develop renewable energy technology.

Solar energy is the most abundant source of energy available, as according to the Department of Energy, 173,000 terawatts of energy continuously strike the Earth. The challenges that face solar panels when trying to harvest this energy source include the amount of sunlight available on any given day, and at the time in which the sun strikes the solar panels, the amount of sunlight that is converted into electricity. On average, about 20% of the energy that hits the panel is able to be converted into electricity,

although newer technologies such as quantum dots and nantennas show the potential to raise the efficiency to new highs.

The wind currents that flow across the Earth are a direct effect of the sun unevenly heating the earth's surface. We harvest this energy by converting the wind's kinetic energy to electricity via a wind turbine.

There are many pros and cons to both solar and wind energy. They are clean, renewable forms of energy that do not have any harmful by-products and will eventually pay for themselves. However, wind and sunlight can be very inconsistent and unpredictable which can limit the energy produced on certain days. Upfront costs for wind turbines and solar panels are high which causes the price of the electricity produced to be more expensive compared to current prices of energy from oil or coal. Even with these disadvantages, solar and wind power are growing rapidly in spite of the fact that it is not a perfect energy solution.

Our project first examines current available sources of energy and their projected life expectancies. Then, the focus shifts to renewable sources of energy, and other sources of energy in development. We then put this information to use and consider our own potential solution to the energy discussion, examining the effects of potentially combining two forms of renewable energy, solar and wind. Finally, we discuss the social impacts associated with the issue of energy, as well as suggest extensions for future investigations.

Chapter 2: Oil

Crude oil and the refined products have a mixture of molecules, both hydrocarbons and compounds containing sulfur, oxygen, and nitrogen. Crude oil is processed in refineries to make gasoline, diesel, heating oil, and other petroleum products. When oil is burned, the sulfur is converted into sulfur dioxide gas, which once dissolved in water can create sulfuric acid. When the sulfur dioxide is precipitated into the rain, it creates acid rain, which can damage trees, injure wildlife and fish, and damage buildings and crops. While acid rain cannot harm humans directly, the gases that are released from the refining process of crude oil can lead to serious health problems in humans. The nitrogen and sulfur oxides once released into the air can react with the other molecules in the atmosphere to create sulfate and nitrate particles. These particles can be transported long distances by wind and can cause damage when inhaled into people's lungs. Studies have showed that there is a relationship between elevated levels of these particles and increase in illness and premature death from heart and lung disorders.

Crude oil is not very useful in its natural state. It has to be refined using chemicals and catalysts in order to turn the crude oil into gasoline, jet engine fuel and other products. During refining the long hydrocarbon chains are broken into smaller chains and heteroatoms are removed and replaced by hydrogen atoms. The chemicals and catalysts that are used pose a great threat to the environment including air and water quality. Some of these catalysts are lead, platinum, mercury and chromium coated. These catalysts are harmful not just to the environment but also to people. For example, platinum compounds are the cause of many forms of cancer and can damage the liver. Other environmental hazards released during the different parts of refinery processes can be seen in Table 1 below. Another highly dangerous pollutant is benzene, which is also released throughout the refining process. Benzene increases the risk of cancer, bone marrow failure, and many other illnesses. It targets the liver, kidney, lung, heart and brain. Another pollutant is polycyclic aromatic hydrocarbons (PAH), which are products of incomplete combustion. PAHs can lead to different forms of illnesses, the main one being lung cancer.

Cracking/coking	Alkylation and reforming	Sulfur removal
Air releases: carbon monoxide, nitrogen oxides, particulate matter, sulfur dioxide, VOCs	Air releases: carbon monoxide, nitrogen oxides, particulate matter, sulfur dioxide, VOCs	Air releases: carbon monoxide, nitrogen oxides, particulate matter, sulfur dioxide, VOCs
Hazardous/solid wastes, wastewater: ammonia, anthracene, benzene, 1,3-butadiene, copper, cumene, cyclohexane, ethylbenzene, ethylene, methanol, naphthalene, nickel, phenol, PAHs, propylene, toluene, 1,2,4-trimethylbenzene, vanadium (fumes and dust), xylene	Hazardous/solid wastes: ammonia, benzene, phenol, propylene, sulfuric acid aerosols or hydrofluoric acid, toluene, xylene Wastewater	Hazardous/solid wastes: ammonia, diethanolamine, phenol, metals Wastewater

Table 1: Primary Wasters from Oil Refinery

http://onlinelibrary.wiley.com/doi/10.1002/9780470922378.ch11/pdf

(Source: The Greening of Petroleum Operations)
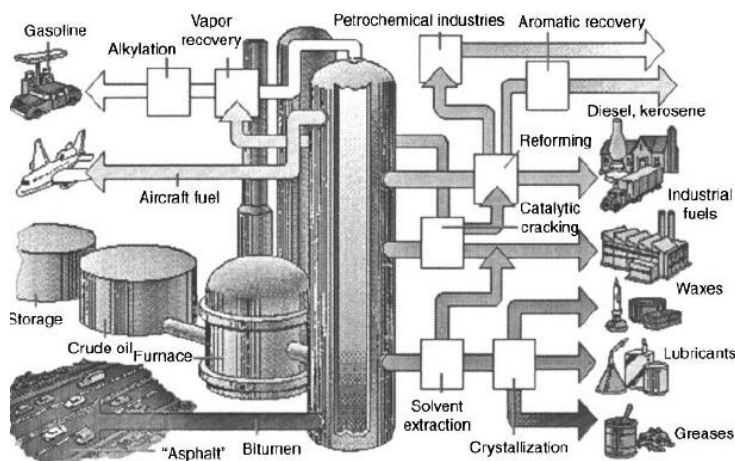
Figure 1: Fractional Distillation Unit for Hydrocarbon Refining

http://onlinelibrary.wiley.com/doi/10.1002/9780470922378.ch12/pdf

(Source: Sustainable Refining and Gas Processing)

Demand

Oil together with coal and natural gas make up about 88% of the world's energy needs. A few of the most impending issues when it comes to oil, as well as other energy resources, are if there is enough oil to meet future demand and price fluctuation. In the last several decades, the worldwide demand for oil has steadily increased. According to the United States Energy Information Administration (EIA), worldwide consumption for oil has increased from sixty-three million barrels of oil a day in 1980, to

about eighty seven million barrels of oil a day in 2010. Figure 2 below shows the linear growth of the world's energy consumption by liquid fuel from 1990 to 2035. The world's liquid fuels consumption is expected to grow linearly at an annual rate of about 1% from 2008 to 2035, with about 112 million barrels per day consumed worldwide in 2035.
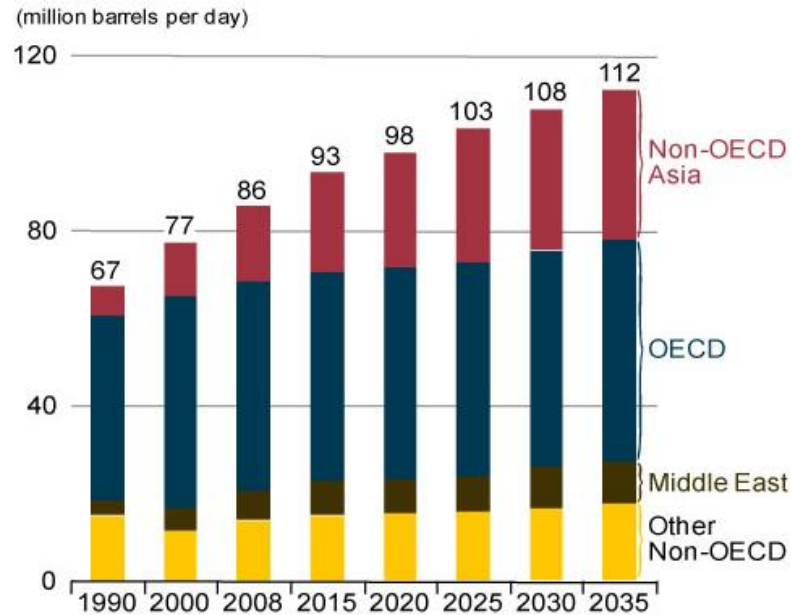
Figure 2: World Liquid Fuels Consumption, 1990-2035

http://www.eia.gov/forecasts/ieo/world.cfm

(Source: International Energy Outlook 2011)
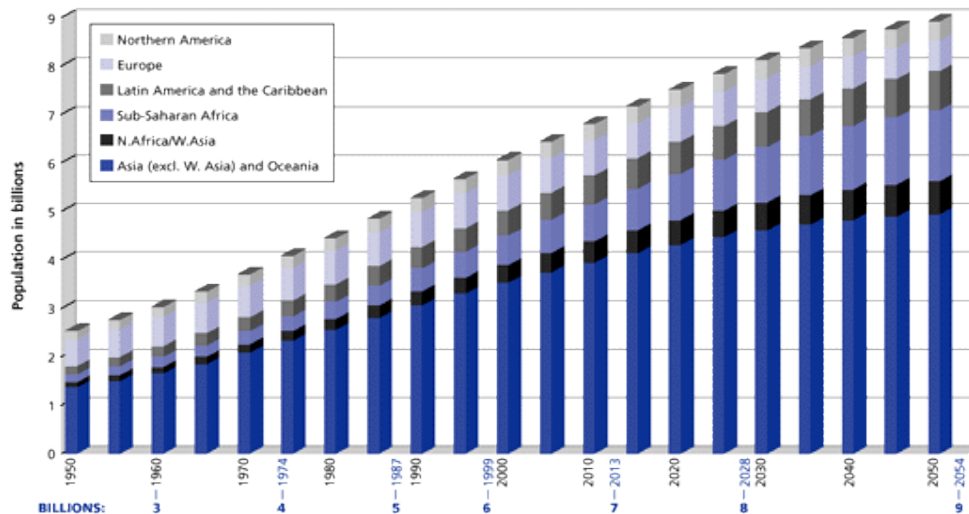
Figure 3: Projected World Population Growth

http://www.globalchange.umich.edu/globalchange2/current/lectures/human_pop/human_pop.html

(Source: University of Michigan)

The increase in demand is associated with many things, such as population growth, economic recovery, and increase use from developing non-OECD countries.. OECD, or the Organization of Economic Cooperation and Development, consists of the United States, much of Europe and several other advanced countries. The population has increased over the last several decades and is expected to increase, such as can be seen in Figure 3. OECD countries consume the largest amount oil, about 53% in 2010; however, OECD countries have a much lower oil consumption growth. In the past decade, 2000 to 2010, oil consumption growth from OECD countries has decreased while in non-OECD countries, oil consumption growth has risen 40%. This trend can also be seen in Figure 2, where the OECD countries consumption growth is less than 1% annually while in non-OECD countries the annual rate is a little more than 2%. As it was mentioned earlier, the reason for this increasing oil consumption is the development in these non-OECD countries. The more they develop, the more energy demand they require and the more oil they consume. The high consumption rate that is expected in these developing countries means an increase in oil production. In Figure 4, the production of oil increases by 26.6 million barrels per day from 2008 to 2035. In response to Figure 2, the production growth is also linear. The graph in Figure 4 shows how the liquid fuel production could continue to steadily increase. As there are many factors involved, including population growth and energy demand that were explained above, it is possible that this line could stabilize at a certain point. Due to the previous years, it is predicted that the liquid consumption would increase at a linear pace and could go on forever.
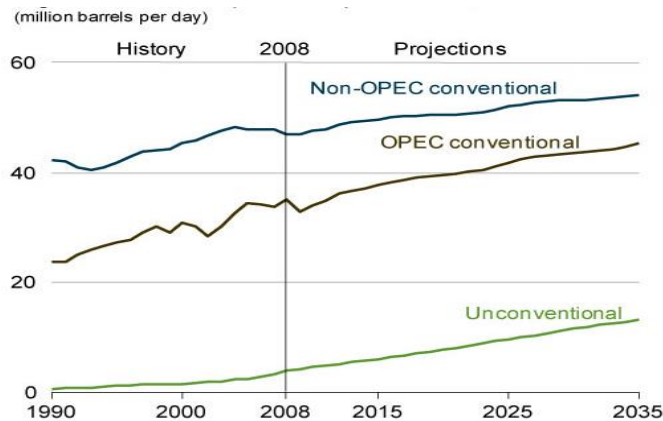
Figure 4: World Liquid Fuels Production, 1990-2035

http://www.eia.gov/forecasts/ieo/world.cfm

(Source: International Energy Outlook 2011)

Peak Oil

A major factor that is important to the demand and supply of oil is peak oil. Peak oil refers to the long-term 'peak' of global oil production, after which the production is expected to decline. This means that eventually all the oil reserves around the world would be discovered and no more oil would be left once these oil reserves were depleted. The idea of peak oil can be seen in figure 5 below.
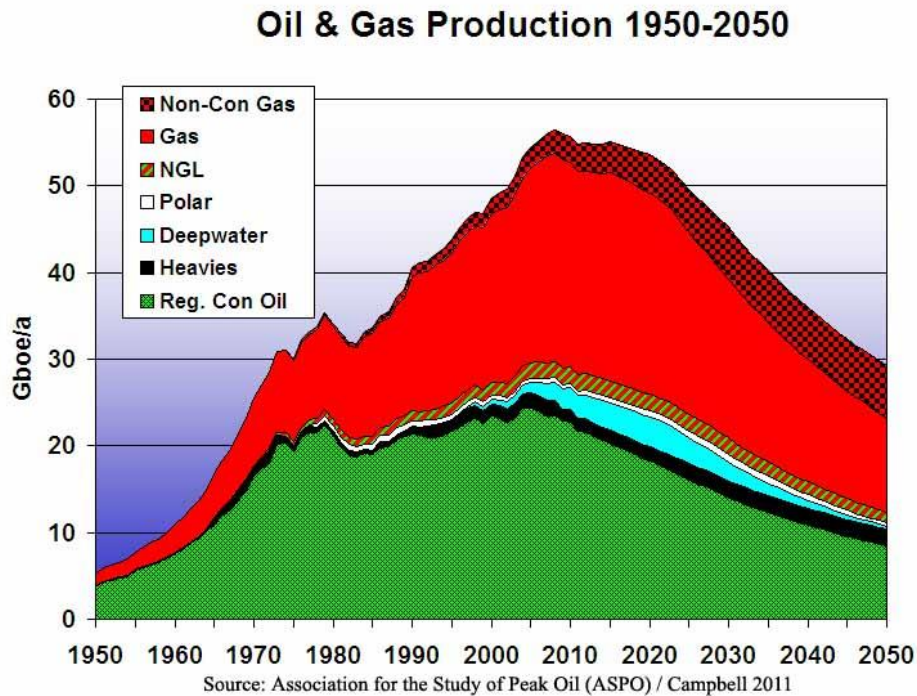
Figure 5: Peak Oil

http://www.geoexpro.com/article/Is_Peak_Oil_Still_a_Concern/fb60bb96.aspx

According to the graph, peak oil would be reached within the next few years or has been reached already. This means that from the point peak oil is reached, the production of oil is expected to decline. The timing of peak oil is highly controversial topic due to the uncertainty of when it would actually happen, although it is believed it will occur somewhere between 2010-to2050. While there is substantial uncertainty about the futures oil supply and demand, according to the EIA, the global supply of crude oil is expected to meet the world's demand for at least the next 25 years.

Another important factor that comes into play is oil prices. In the summer of 2008, oil prices peaked at $140 per barrel then fell to about $100 per barrel later in the year. The demand and the lack of sufficient supply response is one of the reasons why oil prices increased, just as it happened in 2010 when the world was slowly recovering from the global recession in 2008. Prices increased even more at the end

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of 2010 and into early 2011 by the social and political unrest in several Middle Eastern and African countries. During this period, oil prices increased from $82 to $112 per barrel. In Figure 6 below, the fluctuation due to prices over the last 13 years can be seen.

World crude oil prices

dollars per barrel (real 2010 dollars, monthly average)

Sources: Bloomberg , Thomson Reuters . Published by: U.S. Energy Information Administration .
Updated: Monthly | Last Updated: 7/31/2012
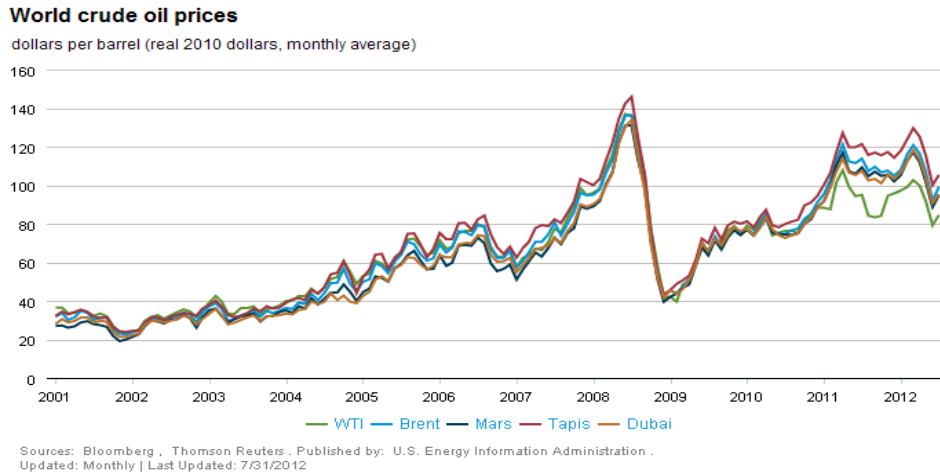
Many types of crude oil are produced around the world. Variations in quality and location result in price differentials, but because oil markets are integrated globally, prices tend to move together.

Figure 6: Oil Price Fluctuation from 2001-2012

http://www.eia.gov/finance/markets/

(Source: EIA)
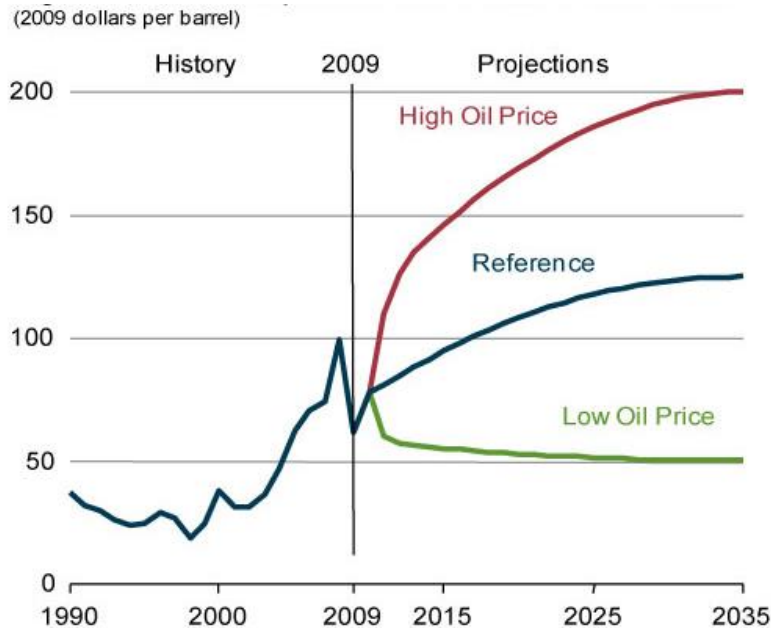
Figure 7: World Oil Prices Forecasts, 1990-2035

http://www.eia.gov/forecasts/ieo/world.cfm

(Source: International Energy Outlook 2011)

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It is expected that oil prices will continue to increase at a much slower rate and reach about $125 per barrel by 2035. Figure 7 above shows three possible cases. The worst case scenario, where prices can reach up to $200 a barrel, the predicted scenario of $125 per barrel and finally the best case where oil price would decreases dramatically to $50 a barrel. Crude oil prices can be affected by weather-related developments, such as hurricanes or tsunamis. For example, in 2005, oil and natural gas refineries along the Gulf of Mexico were shut down due to Hurricane Katrina, which led to a sharp increase in prices as supplies to the market dropped. Long periods of severe cold weather can stretch the capability of the market supply and thus push the prices up. However, this would be a short term fluctuation and eventually the prices would decrease and become stable. Also, there are inventories that act as the balancing point between supply and demand. During periods of excess oil production, such as in late 2008 where there was an unexpected drop in world demand, crude oil and petroleum products were stored for future use. On the contrary, when consumption outweighs current production, supplies can be drawn from these inventories to satisfy the consumers' needs. For this reason, inventories are sensitive to the relationship between current oil prices and expectations of the future. If future oil prices rise, incentives to store the oil for the future will strengthen. On the other hand, if there is an increase in oil storage, which means the productions surpasses the consumption, spot prices would drop to rebalance demand and supply. Oil consumption will continue to increase as will the prices. This means that now more than ever, it's imperative that other means of energy besides oil is used.

Oil Spills

There are many consequences in the use of oil. The most significant consequence is oil spills, which harm wildlife and deplete oil production, costing billions of dollars. There are other more subtle effects to using oil, such as acid rain, and other health issues.
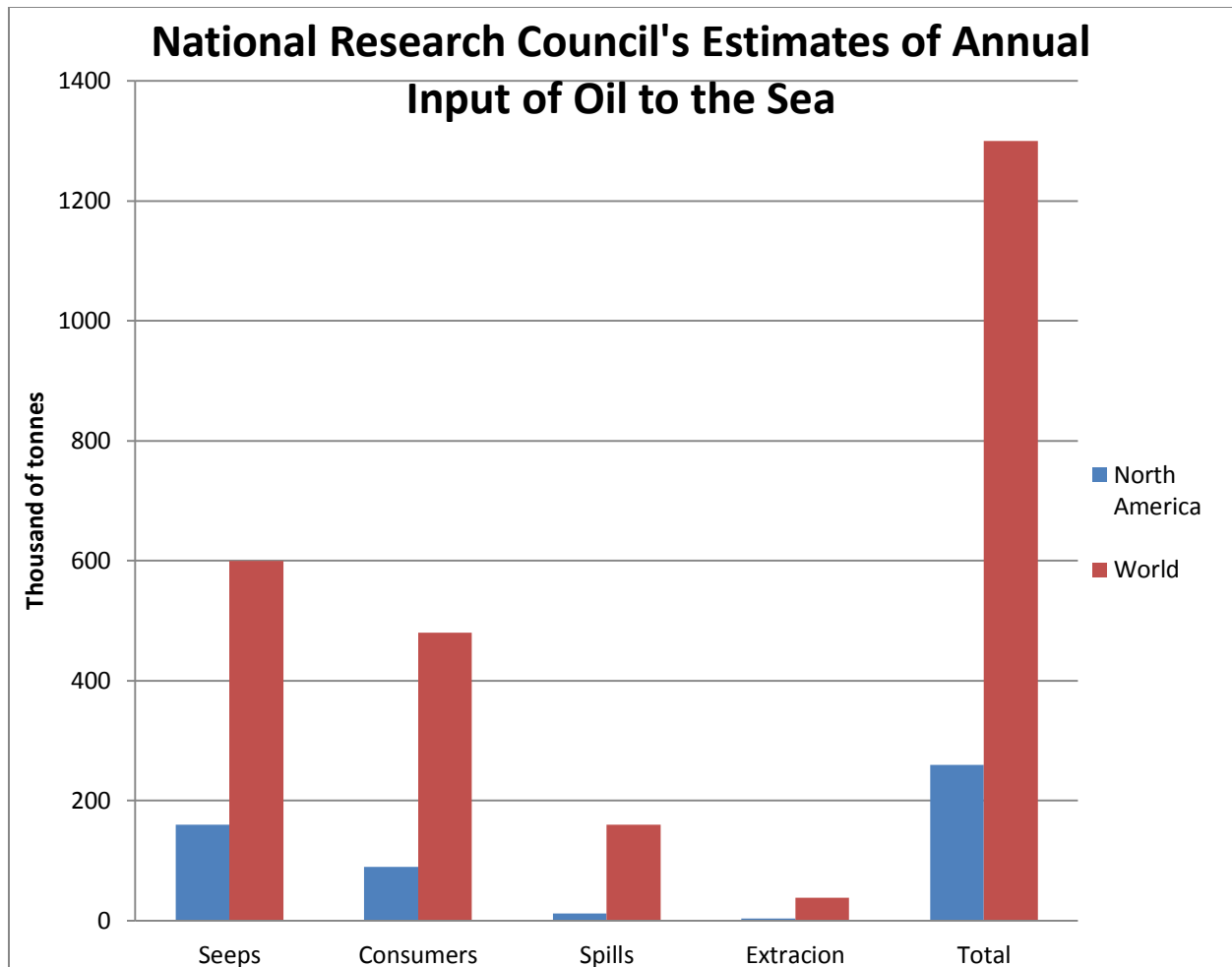
National Research Council's Estimates of Annual Input of Oil to the Sea

(Source: Encyclopedia of Energy)

Crude oil has been released to the natural environment from seeps for millions of years. There are different sources of seeps, including natural seeps, consumer seeps, and spills during oil extraction. A graph of theses seeps can be seen on Figure 8 above. Natural seeps account to about 46% of the oil spilled into the ocean annually. They happen naturally and many of the biological communities around the seep developed and adapted to the oil over hundreds of thousands of years. Therefore, theses seeps are not considered as much as an environmental hazard as man-made oil spills. While man-made oil spills only account for a small amount of the annual oil released into the ocean annually, they have the worst effect on the environment. For example, the Deepwater Horizon oil spill in April of 2010 was the worst accidental oil spill in history, with over 260 million gallons of oil spilled into the Gulf of Mexico. The financial cost to clean up the oil has added up to over $40 billion, with estimates that the cost could

increase. While the oil has been cleaned up, there are many long lasting effects to what happened over two years ago. For one effect, there could be unbalanced food webs. This means that the oil's toxicity may have hit eggs of certain organisms immediately and diminished or wiped out generations. This can cause population dips of certain species, like it happened to the herring population after the 1989 Exxon Valdez oil spill. The population dips not only effects the fragile ecosystem in the Gulf, but also fishermen and seafood eaters around the world. The Gulf of Mexico provides up to 30% of US consumers seafood; the lack of supply due to the oil spill affects the businessmen and in turn affects the consumers.

There are a variety of ways to clean up oil spills. During the Deepwater Horizon spill, oil was burned from the surface of the ocean, some was chemically dispersed and some of it was skimmed from the surface. When oil is burned from the surface of the ocean, there are many worries, such as environmental problems from the particles and gases released as result from burning the oil without filters. Using some oil eating bacteria, such as Alcanivorax, will safely eat oil and eventually die off after the oil is consumed. Some strong chemicals were also dispersed which brought along other environmental problems, since it was believed that these chemicals could harm the environmental life. Booms were placed around the spill to contain the oil, and skimmer equipment was used to try to collect as much oil as possible. Skimmers the float on top of the slick and either suck or scoop the oil into tanks or nearby vessels.

Alberta Tar Sands

Tar Sand or Bituminous Sand deposits are crude oil reserves that are located near the surface that can be extracted and later refined into more usable forms. Bitumen or tar is a very viscous liquid that contains high concentrations of nitrogen, oxygen, and sulfur. For these reasons extraction, transportation, and refining is more expensive than conventional petroleum deposits. Bitumen also contains high concentrations of Asphaltenes compounds which are chains of aromatic, aliphatic, and heteroatom components that have high molecular weights and boiling points. These Asphaltenes are also attracted to one another by hydrogen bonding and other molecular forces which cause a sticky residue to form that can cause pipelines and refining equipment to clog. Pretreatment steps of the petroleum are needed to keep the buildup of Asphaltenes to a minimum. Even with these problems associated with bitumen production, utilizing this resource especially with the conventional oil reserves being depleted can prove to be very valuable. The cost to produce one barrel of synthetic crude oil from tar sand deposits is estimated at around 62 dollars for barrel based on 2006 figures. The operational cost and supply cost are 22 and 40 dollars per barrel respectively.

Alberta's proven tar sands reserves in 2010 were estimated at 170.8 billion barrels of oil which puts them only behind Saudi Arabia and Venezuela for the world's largest oil reserves leaders. The

worldwide bitumen reserves are only estimated at approximately at 250 billion barrels which means Canada hold about 70% of the known worldwide reserves. The Bitumen can be extracted either by surface mining or in situ mining of which surface mining is the less expensive option. Surface mining generally takes about two tonnes of mined tar sand deposits to produce one barrel of synthetic crude oil. Only about 20% of the known tar sands deposits in Alberta can be extracted by surface mining as most of the deposits lie to far underground. In situ mining uses some alternative techniques to extract the bitumen compared to the in situ mining of conventional petroleum deposits since the bitumen is a very viscous liquid. Surface mining is currently the most efficient extraction method to date as 90% of the bitumen can be recovered. From the different extraction processes for in situ mining Steam Assisted Gravity Drainage (SAGD) is the most efficient at 50-60% recovery and 35-40% for Cyclic Steam Stimulation. If conventional in situ techniques were used only about a 20% recovery rate would be achieved. As of 2010 Alberta was extracting about 1.6 million barrels per day of which surface mining accounted for about 53% of the total and 58% of the total went to refining plants to be upgraded to synthetic crude oil. This synthetic crude oil then can be transported usually by truck or pipeline to be further refined into finished products. To be able to refine the bitumen into synthetic crude oil it must go through a process called upgrading in which sand, water, and heteroatoms are removed and carbon chains are broken into smaller ones. This process takes about 1-1.25 gigajoules of energy which is usually supplied by burning natural gas but the energy return on energy invested is still approximately 5.0. Even though there is a surplus in energy gained during this process extra carbon emissions are needed to just get this tar ready to be refined in to finished products where even more greenhouse gases will be produced. These pretreatment plants must also be also on site since the bitumen is extremely hard to transport but the locations of many of these tar sands deposits are located in nature reserves. This causes drilling and building permits to be difficult to obtain.

Bitumen extraction process can be carried out by two general methods of operations, surface mining and in situ mining. Surface mining is the most efficient and cheapest method of extraction but it requires the Bitumen to be located within 250 feet of the surface. The surface mining process is carried out by large excavators and trucks that dig up the tar sand deposits and bring the mixture to a plant to be separated before pretreatment. The excavated material is on average 10-12% bitumen, 83-85% mineral matter and 4-6% water. During this separation process any large oil sand clumps are broken apart and the excavated material is mixed with hot water to lower the viscosity of the bitumen to turn it into a slurry like mixture. This slurry mixture is then spun in a centrifuge drum where the bitumen particles are separated from the sand and are trapped in air pockets that forms a froth on the top of the slurry. The sand is then filtered out and the froth is then skimmed off the top which contains 65% oil, 25% water and 10% solids. The remaining slurry mixture is then pumped to another centrifuge drum where the process is

repeated to extract any remaining oil from the slurry mixture. The froth from both separation processes is then diluted with naphtha and spun in two stages of smaller centrifuges lined with inclined planes, which allow for better efficiencies for particles to separate by settling to the bottom of the centrifuge. In this process about 98% of the bitumen in the froth can be excreted. This bitumen is then ready to be transported to another pretreatment plant to be upgraded to synthetic crude oil.

The situ mining process is more difficult to extract the bitumen from the sand as the high viscosity doesn't allow the bitumen to be pumped easily with normal techniques to the surface. The most common method of extraction is Steam Assisted Gravity Drainage (SAGD). During SAGD a horizontal well is drilled through the tar sand deposit with a steam injection well 5 meters above the extraction well. The steam injection well heats the surrounding bitumen to a high enough temperature to lower the bitumen's viscosity enough so that it can be pumped to the surface. Some hydrocarbon solvents are sometimes pumped in along with the steam to help further lower the viscosity of the bitumen. This method has approximately 50-60% recovery rate for the bitumen. The Bitumen is then pretreated just as in surface mining method to remove any impurities before it is sent to be upgraded to synthetic crude oil. The major problem with the pretreatment process is that the amount of water required to make the slurry mixtures and used in the situ mining process but since the water is being mixed with pollutants none of the water is safe to return the environment. On average to produce one barrel of oil from the tar sands it takes approximately 2-4.5 barrels of water.

Chapter 3: Coal

Coal is one of the most abundant forms of energy in the United States. There are two extraction methods for harvesting coal, surface mining and in situ mining (as explained in the bitumen extraction methods). There are many different forms of coal, with each type containing various amounts of fixed carbon, amounting to the production of different amounts of energy. Because of these attributes, some types are preferable when it comes to producing electricity. The four main types of coal are Anthracite, Bituminous, Subbituminous, and Lignite.

Types of Coal

The type of coal with the highest fixed carbon content is Anthracite, containing 86% to 98% fixed carbon content. Since it has high carbon content, it produces very little of other greenhouse gases. Because it is not as abundant as other types of coal, Anthracite is rarely used, except mainly for space heating and some electrical generation. When a pound of Anthracite is burned, 13,500 to 15,600 BTUs are produced. This is the same as 14.2 to 16.5 million joules per pound burned. Since Anthracite is not common in the United States, we are forced to use the other types of coal that are more abundant.

The most abundant type of coal is bituminous coal. Another name for bituminous coal is soft coal because it contains the substance bitumen, a sticky black and highly viscous material. Bituminous coal contains various compounds which lower the fixed carbon content. The fixed carbon content varies between 46 to 86%. Most of the electricity produced from coal is from bituminous coal, because it is the most abundant type of coal found in the United States. The energy content for burning bituminous coal is less than Anthracite, ranging from 11,000 to 15,000 BTUs per a pound burned which is equal to 11.6 to 15.8 million joules per pound.

The next type of coal is subbituminous coal, which is similar to bituminous coal because they are both soft, black and contain bitumen. The main difference between the two is the carbon fixed content. Subbituminous coal contains 35 to 45% carbon while the remaining percentage are materials that create greenhouse gases when the coal is burned. The one big difference is that subbituminous coal has less sulfur content, making it cleaner to burn than the bituminous coal. When burned, the subbituminous coal produces 8,300 to 13,000 BTU per pound, equal to 8.8 to 137.7 million joules per pound.

The final most common type of coal is lignite, commonly known as brown coal because of its brown color. It has the lowest fixed carbon content of all the types of coal, making it unjustifiable to use as it produces the lowest amount of energy. The carbon content is between 25 to 35%, and when burned, 5,500 to 8,300 BTUs or 5.8 to 8.8 million joules per pound of coal are created.

Electricity from Coal

Electricity is a vital form of energy for not just the United States, but for the entire world. In 2011, four trillion kilowatt-hours of electricity was used. Out of the total electricity consumed, 42% of it was produced through burning coal. The United States consumes 90% of the yearly harvested coal to generate electricity. Until recently, coal has generated the most electrical power per year compared to the amount generated by natural gases and petroleum. With new technologies, natural gas has become more popular and thus has seen an increase in production that rivals coal. Since the 1950s, there have been fluctuations in how much each of these fuels contributed to the overall power generation. The following figure represents the percentage of coal, natural gas, and petroleum power generation from 1950 to present day.

Figure 1. Share of Total Fossil Fuel Generation (All Sectors)

Note: Data through 1988 are for electric utilities only. For 1989 to the present, data include utilities, independent power producers, and the commercial and industrial sectors.
A small amount of generation from other types of fossil gases is not shown (generally <0.5%).
Source: U.S. Energy Information Administration, Annual Energy Review Table 8.2a and Electric Power Annual Table 2.1.A

Figure 9: Power Generation from Fossil Fuels

http://easytobeatmarket.files.wordpress.com/2012/07/fcpgfig.jpg

(Source: EIA- Annual Energy Review and Electric Power)

The major fluctuations in generated power for each fossil fuel tend to be correlated to the fuels' prices and health hazards. More recently, the overall percentage of producing power from coal has been declining, as the United States is becoming more cautious in the carbon dioxide emission. Because of the high carbon dioxide emission, improvements in technology are being implemented to burn less coal and still create the same amount of electrical power. By improving coals' efficiency, carbon emission will decrease and increase coal's projected depletion rate.

Since the 1950s, the production rate and consumption rate of coal have been directly proportional to each other. The decision to use most of the coal collected every year comes from the material's abundance in the United States. In 2011, over a billion short tons of coal were produced. If the United States continues to produce and consume coal at that rate, the coal reserve will last for 200 years. Due to this surplus, the cost to produce electricity from coal is low. A major issue for the future is to maintain coal's surplus while also keeping electricity costs low. As mentioned before, improving coal's efficiency rate to create electrical power will help keep costs low because less coal will be burned. With less coal burned, the surplus will last longer but more importantly carbon dioxide emission will be lowered. In the near future, new policies will be implemented to reduce carbon dioxide emissions. This will cause a price increase for those energy options with high emission. The following figure represents the amount of each fossil fuel that was consumed in 2011 and how much carbon dioxide emission they produced.

U.S. Energy Consumption by Major Fuel Type, 2011

Non-Fossil 18%
Petroleum 36%
Coal 20%
Natural Gas 26%
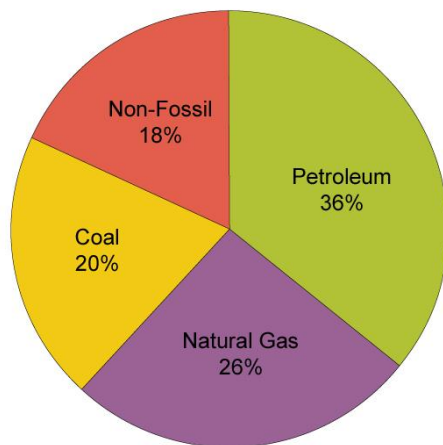
Source: U.S. Energy Information Administration, *Monthly Energy Review,* Table 1.3 (May 2012), preliminary 2011 data.

Resulting U.S. Energy-Related Carbon Dioxide Emissions by Major Fuel Type, 2011

Natural Gas 24%
Coal 34%
Petroleum 42%
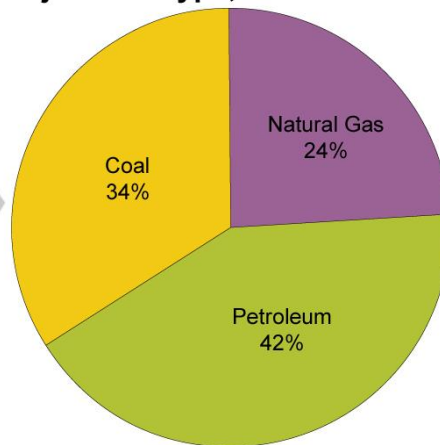
Source: U.S. Energy Information Administration, *Monthly Energy Review,* Table 12.1 (May 2012), preliminary 2011 data.

Figure 10: Carbon Emissions of Major Fuel Sources

http://www.eia.gov/energy_in_brief/images/charts/energy_consumption_major_fuel_type-large.jpg

(Source: EIA- Monthly Energy Review, May 2012)

The graph suggests that only 20% of energy consumed in the United States was from coal but it also contributes to 34% of carbon dioxide emissions. If the ratio of consumption to emission stays around 2 to 1, the coal's price will increase due to the new policies. By lowering the carbon dioxide emission for coal, the price will not be affected by the new policies and keep coal as an inexpensive source of energy for the United States. If prices do increase, natural gas will take over as the number one fossil fuel because it is cheap and produces a ratio of about 1 to 1 in consumption and carbon dioxide emission.

On top of being an abundant energy source, coal is also one of the cheaper energy sources. The national average price for coal is 3.23 cents per kilowatt-hour. It takes an average of 1.03 pounds of coal to create one kilowatt-hour of energy. To compare how cheap it is, the national average price of natural gas is 4.51 cents per kilowatt-hour and oil is about 21.56 cents per kilowatt-hour. Natural gas has been increasing in popularity because it has become almost as cheap as coal and it also emits less carbon dioxide. The average carbon dioxide emission of coal is 2,249 pounds per megawatt-hour and the average for natural gas is 1135 pounds of carbon dioxide per megawatt-hour. Oil emission rate is 1,672 pounds of carbon dioxide per megawatt-hour.

The above prices for all the energy sources were calculated as the average price for the United States. Due to the fact that each state can produce varying amounts of coal, the price is obviously not the same. Applying common economic principles of supply and demand allows for the determination of

coal's price in every state. These prices are affected monthly, as the demand for energy during some months are greater (i.e. for heating and cooling during the summer and winter months). Location can also affect these prices. The following figures represent the cost of coal in each state in 2011, as well as the monthly electric generation of each fossil fuel.
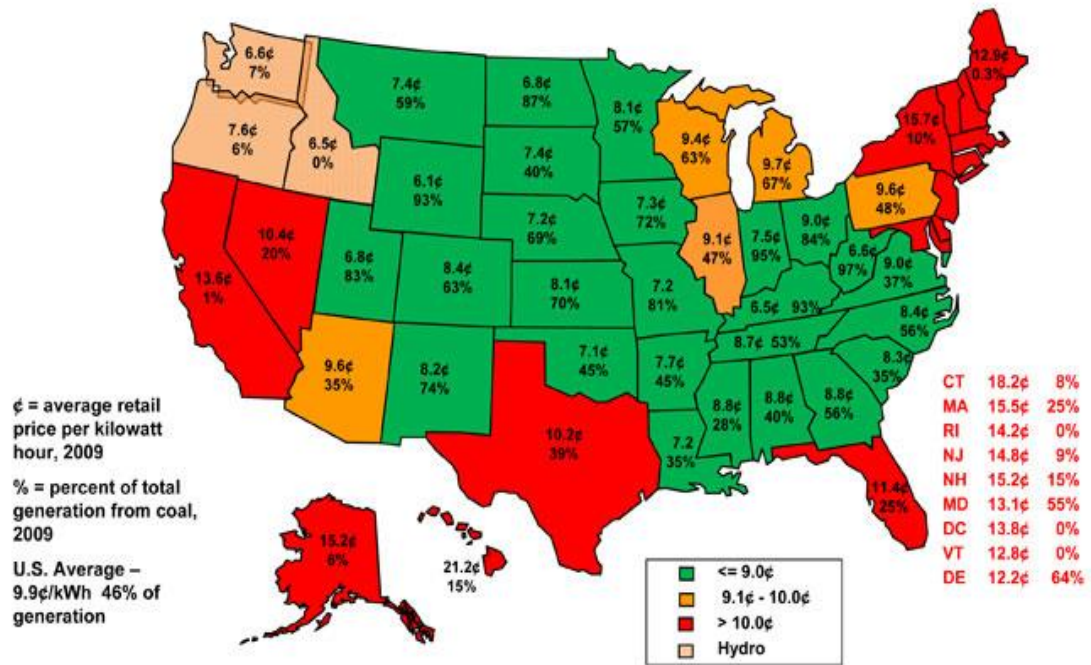
Source: Energy Information Administration, Electric Power Monthly, March 2010

Figure 11: Cost of electricity by state produced by coal

http://www.rmcmi.org/images/default-album/MapCostPerKW.jpg?sfvrsn=0

(Source: EIA- Electric Power Monthly 2010)

Figure 12: Monthly Electric Power Generation

http://www.eia.gov/todayinenergy/images/2012.07.06/CoalNatGasElecGenMatches.png

While coal is a viable source of energy, it is just like everything else, imperfect. Inn order for coal to stay prominent, the consumption to energy generation for coal must be increased. This could be accomplished through new technologies in building coal power plants. Improving this ratio will lower carbon dioxide emissions and therefore keep the cost per kilowatt-hour low.

Given that the most abundant coal form is bituminous, we are forced to use it to produce electricity. Given that the most abundant type of coal is bituminous coal, we are forced to use this to produce electricity. Because this form of coal contains carbon, nitrogen, and sulfur, greenhouse gases are produced when burned. Instead of just burning the coal to convert water to steam, alternatives such as "clean coal" and "liquid coal" are being used.

Clean Coal

Clean coal uses certain technologies to minimize the emission of greenhouse gases by capturing the gases before they are emitted to the atmosphere. "Clean" coal's emissions are reduced by sequestering the carbon dioxide gas produced at the power plant. Sequestration is the process of removing coal in the atmosphere and depositing it into underground reservoirs. One method of removing carbon dioxide from the air is by reacting the gas molecules with magnesium oxide, MgO, or calcium oxide, CaO, to create carbonates The reactions between carbon dioxides and the metal oxides are as follows:

[1] $$CaO + CO_2 \rightarrow CaCO_3$$

[2] $$MgO + CO_2 \rightarrow MgCO_3$$

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According to Howard Herzog, a sequestration expert at MIT, the most expensive part of sequestration is capturing gases from the atmosphere. It costs a total of $49 to capture a ton of carbon dioxide. Not only does it cost more, but the energy output is lower. Due to the cleaner process, the price of coal energy may increase anywhere between 1.04cents/kWh to 3.32cents/kWh. The following figure demonstrates how carbon dioxide is captured and stored to prevent it from escaping.
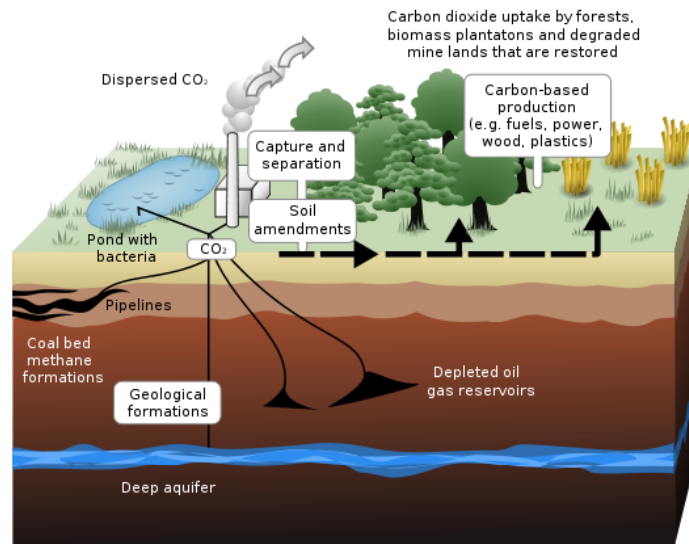
Figure 13: Carbon Sequestration

http://green.blogs.nytimes.com/2009/03/09/chief-barrier-to-clean-coal-cost/

(Source: The New York Times)

While the name suggests that the process of burning coal is better, it is argued that the treatments have no effect on making the emissions cleaner. Any attempt that can improve greenhouse emissions without increasing coal's price and maintain low manufacturing cost for power plants should be applied. Without trying to improve the emissions, the emissions will only get worse when more electricity has to be generated

Liquid Coal

Another attempt to improve coal emissions is by converting rock coal into liquid coal. The main way liquid coal is created is through a hydrogenation process or Bergius process. To produce liquid coal, ordinary coal is finely ground and dried by passing it through hot gas. When it becomes dried, recycled oil and catalysts, such as tungsten and tin, are mixed with the remains. The mixture is then pumped into a reactor that operates at a temperature between 400 to 500°C. The reaction can be summarized as follows;

[3] $$nC + (n + 1)H_2 \rightarrow C_nH_{2n+2}$$

29
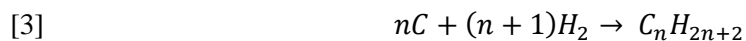
Liquid coal has been looked at to replace petroleum because it is cheaper. The main issue arising from liquid coal is that there are many wasteful byproducts such as greenhouse gases. There are three main factors to consider in determining if liquid coal is better than petroleum. The first factor to consider is greenhouse gas emission. As long as liquid coal emits less greenhouse gases, it would be better for the environment. The second factor is energy content. If liquid coal's energy content is less than petroleum, more coal must be burned to get an equal amount of energy. The third factor is the most obvious, price. Consumers want the best product at an affordable price. If liquid coal can adequately satisfy these three factors, it is certainly an option to consider.

There are other factors to consider, such as how vehicles might adjust to a new type of fuel. The automotive industry has gone a long way to improve petroleum gas vehicles, so it may take some time to get the same results from liquid coal. There will also have to be an easy and affordable way to convert existing vehicles to work with liquid coal. Introducing a new fuel without any means to use it will be pointless. It will be difficult to make the transition in vehicles but liquid coal could be applied in other areas such as heating, or any other application of petroleum.

Chapter 4: Natural Gas

Background

Natural gas is a major source of electricity via gas turbines and steam turbines. An important aspect of using it as a resource, therefore, is the amount of emissions created by burning natural gas. According to the EPA natural gas is actually the cleanest because it is the most efficient fossil fuel to burn, and when it burns at 100% efficiency the only byproducts are water vapor and CO_2. This can be shown through the EPA's table of Fossil Fuel Emission Levels in Pounds per Billion BTU's of energy input, below.

Fossil Fuel Emission Levels - Pounds per Billion Btu of Energy Input			
Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Table 2: Fossil Fuel Emission Levels

http://www.naturalgas.org/environment/naturalgas.asp#greenhouse/

(Source: EIA - Natural Gas Issues and Trends 1998)

For this reason, natural gas is a good way to fill in gaps of energy production where other renewable resources need it. For example, since solar generates power only during the day and only on sunny days, natural gas can be a good stand-in during peak demand to make sure there is still enough supply to meet the energy demand. At the moment, the best way to use natural gas to generate power and keep pollutant generation low is to use a Combined Cycle Gas Turbine. This turbine uses the principle that the exhaust of one heat engine, powered by natural gas in this case, can be used as the heat source for a second heat engine. This extracts much of the heat that is generally wasted in a normal engine, as the first heat source engine will typically use less than 50% of the heat generated.

The price of natural gas varies greatly based upon the location and the type of consumer. During August 2012, the price of 1 million British Thermal Units (MMBTU) of natural gas varied between $1.90 and $4.25 wholesale and each MMBTU generated approximately 1 gigajoule of electricity. The worldwide average price for a consumer using natural gas is approximately $0.08 per KWh

Based on current estimates of obtainable natural gas resources and a 2007 estimate of world demand natural gas will be available for about the next 100 years. There are new technologies, though, that could potentially increase this lifespan. For example the newest and likely most controversial method is "Fracking," which is an abbreviation for "Hydraulic Fracturing." This technique involves using a drill to force a mixture of water, lubricants, and other chemicals into underground rock, especially shale, and then breaks it apart to released trapped deposits of natural gas. The concerns about this method of gas extraction are numerous, however. Many people worry about the liquid contaminating underground water supplies, the chemicals potentially making their way to the surface over time, and also surface

contamination from potential spills and flowback- the fracking liquid that is brought back to the surface by the drill along with the natural gas.

Methane Hydrates

Methane Hydrate is a potential energy source that has yet to be tapped and could provide energy for many generations. Methane hydrate is methane molecules trapped in an ice crystal lattice, deep in the ocean or on permafrost land. The permafrost hydrates usually exist between 300 to 500 meters and the oceanic deposits between 1000-5000 meters below the surface of the earth.
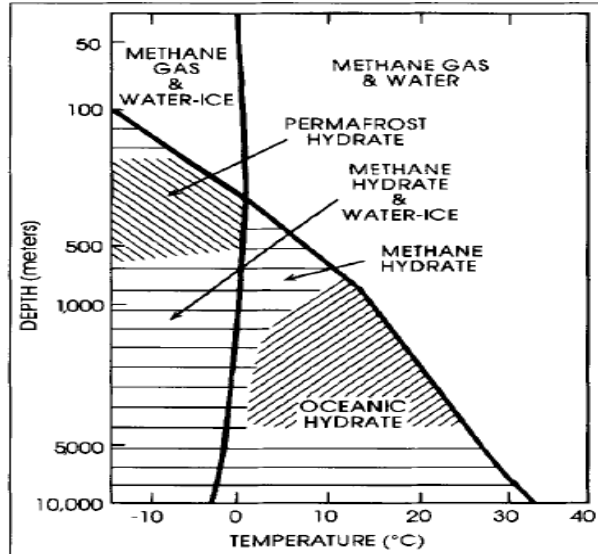
Figure 14: Methane Hydrate Water Phase Diagram

http://onlinelibrary.wiley.com/doi/10.1111/j.1747-5457.1998.tb00786.x/pdf(Source: Journal of Petroleum Geology, July 1998)

These hydrates can only exist under extreme conditions of low temperature and high pressures as shown in the figures below. If the methane hydrate equilibrium is shifted from where it normally exists above the curve to below the curve then the methane would separate from the lattice ice structure. The places where methane hydrate can exist are called the hydrate stability zones.

32
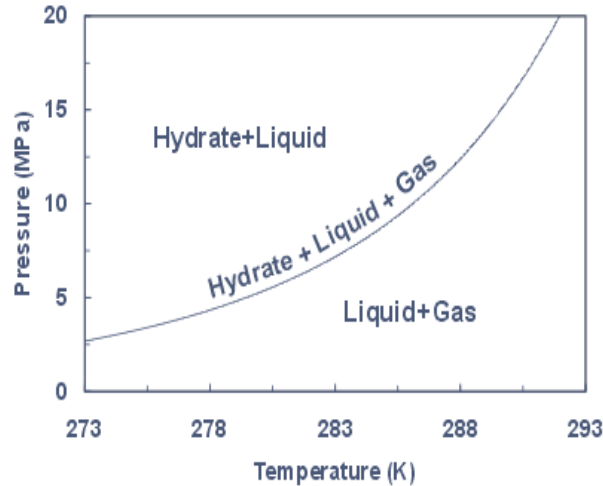
Figure 15: Temperature vs. Pressure Phase Diagram

http://www.pet.hw.ac.uk/research/hydrate/hydrates_where.cfm

(Source: Heriot-Watt Institute of Petroleum Engineering)

Origins and Properties

Methane is present in these areas as a result of microorganism decaying organic matter in an anaerobic, low oxygen, environment. Organic matter is usually composed of carbon, hydrogen and phosphorous which in the presence of microorganisms break down the organic matter in a process called methanogenesis. The end result of methanogenesis produces carbon dioxide, methane gas, ammonia, and phosphoric acid. In the intermediate steps of the reaction acetate fermentation and the decomposition of carbon dioxide take place which further produce methane gas as shown below.

[4] $(CH_2O)_{106}(NH_3)_{16}(H_3PO_4) \rightarrow 53CO_2 + 53CH_4 + 16NH_3 + H_3PO_4$
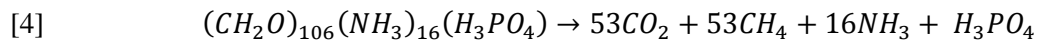
Acetate fermentation Process

[5] $CH_3COOH \rightarrow CH_4 + CO_2$

Reduction of carbon dioxide

[6] $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

This process can take place either in the stability zone or below it called the "deep methane influx" in which the gas flows upwards until it reaches favorable conditions for a hydrate to form. The amount of methane influx has been estimated to flow around 128mol/m^{2}yr or 2.05Kg/m^{2}yr at 12.3 °C. This provides a constant supply of methane to slowly replace the hydrates that would be extracted which would further increase the known gas reserves.

In order to access these methane molecules for extraction purposes, the methane must be removed from the lattice structure. This lattice structure is usually a type I unit cell composed of two pentagonal dodecahedron, 5^{12}, and six tetrakaidecahedra, 5^{12} and 6^2, structures each of which contains a total of

46H$_2$O, S$_2$L$_6$•46H$_2$O. The Van der Waals forces present in these lattice structures are strong enough to trap molecules that are small enough to fit inside the lattice cages. By trapping these molecules the hydrate actually becomes more stable and this allows the deposit layers to stack on top of themselves.
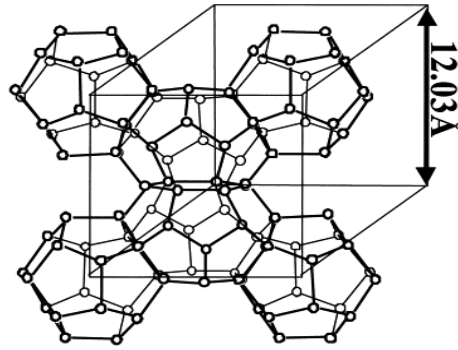
Figure 176: Unit Cell of a Hydrate
http://www.sciencedirect.com/science/article/pii/S0360544299000365

(Source: Journal of Energy)

With the large presence of methane, these zones cause the methane to be the primary molecule to be trapped inside these lattice structures. If any other molecules are present with an atomic radius that is smaller than 4.33A or 3.95 A for the large and small lattices, respectively, then that molecule could also be trapped inside the lattice structure along with the methane. This property is intriguing to many scientists as carbon dioxide is one molecule that is also able to fit inside these lattice structures and could allow for carbon sequestration by replacing the methane with carbon dioxide. Carbon sequestration could be one way to not only reduce our carbon emissions by switching from oil and coal to natural gas but also remove some of the carbon that would be put into the atmosphere by storing it in carbon dioxide hydrates.

Being able to tap into this valuable energy resource would greatly reduce our dependence on oil and reduce the amount of greenhouse gases that would be produced. The amount of estimated methane hydrate reserves in oceanic reserves to be 30,000-49,100,100 trillion cubic feet (TCF) and 5,000 to 12,000,000 trillion cubic feet (TCF) in permafrost regions. The current global estimates of natural gas are 13,000 trillion cubic feet of which the United States has about of 2203TCF of known reserves that could be recovered. The United States in 2011 used approximately 24TCF and if the usage remains constant then the United States supply would last 92 years. The Gulf of Mexico is estimated to have approximately 21,000 TCF of methane hydrate reserves, according to the Minerals Management Survey.. If this supply was added to the current known United States methane reserves, then this would last the United States over 950 years, assuming the current rate of consumption remained the same. Just tapping into this one known reservoir of methane hydrate this could potentially could replace all coal and oil dependence if

other reserves across the United States such as Blake Ridge on the Coast of the Carolinas and the North Slope of Alaska. The large volumes of the methane gas can be explained by the large quantity of gas in a small area, 1 m^3 of hydrate disassociates at atmospheric temperature and pressure to form 164 m^3 of natural gas plus 0.8 m^3 of water. This means that even small hydrate deposits in remote areas could be worth extracting if transportation costs were feasible.

Locating Hydrates

Methane Hydrate was first discovered in the 1960's in a Messoyahka gas field of the Western Siberian basin. Research programs across the world then were started to figure out how to identify the locations of this valuable resource. Blake Ridge is a shelf 450km off the coast of Savanna, Georgia which was known to have deposits of hydrates but in unknown quantities. Using seismic waves deposits of hydrates can be found in a general area by looking for the Bottom-simulating reflectors (BSR's). These appear as distinct lines on seismic picture as shown in the figure below. However this does not give composition of the methane or the direct location of the deposits. Blake Ridge project in 2003 worked to find a way to determine more accurately where the methane hydrate deposits were and try to give the saturation levels of the methane at these locations. Using a lens to measure the velocity of seismic waves returning from the tested area show that higher velocities (1910m/s) were found in the BSR regions while lower speeds (1820 and 1849 m/s) occurred outside of the BSR region. Since methane hydrate has a higher Primary Wave of 3.3km/s compared to the sediment surrounding it of approximately of 1.6km/s, the higher velocities measured give higher concentrations of methane hydrate deposits. The Blake Ridge project determined in the area tested that hydrate lens contains at least 13% bulk methane hydrate within a 2-km^3 volume, yielding 3.2×10^{10} kg [1.5 TCF (4.2×10^{10} m^3)]
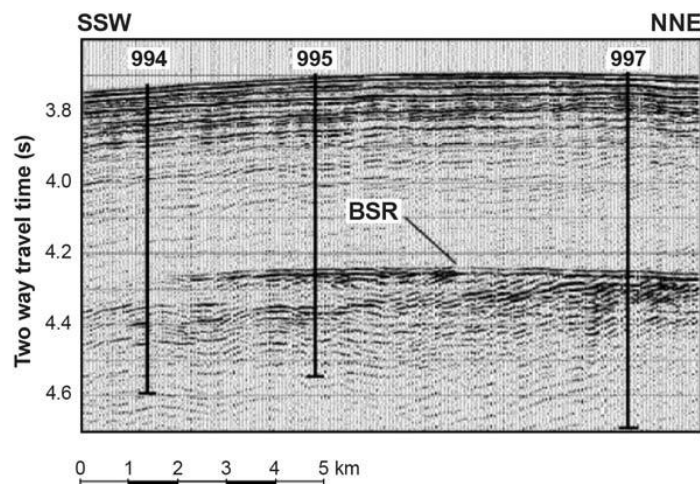
Figure 17: Seismic Image of Black Ridge

http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2011Reports/MH_Primer2011.pdf

Extraction Methods

The current technology allows for three different extraction methods to remove the methane from the lattice structure. The three different methods that can be used are depressurization, diffusion, and/or heating. Depressurization is currently the cheapest method of extraction while the heating of methane hydrates is the more expensive option. Extraction occurs as all these methods drive the solid methane hydrate across the equilibrium curve causing the mixture to be liquid water and gaseous methane.

[7] $$CH_4 6H_2O \rightarrow CH_4(g) + 6H_2O(l)$$

This then can be pumped up to the surface where the water can be separated from the water in a separate extraction process.

Depressurization is the method that experts believe is the most efficient and cheapest way to extract the methane. This process is carried out by lowering the pressure of the target area and drilling under the deposits in the free gas zone, which is a porous region where gas flows as it waits for conditions to be right to form methane hydrate. By drilling into this region and removing some of the sand and water in the drilling process the pressure will decrease under the methane hydrate reserves and slowly dissociate the methane from the ice crystals. At first the difference in pressure will cause a free flow of gas, water and sand mixture to the surface but eventually a pump will be needed for a continuous flow of the mixture. The thermal dissociation of methane from the hydrate lattice is the process of injecting a heated liquid, usually steam, down to hydrates. This drives the equilibrium towards the liquid phase which allows the water and methane to be pumped up to the surface. This is more expensive than the depressurization process as energy needs to be spent to heat the liquid being pumped down the well. It is estimated that the amount of energy required to heat the liquid is about 6% of the total energy from the methane being extracted. Chemical injection is the final process for extraction which is very similar to the thermal dissociation process as a compound would be pumped down the well to cause the equilibrium of the methane hydrate to become unstable. The chemical that can be injected for this process must be able to fit into the lattice structure of hydrates; if not, the methane will not be able to dissociate out of the lattice structure. Another issue that needs to be considered is the flow rate of the chemical being pumped. If the concentration is too high or if it is too low, the methane will not separate from the lattice structure. This is a new idea for extraction and more laboratory testing needs to be done. This process has led to the idea of replacing the methane hydrate with CO_2 as a way to store excess the amounts underground to also help fight global warming. The two chemicals that are currently being tested are methanol and ethylene glycol, however both of these have problems. Extra extraction steps at the surface needs to be taken to

extract the chemical from the water and methane so it can be reused. Methanol is cheaper than the ethylene glycol but its extraction cost would be greater.

Ignik Sikumi Trial

The Ignik Sikumi gas hydrate trial used a combination of the depressurization method and chemical injection of N_2 and CO_2. The process is carried out by injecting N_2 initially, then over a period of two weeks, a mixture of N_2 and CO_2 is injected. It was determined that a mixture below 25% CO_2 and 75% N_2 was considered ideal. Over a 13 day period 57 thousand standard cubic feet of CO_2 was pumped into the well. After a stepwise depressurization of methane hydrate and the gas mixture was performed, which the difference in pressure caused the mixture to flow to the surface without the need of a pump. After the natural flow upwards, a pumped was then used to continuously move the methane to the surface. The composition of the gas stream and sand build up was carefully monitored throughout the experiment. The test proved to be successful as approximately 998 million standard cubic feet of gas was analyzed using a gas chromatograph and found that 82.2% of the gas recovered was methane and the remaining was the CO_2 and N_2 mixture. The pipe was filled with cement and capped and the area was cleared to remove any trace of the operation. The project was considered a success as the project team was able to produce a steady stream of methane gas mixture from the methane hydrate deposits. With the successful results of this project the United States Department of Energy has increased the funding for methane hydrate research to 5.59 million dollars to 14 laboratories across the United States.
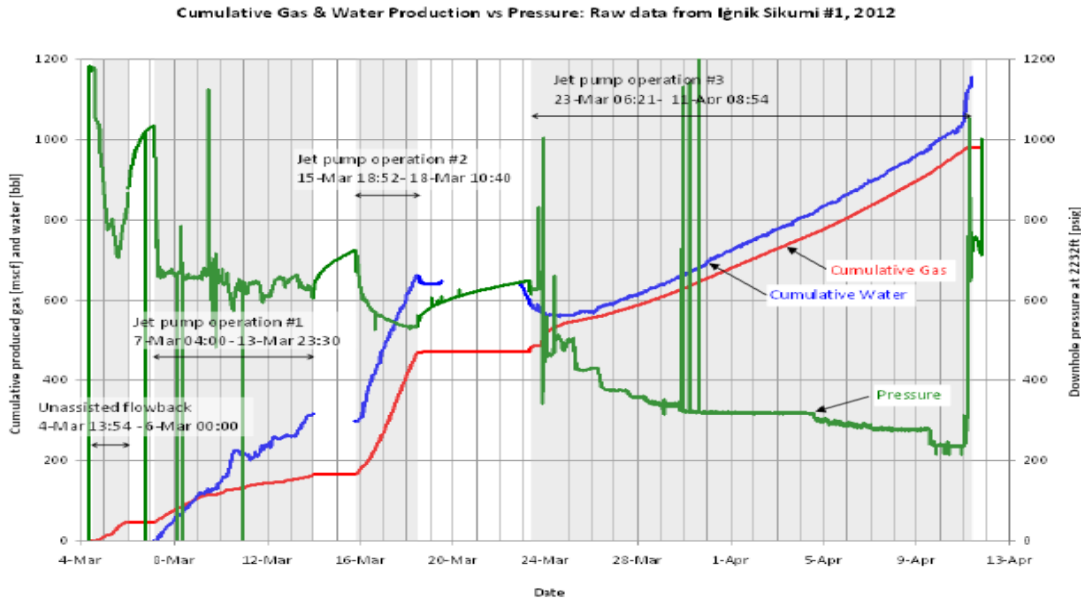
Figure 18: Flow back Data from Ignik Sikumi

Well http://www.netl.doe.gov/technologies/oil-gas/publications/Hydrates/2012reports/nt0006553-semi-annual-report-6-30-12.pdf

(Source: ConocoPhillips)

Sequestering CO_2 in Hydrates

Sequestering of CO_2 in the process of releasing the methane from the hydrate structure seems to be a perfect way to combat global warming. A ConocoPhillips-University of Bergen team has shown promising experimental and modeling results for the process in porous media settings at conditions well within both the CO_2-hydrate and CH_4-hydrate stability fields. These results include: 1) relatively rapid CH_4 release; 2) exchange of CH_4 with CO_2 approaching 70%, and 3) exchange occurring with no observable water liberated during the process. These experimental results need to be validated on a larger scale but the initial results seem to be promising.

[8] $$CO_2(H_2O)n \rightarrow CO_2(g) + nH_2O \ \Delta Hf = 57.98 \ ^{kJ}/_{mol}$$

[9] $$CH_4(H_2O)n \rightarrow CH_4(g) + nH_2O \ \Delta Hf = 54.49 \ ^{kJ}/_{mol}$$
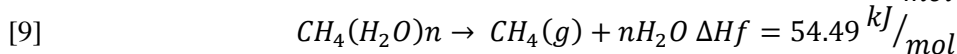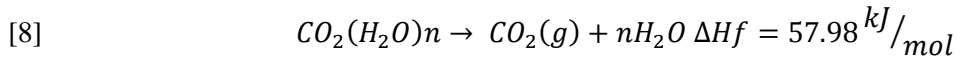
These results were not expected since by the heat of formation, ΔHf, of the CO_2 hydrate is higher than that of the H_2O which favors the CH_4 hydrate forming over the CO_2. Another benefit of this proposed method is that the amount of water that is pumped up is much smaller than that of normal depressurization which would help reduce the amount of amount of sand that would need to be filtered and reduce the cost of separating the methane from the water at the surface. Other studies have shown that mixed gas injection (i.e., CO_2 + N_2) can boost recovery to 85%. If this efficiency could be achieved this would make carbon sequestration during the methane hydrate production very viable but the recent results

of the Ignik Sikumi well showed that the more efficient composition of CO_2 and N_2 is using a 25% to 75% ratio respectively. If the efficiency of carbon dioxide wanted to be increased in hydrate deposits then a different mixture of chemicals or operation parameters need to be considered to allow for a higher ratio of CO_2.

Environmental concerns must be taken into place when pumping carbon directly into the ground or ocean floor. The ocean is a very delicate part of our environment and disrupting it by drilling could affect the ecosystem and currents. The ocean is affected by temperature and its salinity, which is the average concentration of dissolved salts in the ocean. These two things determine the ocean's density which controls currents and more importantly the amount of light that penetrate is the surface of the ocean. The process of depressurization removes water as it pumps the hydrate to surface which can distribute the natural salinity of ocean in that area, but with more efficient methods of methane removal would allow drilling in areas without too much worry. If CO_2 was too be sequestered in the ocean in hydrates then the location of these hydrates must also be chosen carefully as some methane hydrates deposits in permafrost regions are no longer stable for hydrate formation and methane is leaking into the atmosphere. If CO_2 were to be sequestered then the locations for these deposits must be in a place that does not run the risk of releasing the CO_2 back into the atmosphere at a later date.
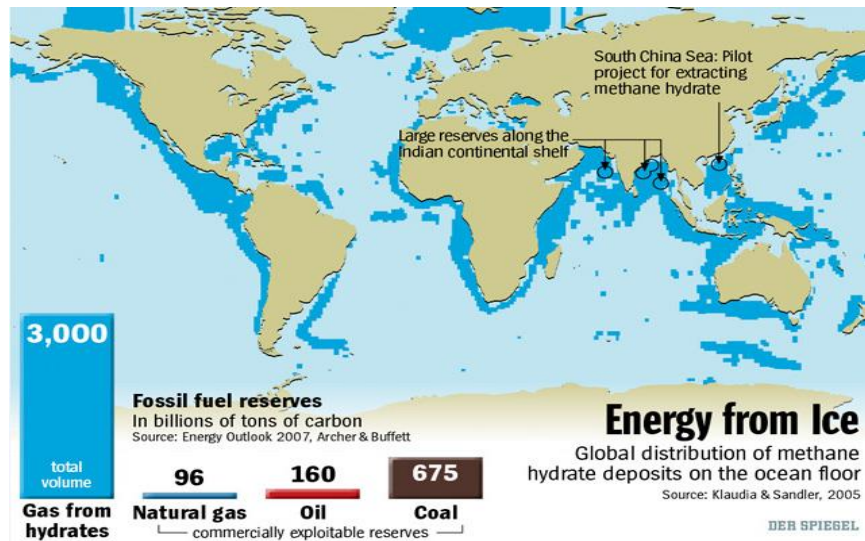
Figure 19: Fossil Fuel Reserves

http://theresilientearth.com/?q=content/arctic-armageddon-or-methane-madness

Calculated Gas In-Place in Hydrate-Bearing Sands
Total Median = 43,311 tcf
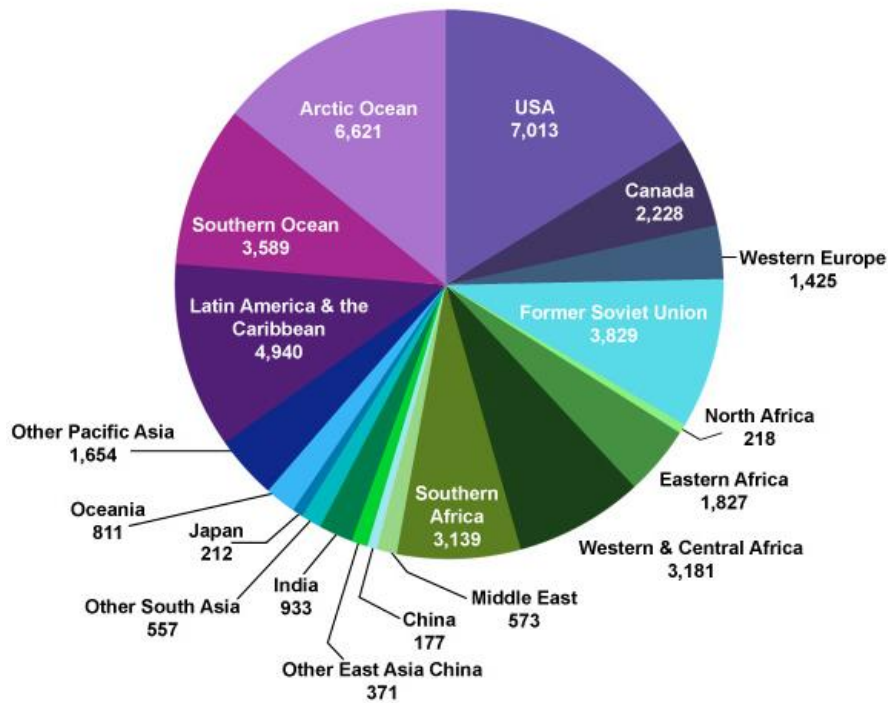
Figure 20 Methane Hydrate Reserves by Country

http://www.searchanddiscovery.com/documents/2012/80221prabhakar/ndx_prabhakar.pdf

(Source: Gas Hydrates as an Unconventional Resource: Asian Perspective)

Methane hydrate is one of the most promising sources of energy coming in the near future. With the successful Alaska North Slope field trial, funding in the United States has increased and future trials will probably happen. The process of how the methane should be extracted from the water and how it should be transported still needs to be looked into. The drill sites that are located further away from natural gas power plants would have to liquefy the methane on site if the gas was to be transported by a pipeline. We think that for the near future that these drill sites should be built closer to power plants where the gas can be easily transported without a long pipeline. These locations which we think it would be ideal are Japan, Malaysia, and New Zealand because they have large off coast reserves which have natural gas power stations close to the coast line. Japan would be an ideal country for this new technology as in light of the Fukushima tragedy Japan is looking to shut down all of its nuclear power plants for safer sources of electricity and methane hydrate could be their answer to their situation. If methane hydrate reserves across the world are efficiently drilling and extracted safely then the world could use this to replace oil when prices become too expensive.

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Chapter 5: Nuclear Energy

The demand of energy is increasing with the number of countries that are becoming more developed. With this increase in demand and the awareness of global warning, clean alternative energy resources to oil and coal are growing in popularity. Nuclear energy is one such energy source that provides clean and cheap electricity. However there are limitations to using nuclear energy as a resource such as placement of the power plant, obtaining the fuel to run the plant, and the disposal of the hazardous waste materials.
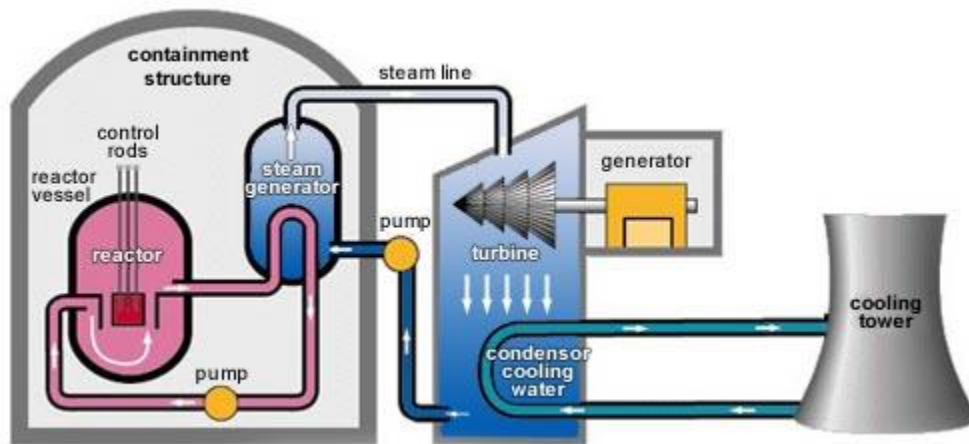
Figure 21: General Model of a Nuclear Power Plant
http://www.cameco.com/uranium_101/uranium_science/nuclear_reactors/

After World War II nuclear power plants were being built as nuclear fusion technology was being used for power instead of bombs. Nuclear fission occurs in these reactors by bombarding the nuclear fuel with neutrons to increase the speed of the decay of the nucleus which occurs naturally. When the fission occurs more neutrons are released which causes a continuous fission to occur.

[10]
$$^{235}_{92}U + ^{j}_{0}n \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + ^{i}_{0}n$$
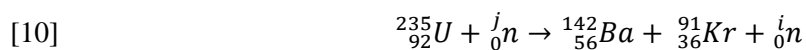
The neutrons released during the fission reaction pass through a moderator to slow down their speed so the fission is more efficient. These moderators are usually graphite or water. Heavy water is the most efficient moderator since it doesn't absorb any of the neutrons since the hydrogen bonded to the water is deuterium which already has an extra neutron. The heat given off by these reactors is then used to boil water to create steam which powers a generator that generates electricity. There are several different types of reactors currently in use that vary on which moderators are used and how the steam is generated to power the generator.
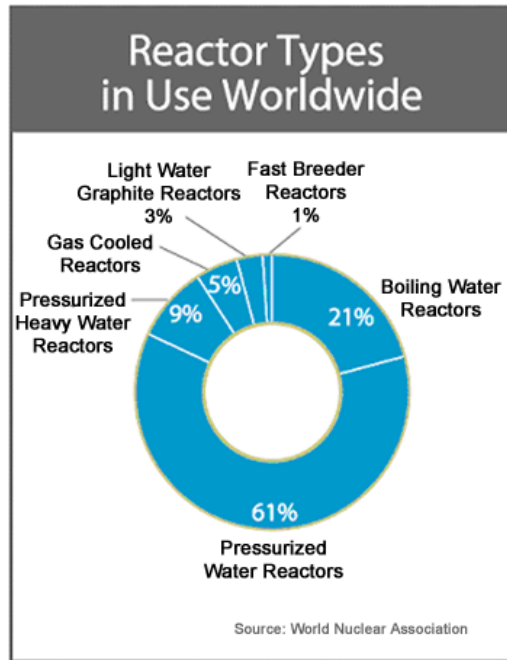
(Source: World Nuclear Assicoation)

Breeder Reactors

Breeder reactors are a controversial type of nuclear reactor. They use uranium-238, natural uranium, which does not undergo fission as readily as uranium-235 but when U-238 absorbs a neutron it becomes plutonium-239 which can be used in nuclear weapons. However these reactors can produce up to 30% more fuel than they use. The reactors run at such a high temperature but the neutrons do not want to be slowed as the plutonium would be consumed so fast that liquid sodium is used as coolant. This also poses another safety issue as sodium is a very reactive element especially when it comes in contact with small amounts with water. Thorium reactors are also being looked into especially in India where Thorium-232 is abundant. Th-232 like U-238 is not fission ready but like U-238, it can be used to produce U-233 which is used to power reactors. India currently uses Th-232 in some reactors along with U-238 to produce both Pu-239 and U-233. More plants are being built designed to use Th-232 that will take another 10 years to finish.

Production

As of 2010, nuclear energy provided for 13.5 percent of the world's total energy consumption. Currently there are 30 countries operating 435 nuclear power plants and 66 more power plants are being

built in 14 countries. Currently, nuclear power is one of the cheapest cleanest energy sources, ranging from $0.03 to $0.08 per kWh. The fuel cost of nuclear power is much cheaper per kilowatt hour than that of coal and oil since 1 kg of uranium has 20,000 times more energy than that of 1 kg of coal. However the power plants initial cost makes up for almost 70-80% of the cost of the electricity produced. Attempts at reducing the cost of nuclear power plants include reduction of construction and operation costs by having multiple reactors at the same site. Construction costs vary depending on the area in which it is being built, and restrictions for nuclear power plant construction do not allow for nuclear power construction at all. Environmental factors are the major causes in price fluctuations in nuclear reactor construction, especially in high risk areas for earthquakes. Also if the reactor is not next to a body of water, a way to supply cooling water to the reactor needs to be developed, resulting in the price of such reactors to be much greater than those built next to water. With all these new power plants in construction, the consumption of uranium will rise, but new sources of uranium will be discovered to meet the demand. The current resources of uranium that cost under $130/kg to extract is currently at 14.8 million tonnes and another 4.7 million tonnes of more costly to extract uranium identified uranium as of 2006. If the current rate of uranium consumption continues, then the uranium supply of the identified resources would last about 200 years. If technology of underwater extraction improves so that it is more cost efficient then approximately 4.5 billion metric tons would be made available. With breeder reactors producing more fuel than they consume, supplies could be estimated to last 60,000 years. The following figure shows the current estimated reserves of uranium. Soft ores contain a higher percentage of Uranium and are easier to extract compared to the hard ores, making soft ore Uranium cheaper.
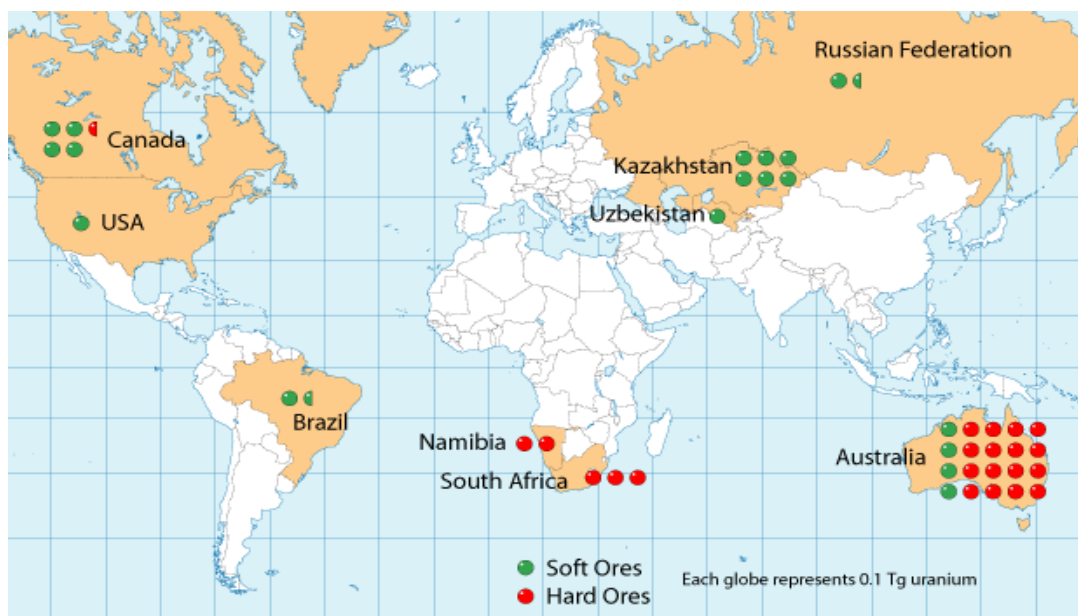
Figure 23: World's Uranium Reserves

http://watd.wuthering-heights.co.uk/nuclear/uraniumreserves.htm

Technology advancements will also help reduce the cost and the amount of uranium required to run the plant. Advancements are focusing on plant safety and better efficiency to produce less waste. Reprocessing the used fuel again allows for less waste to be produced and better efficiency. The high radioactive waste is usually stored on-site in steel containers and are usually in a manmade pond. This process usually costs about 5-10% of the price of the electricity generated. The radioactive material in these containers will decay over decades and will be safe to transport and be able to be stored in a location permanently usually underground. Environmentalists oppose this method of storage because the containers could leak radioactive material into the ground. The amount of opposition that nuclear power plants face with their proposals is the reason why significant amounts of time are needed for approval.

Nuclear Safety

Nuclear power plants have faced most opposition especially due to the fear of a plant meltdown or a release of radioactive waste into the atmosphere. There have been a few serious nuclear power disasters since the being of the nuclear age, most notably Chernobyl, Three Mile Island, and Fukushima plants. The Chernobyl meltdown occurred on April 26, 1986 during a routine shutdown of the fourth reactor. It is estimated that all of the xenon gas, about half of the iodine-131 and cesium-137, and at least 5% of the remaining radioactive material in the Chernobyl 4 reactor core (which had 192 tonnes of fuel) was released in the accident. The initial casualties directly from the explosion and immediate radiation poisoning were 28 as 20,000 millisieverts of estimated radiation was exposed to the workers and first responders. The current death toll from this accident is estimated at 4000-5000 deaths related to radiation exposure. Over a thousand children from the contaminated areas developed thyroid cancer although there was a 98% survival rate. As of 2005, the total cost in US dollars is estimated at $235 billion, with the cost expected to rise as a new containment structure is currently being constructed to allow for the radioactive material to be safely removed. This is one of two nuclear disasters to reach the highest rating, a level 7 rating, on the international nuclear energy scale.

The Three Mile Island nuclear reactor was destroyed on March 28, 1979, when a near meltdown occurred with the second reactor. During shutdown, some coolant was supposed to be removed but the valve never closed and coolant kept draining, causing the reactor temperature to rise and pressure to build. A system malfunction also said that the drain valve was closed so operators did not know coolant was draining at a dangerous rate. The increased pressure in the reactor from the steam generated by the overheating of the reactor also made the operators believe the reactor was too full of water and they started to drain even more water as they were trained to do. The valve was eventually was closed and water was restored to the reactor and allowing the reactor to be safely shut down. Minimum amounts of radioactive material were released into the atmosphere when the buildup of gas inside of the reactor was

released into the air, but the gas was filtered first to remove as much particulates as possible. No injuries occurred from this incident, but instead, much awareness of plant safety and operator training resulted. In total, the cost was about $973 million for clean-up and waste removal. This incident caused much fear and nuclear plant construction was halted for almost 30 years in the United States.

On March 11, 2011, a magnitude 9 earthquake occurred just off the coast a Japan causing a tsunami that caused Fukushima Daiichi nuclear power plant to lose power and the backup power sources. This loss of power caused the cooling system to shut down and the reactor to overheat. The plant survived the earthquake and all the reactors were on emergency shutdown, however 40 minutes later, a Tsunami struck the plant and came over the six foot sea wall that surrounded the plant and flooded the backup generators that were running the pumps for the cooling fluid. Sea water was used to cool the reactors but these efforts failed too and the reactor continued to overheat. A hydrogen molecule from the steam and zirconium from the fuel rod is believed to have made a side reaction that created a buildup of hydrogen gas in the reactor that led to explosions. These explosions let the radioactive material to be exposed to the atmosphere. The tsunami carried leaked radioactive material from the reactors both inland and out to sea through the sea water. The radiation exposure as seen in the figure below will be estimated to cause about 1000 cancer related deaths from the radiation exposure which is 0.1% percent increase from the previous year cancer death toll. The amount of radiation released is only about 1/10 the amount released by the Chernobyl meltdown. The cost of the compensation for residences, the cleanup of the surrounding land, and the removal of the radioactive wastes are estimated to cost Japan $250billion and this estimate may rise or fall if compensation is offered to all the residences. The Fukushima meltdown is the only other disaster besides Chernobyl to receive a rating of 7 on the INES rating scale.
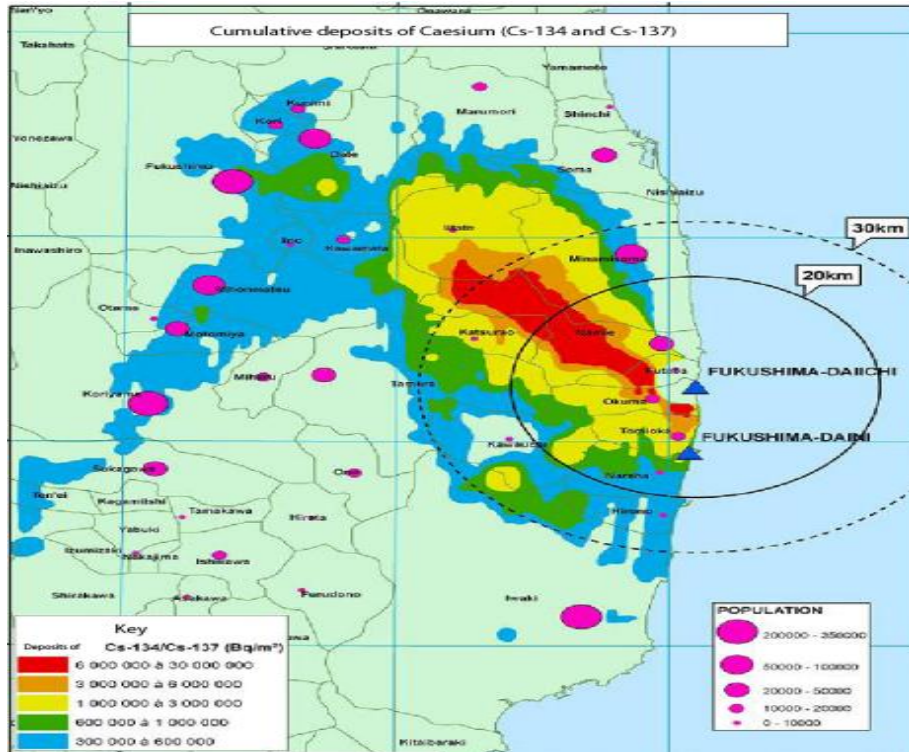
Figure 24: Deposits of Cesium following Fukushima Meltdown

http://www.fas.org/sgp/crs/nuke/R41694.pdf

(Source: Congressional Research Services)

Safety in reactors is improving with better regulations and reactor designs. Currently about 85% of the world's nuclear energy is generated by reactors that were designed for naval use. These reactors are still safe but more advanced reactor designs are available. Third generation reactors have been operating in Japan since 1996 and more of these advanced reactors are currently being built in Europe, Russia, Japan, China and the United States. These reactors do not require human intervention for a disaster situation that calls for an immediate shutdown of the reactor, allowing for quicker responses and shutdown times to help reduce the chances of core meltdown. This allows for quicker responses and shutdown times which helps reduce the chances of core meltdown. The reactors are also more durable against serious damage such as a car bomb or aircraft impact to reduce the amount of radioactive material that would be released. With all the risks in nuclear plants for severe situations to occur the amount of fatalities compared to other sources of energy is minimal as seen in the table below. This displays how safety is a major concern and focus in nuclear power plants.

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Summary of severe* accidents in energy chains for electricity 1969-2000

	OECD		Non-OECD	
Energy chain	Fatalities	Fatalities/TWy	Fatalities	Fatalities/TWy
Coal	2259	157	18,000	597
Natural gas	1043	85	1000	111
Hydro	14	3	30,000	10,285
Nuclear	0	0	31	48

Table 3: Accidents in the Energy Sector

http://www.world-nuclear.org/info/inf06.html

(Source: World Nuclear Association)

Future of Nuclear Power Plants

A new generation of nuclear reactors, 4th generation reactors, are currently in development and are expected to be developed around 2020-2030. These new reactors are not only going to produce electricity but also most of the reactors are going to capture the Hydrogen byproduct which could be used as fuel for cars or other energy needs. This might stimulate Hydrogen fuel technology in the coming years which would be another big step in removing the world's dependence of oil. A list of the proposed reactors are shown in the table below.

Reactor Type:	Neutron Spectrum	Coolant	Temperature (°C)	Pressure	Fuel	Fuel Cycle	Size (Mwe)	Uses
Gas Cooled Fast	Fast	Helium	850	High	U-238+	Closed, onsite	1200	Electricity
Lead-Cooled Fast	Fast	Pb orPb-Bi	480-800	Low	U-238+	closed, regional	20-180 300-1200	Electricity Hydrogen
Molten Salt Fast	Fast	Fluoride Salts	700-800	Low	UF in Salt	closed	1000	Electricity & Hydrogen
Molten Salt - Advanced High Temperature	Thermal	Fluoride Salts	750-1000	Low	U02 Particles	open	1000-1500	Hydrogen
Sodium-Cooled Fast	Fast	Sodium	550	Low	U-238 & MOX	closed	300-1500	Electricity
Supercriticcal Water-Cooled	Thermal/Fast	Water	510-625	Very High	U02	open(Thermal)	300-700	Electricity
Very High Temperature Gas	Thermal	Helium	900-1000	High	UO2 prism/ pebbles	Open	250-300	Electricity & Hydrogen

Table 4: Generation 4 Nuclear Reactors
http://www.world-nuclear.org/info/inf77.html

(Source: World Nuclear Association)

New licensing of nuclear power plant permits have been increasing over the last decade throughout the world but recently the United States have approved new licenses. In February 2012 a combined construction and operating license was approved for Vogtle, GA for two new reactors. This will be the first reactor built in the United States since the Three Mile Island Incident. The construction of the plant was delayed to begin in October 2012 and both 1200MW reactors are supposed to be operational

by November 2017. The Watts Bar Reactor in Tennessee was under construction before the Three Mile Incident but then construction was halted after the incident. Now construction is planned to be renewed and the reactor is supposed to be the first reactor operational in the United States in almost 40 years. Since the Voltage GA reactor was approved for construction six more proposals were approved and all these reactors are planned to be online by 2025. Most of these reactors are located in the southeastern United States as electricity prices are above the average for the United State and the nuclear power plants would be more profitable in these regions.
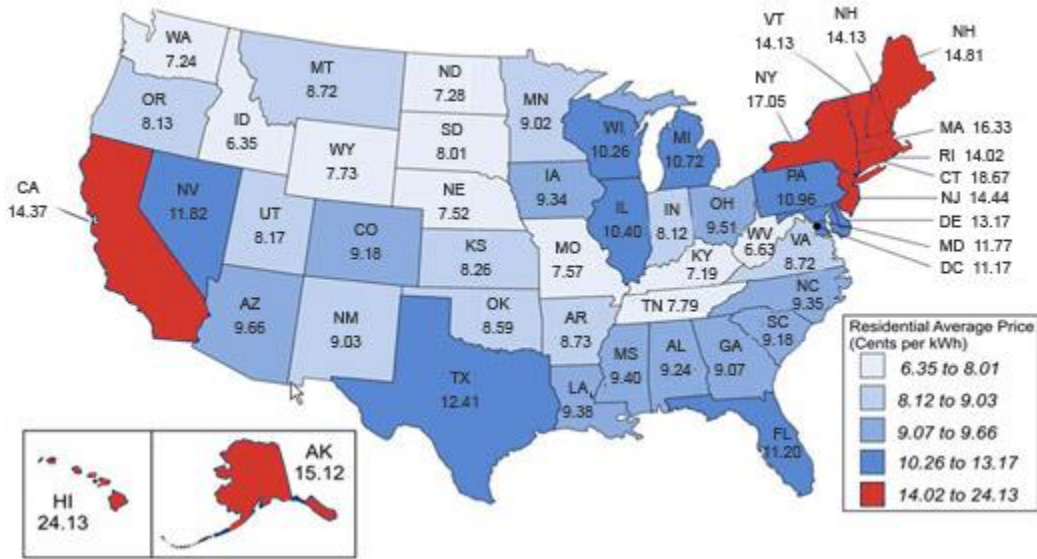
Figure 25: Average Price of Electricity (kW/hr)

http://www.electricchoice.com/electricity-prices-by-state.php

(Source: Electric Choice)

Even though the northeast has higher average electricity cost per kilowatt hour the locations suitable for nuclear power plants are much fewer. The full list of location, type of reactor, and date of operation can be seen in the table below for approved and proposed reactors in the United States.

Site	Technology	MWe gross	Proponent/utility	COL lodgement & issue dates	Loan guarantee; start operation
Watts Bar 2f, TN	Westinghouse PWR	1218 (1177 net)	Tennessee Valley Authority	No COLf	on line Dec 2015
Vogtle* g, GA	AP1000 x 2	2400	Southern Nuclear Operating Company	24/7/08, COL Feb 2012	granted loan guarantee; 11/2016, 11/17
V. C. Summer, SC	AP1000 x 2	2400	South Carolina Electric & Gas	31/3/08, COL March 2012	short list loan guarantee; 2017, '18
Levy County, FL	AP1000 x 2	2400	Duke Energy (formerly Progress Energy)	30/7/08, COL target late 2013	2024, 25
William States Lee, SC	AP1000 x 2	2400	Duke Energy	13/12/07, COL target late 2013	2021, 23
Shearon Harris, NC	AP1000 x 2	2400	Duke Energy (formerly Progress Energy)	19/2/08, expected late 2014	2020
Turkey Point, FL	AP1000 x 2	2400	Florida Power & Light	30/6/09, COL target 12/14	2022, 23
Bellefonte 1 g, h, AL	B&W PWR	1263	Tennessee Valley Authority	30/10/07 for unit 3 (and unit 4)hbut COL review suspended	2018-20

Table 5: Planned Nuclear Reactors in the United States

Site	Technology	MWe gross	Proponent/utility	COL lodgement & issue dates	Loan guarantee; start operation
Comanche Peak, TX	US-APWR x2	3400	Luminant (merchant plant)	19/9/08, COL target 12/14	2019, 2020
South Texas Project*, TX	ABWR x 2	2712	Toshiba, NINA, STP Nuclear (merchant plant)	20/9/07, delayed	short list loan guarantee; 2016, 17
Clinch River, TN	mPower x 2	360	TVA	expected 2012	2020
Callawayj, MO	Westinghouse SMR x 5	1125	Ameren Missouri	24/7/08 for EPR then cancelled, no decision re SMRs	
Calvert Cliffs*, MD	US EPR	1710	UniStar Nuclear (merchant plant)	7/07 and 13/3/08, delayed, in 2012 barred	refused an offered loan guarantee, needs US equity; 2017
Grand Gulf, MS	ESBWRi	1600	Entergy	27/2/08 but COL application review suspended for some years	
Fermi, MI	ESBWR	1600	Detroit Edison	18/9/08, no decision to proceed but COL target late 2013	
River Bend, LA	ESBWRi	1600	Entergy	25/9/08 but COL application review suspended	
Nine Mile Point, NY	US EPR	1710	UniStar Nuclear, (merchant plant)	30/9/08 but COL application review partially suspended	
Bell Bend (near Susquehanna), PA	US EPR	1710	PPL merchant plant	10/10/08, delayed	2018-20
Blue Castle, UT	unspecified	Perhaps 1200	Transition Power Development	ESP application expected 2013	
Salem/Hope Creek, NJ	To be decided	Perhaps 1200	PSEG	ESP only 25/5/10, target late 2014	On line 2021

Table 6: Proposed Nuclear Reactors in the United States
http://www.world-nuclear.org/info/inf41.html

(Source: World Nuclear Association)

If all these reactors are approved and no construction delays then by 2025 a total of 38478MW/yr of new nuclear energy will be produced in the southern United States. This will increase the amount of BTU's produced from 2010, 8.44 quadrillion BTUs, to 9.60 quadrillion BTU's in 2025. Although there is an increase in production for nuclear energy the percentage of electricity produced from nuclear is expected to decrease to around 18% from 20% in 2010. If the price of electricity remains constant by the

time nuclear plants become operational, then the average price of electricity could drop to anywhere between a 0.5-0.75 cent/kW. This might seem like a small drop but the areas directly around the plant could see electricity costs to be around 5-8cents/kW as most of the electricity would be supplied by the nuclear plant itself.

Conclusions

After taking an extensive look into nuclear power and all the different types of reactors I believe nuclear power is a viable alternative to fossil fuels and should be continued to be used in the future. Even though there are risks associated with nuclear energy, the technology for safety is greatly improving and nuclear energy sees much fewer incidents compared to other energy producing plants around the world. Although the increase in safety awareness is more active, countries such as Japan and Germany are completely shutting down their nuclear programs for safer renewable sources of energy. This is setback for nuclear energy, but we believe that nuclear energy can overcome this obstacle with the new reactor designs and the hundreds of plants looking for permits across the world. Careful and more innovative site locations and designs could help reduce the risk of population safety and environmental concerns. One idea that could be researched further is having a nuclear power plant partially underground by having the actual reactor underground and having the cooling towers and electricity generation above ground. In the off chance that a disaster occurred, nuclear wastes would be more contained. These reactors would have to be located in earthquake free zones and have the ground around the reactor lined with concrete or another material to prevent any radioactive waste from seeping into the ground. This might raise the cost of construction which in turn would raise the cost of the electricity produced by the plant but this may be still cheaper than the current electricity costs in the long run. Another option that could be considered is having the nuclear power plants off shore either on existing islands or on man-made structures. The first major concern would be storms and waves that could damage the plant similar to what happened in Japan. If proper sea walls were implemented and locations that were away from hurricanes were utilized then these plants could operate safely. These locations would provide sufficient access to cooling water for the reactor and could be built far enough away from highly populated areas. The construction costs and cost of electricity needs to looked further into again but these locations could help bring nuclear power where suitable on land locations are scare and electricity costs are high for example New England. However, nuclear power needs to be supplanted with renewable energy since there will not be enough uranium to completely replace oil and coal. Wind turbines and solar panels onsite would only provide a small amount of electricity that could help minimize the operational costs of the plant. Also the area around the nuclear power plant that is secluded and does not allow for construction could be used to put either a wind or solar farm that could increase the output of electricity. All these ideas need to be further researched and

could make nuclear energy more appealing to the population and provide cheaper electricity to areas that might not have had the option before. Nuclear energy is however a good way to slowly wean the world off the dependence of oil in my opinion.

Chapter 6: Biofuel

As the demand for oil increases, common economics suggest that the price of oil and gasoline will only increase. Just within a few years, the price of gasoline has doubled from $2.00 a gallon to about $4.00 a gallon. This high price for gasoline has caused a high demand for new forms of fuel that are cheaper and also better for the environment. To move away from gasoline, a new fuel needs to be used to provide the energy needed. There are many viable options for new energy sources but one that is gaining popularity is biofuels. Biofuels are renewable fuels that are produced from breaking down certain types of plants to produce liquid fuels. The two main types of biofuels are bioethanol and biodiesel.

Bioethanol is an alcohol that is produced through breaking down varies plants. The most common plants used are corn and sugar cane. The most common method to create ethanol is fermentation. Fermentation is a process where sugars are broken down into cellular energy and the waste products result in ethanol and carbon dioxide. Another method use is gasification, where an intense heat is used to burn the starches in plants and cause the wastes to form into gases. The gases are then processed into ethanol.

Ethanol is used mainly with gasoline. There are two common types of gasoline and ethanol mixtures, E10 and E85. E10 is the more common type of fuel used because it takes little to no modifications on the vehicle to perform. E10 fuel is 10% ethanol and 90% gasoline. The energy content for ethanol is two thirds the energy content of gasoline therefor more ethanol has to be burned to get the same amount of energy as you would get from gasoline. Because of this, most vehicles today still run on E10 and not on E85. E85 is 85% ethanol and 15% gasoline. As mentioned before, more E85 will be burned in order to achieve the same amount of energy output for the system.

There are three main types of ethanol and they are based on what material was used to create the fuel. The first type of ethanol is sugar cane ethanol. Because fuel is needed to burn the sugar canes to produce the ethanol, common fossil fuels such as coal are used to start the process. If only 10-12% of the input fuel is from fossil fuels, there is a reduction of 90% of carbon dioxide emissions when compared to gasoline. Sugar Cane Ethanol is also cheap, costing 25-35 cents per liter of gasoline equivalent. Prices are calculated in liter of gasoline equivalent, or lge for short, because ethanol needs more than one liter of fuel to produce the same amount of energy that gasoline produces in one liter. The next ethanol is corn ethanol. Corn ethanol has a high energy input from fossil fuels and only emits 15-25% less carbon dioxide from gasoline. The price to produce corn ethanol is also much higher than sugar can ethanol. Prices range from 60 – 80 cents per liter of gasoline equivalent.

Cellulosic Ethanol

The main form of biofuel ethanol created in the United States is corn ethanol. While corn ethanol is a cheap form of biofuel, in order to create it, feed corn must be grown and broken down. The land that is used for the corn could be used for other options like live stock or farms. Another option in the biofuel technology is cellulosic ethanol. While the ethanol has a lot of ways to go before it becomes a prominent source of fuel, it has potential. Instead of breaking down sugars in plants, the cellulose of the plant can be used to produce ethanol. The majority of a plant is made up of cellulose. Because of this, waste will be minimized if the cellulose, along with sugar is used to produce ethanol. Even with current technologies, only 40% of the available energy in cellulose is produced to energy. To better improve this number, genetically modified microalgae have been created that takes cellulose and breaks it down into simple sugars. A microalga is a photosynthetic microorganism that converts carbon dioxide into carbon lipids. Microalgae will be available for economical use in the next 10 to 15 years.

Cellulosic ethanol when used, releases 86% less greenhouses gases than gasoline. To compare to the other bioethanol created, corn ethanol emits 52% less greenhouses gases than gasoline. On top of being more environment friendly, researches claim that cellulosic ethanol will be cheap. As of 2012, the U.S. Department of Energy set a benchmark for the ethanol to have a production cost of $1.33 per gallon. To this point in time, the goal has not been met says Andy Aden, a process engineer who studies cellulosic ethanol production at the National Renewable Energy Laboratory in Golden, Colorado. While pricing is a conflict, over time as the technology improves, the cost will decrease. Along with cost, there is a conflict in producing enough biomass to make ethanol on a large scale. Since most of the energy source will come from growing plants, where the plants will be grown is an issue. Given that one major form of energy source is switch grass, researchers envision spreading the grass all over the country. Once the energy source is spread across a long distance, more energy must be used to transport the fuel source to the plants. Prior to actual field studies, it was estimated that cellulosic ethanol would cost $30 per ton. After recent field studies the cost is between $80 to 130 per ton. It will also cost $1.30 to $1.48 of grass and wood chips to produce a gallon of ethanol. Because the costs are much more than expected, companies like BP have decided to stop production on their cellulosic power plants because the costs would be 10 times higher than corn ethanol.

In order for cellulosic ethanol to take over the biofuel business, it will have to compete with corn ethanol. In order to compete, the cost to produce the ethanol must decrease. The main issue with cellulosic ethanol is finding the energy source. If the grass and wood chips are coming from all over the country, the output energy production of the plant is being negated by the amount of fuel burned to transport the fuel sources. As the technology improves, the energy output from the fuel sources will

increase and plants will be able to produce more ethanol with the same amount of fuel source. With less grass and wood chip needed, the transportation costs can be minimized.

Chapter 7: Solar Energy

Solar energy, in a broad sense, is the energy from the sun. For those of us with an average work day, we see quite a bit of this solar energy in the form of sunlight in approximately twelve hour intervals. Naturally, one would assume that solar energy is rather abundant, and in a sense, it is. According to the U.S. Department of Energy, solar energy is the most abundant resource on earth, as "173,000 terawatts of energy strike the Earth continuously," which is "more than 10,000 times the world's total energy use." If solar energy is such an abundant resource, then why has the world not shifted towards solar energy? As it turns out, there are many other factors involved that make this shift somewhat of a challenge.

Despite the abundance of solar energy, harvesting this energy and transforming it into a resource that we can use is somewhat of an obstacle. Solar panels and solar cells are common methods of collecting solar energy and generating electricity from it. These devices can be found in anything ranging from large scale equipment, such as satellites, to small scale electronics, such as calculators. Solar cells became the main source of electric power for satellites in the 1960s, and the use of solar cells expanded in building-integrated systems in the 1990s. The biggest limitation of solar cells is its ability to capture sunlight. In order for a solar cell to utilize its potential, it needs to be near a source of sunlight. Any device that is inside some enclosed area will be limited in the amount of energy it can produce simply because it is cut off from a source of solar energy. If the weather conditions block the source of sunlight, solar panels will decrease in productivity. Typical solar cells have efficiency levels of anywhere between 10% and 30%. To provide an estimate of the cost of a typical solar panel, a commercial solar panel was found from SparkFun Electronics. A 14.125 x 11.5 x 1" solar cell that outputs around 8 Volts at 1.25 Amperes (10 W in the open sun) costs about $60.00. To meet a demand of 30 gigawatts, assuming the cost of the SparkFun Electronics solar panel of $60/10W, we would need about $180 billion.

One's location also has a heavy impact on the ability to utilize solar energy. According to Wholesale Solar, even within the United States, there are six different zones with differing amounts of solar insulation (full sun hours) (Figure 27). In Zone 1, which consists of small portions of Nevada, California, and Arizona, the average amount of solar insulation is six hours through the year. In Zone 6, which includes portions of Washington and Oregon, the average is 3.5 hours. These numbers seem low, but they also account for the hours of sunlight during the winter time, as well as the amount during the summer. The number of hours of sunlight will be longer during the summer and shorter during the winter.

Factors such as geographical obstructions to sunlight and altitude certainly play a role in affecting these hours of sunlight.

In general, a solar cell can substitute a battery in an electrical circuit. Typically, lead-acid batteries are used over lithium and nickel metal hydride batteries, as they have lower maintenance requirements (lead-acid batteries typically have a lifespan of 5-8 years in automotive applications, and 20 years in stationary applications, vs. lithium-ion batteries with a lifespan of 2-6 years) and lower costs (lead-acid batteries have an energy per consumer price of 5-8 W-h/$, whereas for lithium-ion, this number is 2.8-5 W-h/$), despite having lower energy-to-weight ratios (0.11-0.14 MJ/kg vs. 0.58 MJ/kg). When sunlight hits a solar cell, which is typically made of semiconducting materials (like silicon), the energy from the photons from sunlight will excite electrons in the atom of the semiconducting material, and these electrons flow through the material. Electrical energy and power is based on current (the flow of moving electrons) and the voltages (the amount of energy per charge); hence, when an electron is excited from these photons, the solar cell acts as a DC voltage source and produces electrical energy.

High prices in solar energy is not really due to a deficit in supply, since, as mentioned before, we have more than 10,000 times what we need. Much of the cost is from the supplies needed to build a reliable system that can collect solar energy, convert it to electrical energy, and deliver it to its destination. Most of the component costs come from the installation of solar panels and batteries. According to Green Econometrics, with the above factors considered, the cost of solar energy comes out to about $0.38 per kilowatt-hour, compared to its oil counterpart at $0.05 per kilowatt-hour for a barrel. According to Jason Morgan of Nuclear Fissionary, the cost of any energy mainly comes from the construction of an entity to harvest and produce energy. They claim that without production costs, solar energy costs $0.22 per kWh, simply from construction costs (See Figure 26). Regardless of the actual number, there is a trend to notice. Solar energy, despite its abundance, is one of the more costly of energy sources. To meet a 2012 demand of 30 GW with these energy costs, the cost could be anywhere between $6.6 million to $11.4 million per hour. If the efficiency can improve in new emerging technologies such as quantum dots, or even improved designs on existing equipment, these costs will inevitably decrease, making solar energy a significantly more viable choice for the future as society progresses.

According to a Forbes report, solar panel makers are expected to supply 59 gigawatts worth of solar panels worldwide in 2012, when the demand is only 30 gigawatts. The oversupply of solar panels led to a 50% drop in wholesale solar panel prices in 2011. Suppliers would argue that this is a problem, as many jobs would need to be cut in order to balance the market. Consumers on the other hand, would argue that lowered costs are good, making solar energy more viable for the future. The U.S. Department of Energy indicates that they expect 3.3 gigawatts of solar panels to be installed in 2012. The United States installed nearly double the amount in 2011, indicating that there is an upward trend in the supply of

solar panels. However, new tariffs on panels imported from China will level off this upward trend in the near future. This is due to the fact that China's subsidies have harmed the U.S. solar industry, causing about a dozen U.S. solar manufacturers to go bankrupt. These tariffs range from 24% to 36% on solar panels imported from 60 Chinese manufacturers and up to 255% for other Chinese suppliers.

Solar energy will be available as long as the sun still shines. The star is expected to exist for another five billion years, so many generations will still have access to solar energy. More determining factors for how long the energy will last depend more upon the lifespan of the equipment necessary to collect and store solar energy. Simply collecting solar energy and converting it into electrical energy with a solar panel will not always be reliable, as a constant source of sunlight would be necessary in order to continuously produce usable energy. Hence, a lead-acid battery could be used in conjunction with the solar panel is used to store excess energy for use when sunlight is not readily available. Typical solar cells last about twenty-five years before their efficiency declines, and batteries typically last around ten years. To meet a demand of 30 GW, assuming specifications similar to that of the SparkFun solar panel mentioned previously, 3 billion solar panels would be needed, costing $180 billion. Estimating from a lead-acid battery found on Amazon.com with a 216 V capacity and costing $35, 139 million lead-acid b (Pearson, 2007)atteries would be necessary, costing $4.8 billion. To last 25 years, the batteries would need to be replaced up to 3 times, so the total cost for a system meeting the 30 GW demand for 25 years would be approximately $195 billion. Overheating is a typical issue that solar cells and batteries could face, as with any electrical device, and is a factor that many new technologies are addressing when synthesizing solar cell systems for solar energy harvesting.

Japanese Space Solar Project

The Japanese have planned a solar project using satellites in space to collect solar energy and beaming them to the Earth as microwaves. According to NASA, this project is expected to cost roughly $21 billion USD, predicted to power 300,000 homes within 30 years. The satellite itself would be equipped with a 4 km² array of solar panels, able to produce 1 GW, and would orbit 36 km above the Earth's surface. As of 2009, NASA has spent $80 million on research, and they estimate that the cost of supplying electricity from this orbiting solar array will be approximately $1 billion per megawatt.

Costs of Solar Energy: Implicit and Explicit

Solar energy is one of the most abundant forms of energy that current technology is able to harvest. This form of energy is also considered one of the cleanest out of the ones available, mainly because there appears to be negligible carbon emissions or the production other Greenhouse gases, which lead to the phenomenon known as Global Climate Change (otherwise referred to as Global Warming). Despite these benefits, solar energy is still one of the more costly forms of energy, not simply due to explicit costs such as production, but also due to various implicit costs.

Explicitly, solar energy can cost anywhere between $0.22 to $0.38 per kilowatt-hour. These costs, many times more than other forms of energy (4-7 times more than that of oil), include costs of not only converting the resource to a usable form, but also the costs of the equipment needed to do so. Photovoltaic cells are commonly used to accomplish the task of converting solar energy to the electricity that society uses daily. However, these cells are relatively inefficient, producing approximately a quarter of its input as electricity; thus, these cells must be used in "utility-scale solar power plants."

As defined by the Solar Programmatic Environmental Impact Statement (Solar PEIS), a "utility-scale" solar power plant has a generating capacity of at least 20 megawatts. The Union of Concerned Scientists estimates that such power plants require approximately 1 square kilometer for every 20 to 60 megawatts of energy generated. If the world demand for energy were about 30 gigawatts, the amount of land that these plants needed to meet this demand would be anywhere between 500 square kilometers to 1,500 square kilometers. If we were to consider sections of land that would be usable for utility scale plants (farmable land, dry land, land without topsoil) less than 1% of this land would be used. For comparison, an article on National Geographic states that a 100 by 100 square mile area of Nevada can hold enough solar energy resources to meet the electricity needs of the United States. Although the effect can seem small overall, there are many impacts to land in the construction of solar facilities. Areas of land need to be cleared and graded, which can lead to soil compaction, limiting vegetation growth in the area, as well as decreasing the soil's ability to absorb rainfall, leading to more runoff and erosion. In combination with the potential of hazardous wastes from these facilities, this could be very damaging to the environment, leading to a loss of habitat in the area.

Despite being considered a clean source of energy, solar energy production can still lead to hazardous wastes. The manufacturing of photovoltaic cells can use cadmium and arsenic, both hazardous materials. Inert silicon, common in many semiconducting materials, can also be harmful to workers if it is breathed in as dust. Some concentrating solar power (CSP) systems (systems that use mirrors and other reflective materials to concentrate light into a small area) may also use oils, molten salts, hydraulic fluids, coolants, and lubricants that can produce spills.

CSP systems have other potential costs other than the hazardous wastes that they may produce. Depending on the albedo and angle of reflectivity of these systems, they have the potential to interfere with aircraft operations if the reflected solar rays were accidentally directed into aircraft pathways. Although seen in typical solar facilities, high temperature considerations are even more significant when concentrated, potentially leading to safety risks. Some sources argue that an increase in electric and magnetic fields in an area of CSP systems could potentially lead to health risks, although the World Health Organization argues that there is no heavy evidence that electromagnetic fields are direct and major causes of health concerns.

With any major technological breakthrough, there is always a change in the global market demand of resources and labor, a major contributor to structural unemployment. A study in Spain indicated that every green job created in Spain led to the elimination of 2.2 jobs in the fossil fuel industry. According to an analysis by Pew Charitable Trusts, solar jobs accounted for 65% of energy generating jobs in 2007. According to the Center for American Progress however, 156,908 solar energy jobs are expected to be created by 2025 in the states of Arizona, California, Colorado, Nevada, New Mexico, and Utah, bringing in an estimated $111 billion dollars (see Tables 8 and 9). Figure 31 illustrates various different job growth scenarios, but all indicate some form of growth, whether in a linear fashion or an exponential fashion. These varying growth predictions likely take into account factors such as tariffs and Chinese-American relations, as China is a major supplier of photovoltaic cell panels. With such a growth in the number of solar energy related jobs, seemingly the benefits outweigh the costs of jobs in the fossil fuel sector.

From our point of view, we believe that solar energy is an excellent solution to the energy problem that society faces. The main reason that solar energy is not currently used is due to the fact that the costs outweigh the benefits. With only about 25% efficiency, it is easy to see why society is hesitant to completely shift to solar energy. However, solar energy is abundant, especially with the sun's life expectancy of another five billion years. If we can find a way to make solar energy more efficient in terms of both energy production and cost, we should undoubtedly make the change to solar energy.

Other Investigations of Solar Energy

The use of photovoltaic cells is one of the more commonly used techniques to convert solar energy into electrical energy. However, photovoltaic cells are largely inefficient, with perhaps 25% efficiency at best, in addition to considerations such as the amount of sunlight per day and various other implicit and explicit costs. Thus, other investigations have been made, such as those made in quantum dots and the beaming of microwaves.

Quantum dots have semiconductor-like properties, as well as discrete molecule-like properties, and have been investigated in microelectronic applications in transistors, solar cells, LEDs, and diode lasers. The size of the dot directly affects the amount of energy released by the quantum dot; the smaller the size of the crystal, the more energy is needed to excite the electrons in the dot, which releases more energy when the dot returns to its resting state. The energy of a quantum dot can be expressed as the sum of its band gap, confinement, and exciton energies.

Excitons are a mobile concentration of energy in a crystal formed by an excited electron-hole pair. Quantum dots, using a process called multiple exciton generation (MEG) made of lead selenide can produce up to seven excitons per photon of sunlight, whereas photovoltaic cells today produce only one exciton per photon. Current photovoltaic cells also lose quite a bit of energy as heat. Although quantum dots are not seven times more efficient than photovoltaic cells, they do have a theoretical efficiency of anywhere between 31% and 44%, which is certainly more efficient than the 25% efficiency of photovoltaic cells. In current photovoltaic cells, a single high-energy photon can only excite a single electron, regardless of the energy difference between that of the photon and the amount needed to excite an electron. Any excess energy warms up the cell. With quantum dots, which are anywhere from 2 to 10 nanometers in size, more electrons can be excited by a single photon. Since these molecules are discrete, the photon would need to carry energy at integer multiples of the energy needed to excite an electron in order to excite multiple electrons. As of December 2011, the National Renewable Energy Laboratory (NREL) has been able to build a device with 4% efficiency using quantum dots. They are also investigating quantum dot materials other than lead selenide, mainly because of the toxic nature of lead.

The idea of beaming energy onto the earth has existed since the early 1970s. Ideally, through the use of a satellite in space, solar energy could be collected in ways more beneficial than through the use of current solar collection methods on the planet. These theoretical benefits include a collection rate of approximately 144% of the maximum attainable on the Earth's surface, a collection period of nearly twenty-four hours a day versus a maximum of about twelve on the earth's surface, the elimination of weather, plant, and wildlife interference with energy collection, and the ability to redirect power where needed.

One of the major problems with space-based solar power is the cost to maintain these systems. Panels in space degrade about ten times faster than they would on the Earth, providing an estimated lifetime of the system to be about a decade. Space debris could also pose a problem to such a system. Thus, the cost of maintaining the space-based solar power systems would be higher than the gains of solar-powered energy. As previously mentioned, the Japanese have been working on such a system. One of the feasible methods of transporting the collected energy from space to Earth is through the use of microwaves. A microwave beam for this application could have an intensity of up to 23 mW/cm², which

exceeds the US Occupational Safety and Health Act (OSHA) workplace exposure limits for microwaves, which is 10 mW/cm². However, this exposure could be limited by dispersing these microwaves around the world, but this would reduce efficiency.

According to an article dated April 2012, former NASA engineer John Mankins introduced an idea that could potentially lead to a prototype for a satellite beaming solar power to Earth. The idea is to use mirrors, arranged similarly to a petal on a flower, to constantly direct sunlight to solar cells. The design uses small, lightweight, mirrors and solar cells to minimize the cost of construction and transportation. The satellite would also be far enough away from the Earth so that it would never be dark In Italy, there is a similar idea with a flower-petal shaped system of solar panels, except they are floating in water. The system turns throughout the day along with the sun's rays, while the water beneath the system cools off the system.

A collaborative work by the 3M Renewable Energy Division and Gossamer Space Frames developed a parabolic trough solar collector, designed to reduce equipment and installation costs for CSP systems by 25%. Currently, this collector is installed at the Sunray Energy facility in Dagget, California and uses a high reflectivity 3M Solar Mirror film with mechanical designs from Gossamer Space Frames. These reflector panels are 50% lighter than glass with 94.5% reflectivity and an optical accuracy of 99%. As of October 2011, the output peak of this system is about 275 kW. According to the U.S. Department of Energy, typical household appliances use about 31 kW of energy. Thus, this system could currently supply about 9 households. In retrospect, this number is not at all impressive, but certainly a step in a direction that could make solar energy viable.

With all of these innovations revolving around redesigning the arrangement of mirrors, it seemed appropriate to investigate the reflectivity and refractivity of concave and convex mirrors. Snell's Law describes how light travels through a medium:

[11] $$\frac{sin\theta_1}{sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

θ_1 is the angle of incidence, the angle measured normal to the surface of a mirror (in our case), and θ_2 is the angle of refraction, the angle measured normal to the mirror after the light passes through. v_1 and v_2 are the velocities of the light wave in air and after passing through the mirror, respectively. n_1 and n_2 are the indices of refraction of air and the mirror, respectively. For the purposes of solar energy collection through the use of mirrors, we are not necessarily interested in refraction, but instead, reflection. As it turns out, there is a relationship between the indices of refraction and reflection for normal incidence:

[12] $$R = \left|\frac{n_1-n_2}{n_1+n_2}\right|^2 * 100\%$$

where R is the amount of incident power reflected. There are two Laws of Reflection, and are modified slightly between concave mirrors and convex mirrors. For concave mirrors, these laws are:

Any incident ray traveling parallel to the principle axis on the way to the mirror will pass through the focal point upon reflection. Any incident ray passing through the focal point on the way to the mirror will travel parallel to the principle axis upon reflection.

For convex mirrors, the laws are as follows:

Any incident ray travelling parallel to the principal axis on the way to a convex mirror will reflect in such a manner that its extension will pass through the focal point. Any incident ray traveling towards a convex mirror such that its extension passes through the focal point will reflect and travel parallel to the principal axis.

The principal axis is the imaginary line that passes from the mirror's surface through the mirror's center. See Figures 31 and 32 for diagrams of these laws.

An idea by Desertec was to utilize the abundance of sunlight in Africa (primarily the Sahara Desert) by collecting this solar energy and transporting it to Europe via power lines. The researchers are Desertec concluded that concentrated solar power systems were much more effective than simple photovoltaic cells.

With CSP systems, the solar energy collected can be used to heat fluids such as water, oil, or molten salt, and can then be stored for longer periods of time by pumping these fluids into insulated containers or transferring the heat to materials like concrete. The heat can then be extracted after sunset if needed. Photovoltaic cells, on the other hand, can only store its energy by electricity, pumping water to a reservoir, and then releasing this energy via hydroelectric dams.

The plan for transmission is to use High Voltage Direct Current (HVDC) power lines. According to Desertec, alternating-current grids lose up to 45% of their energy loads at long distances, whereas HVDC losses are around 10-15% at 4 km. This is a matter that needs to be investigated, since the current standard used throughout the world are AC power lines.

Desertec hopes that they will be able to use 17 square kilometers of the Sahara for solar farms, and use HVDC cables to carry 100 GW of power across the Mediterranean and Europe. Hopefully this will be possible, as long as politics and cultural differences do not impede in this new prospect towards solar energy. If this project succeeds, political tensions near oil resources in the Middle East may lessen as a result.

Nantennas

There is a brand new technology that has just been discovered that could possible revolutionize the way solar panels are currently designed. This new technology is known as "nantennas," antennas on a nano scale. A team from the Idaho National Laboratory has been working on a special design of antenna that will vibrate when it is hit by different frequencies of light. Currently they have successfully gotten them to vibrate both from visible light as well as infrared light. In addition the nantennas also collect energy from the light with a 95% efficiency and convert it to electricity. The initial problem with this was that the frequency at which they're vibrating is on the order of terahertz, and in order to convert this to usable electricity they would need some kind of converter to lower this. The other major hurdle facing them was finding a manufacturing technique to allow them to easily print these tiny antennas over a film so that they could be applied to a surface. At this time, both problems appear to have been solved, but the product needs more financial backing in order for it to be released into the market and as such the team is currently talking to the Department of Energy as well as private backers. In an interview with phys.org the creator explains that they believe that they can have their product on the market in approximately five years and that it can revolutionize the solar industry. He also comments that this new type of solar panel will be created on a thin flexible plastic film giving this new solar energy collector a wide variety of uses that conventional solar panels cannot currently match. If this new technology is even half as successful as these articles make the nantennas sound, it seems that the team could easily implement solar power into its own league of renewable energy producers. The creator even comments on potentially placing them inside factories where excess heat is generated so that the panels could collect some of that waste energy and turn it back into useful electricity. This has the potential to drastically increase the efficiency of many different industrial applications on its own. Between these two uses this product sounds like it would be extremely useful and one can only imagine the many ways to take advantage of it once it is used widely. Its inventor cites roof shingles as one future possibility and if this material can be made durable enough it could potentially work on many different building surfaces or even cars. This truly sounds like a dream technology and we can only hope and wait to see if it can live up to these high hopes.

Total Cost of Electricity Production per kWh
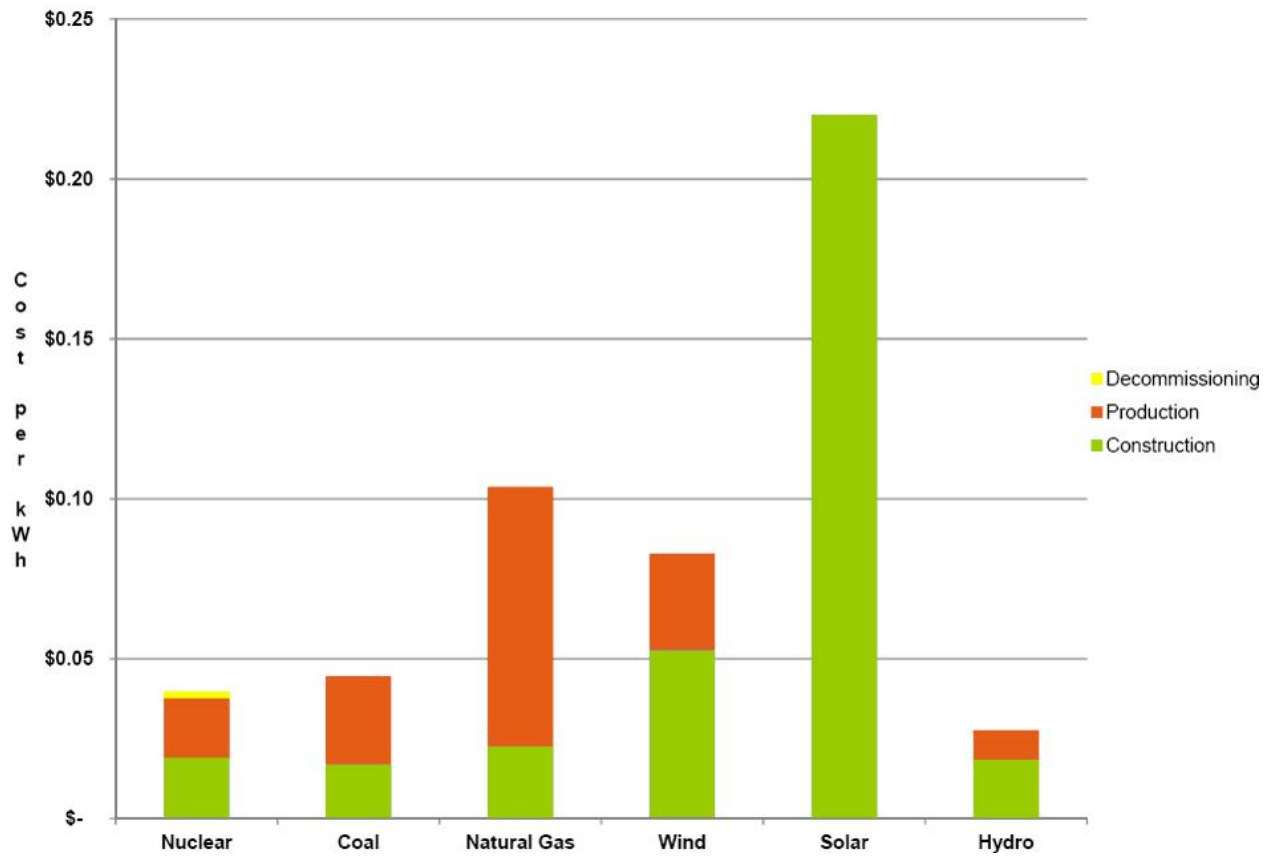
Figure 26: Estimated Cost of Electricity Production (kW/hr)

http://nuclearfissionary.com/2010/04/02/comparing-energy-costs-of-nuclear-coal-gas-wind-and-solar/

(Source: Source: Jason Morgan, Nuclear Fissionary)
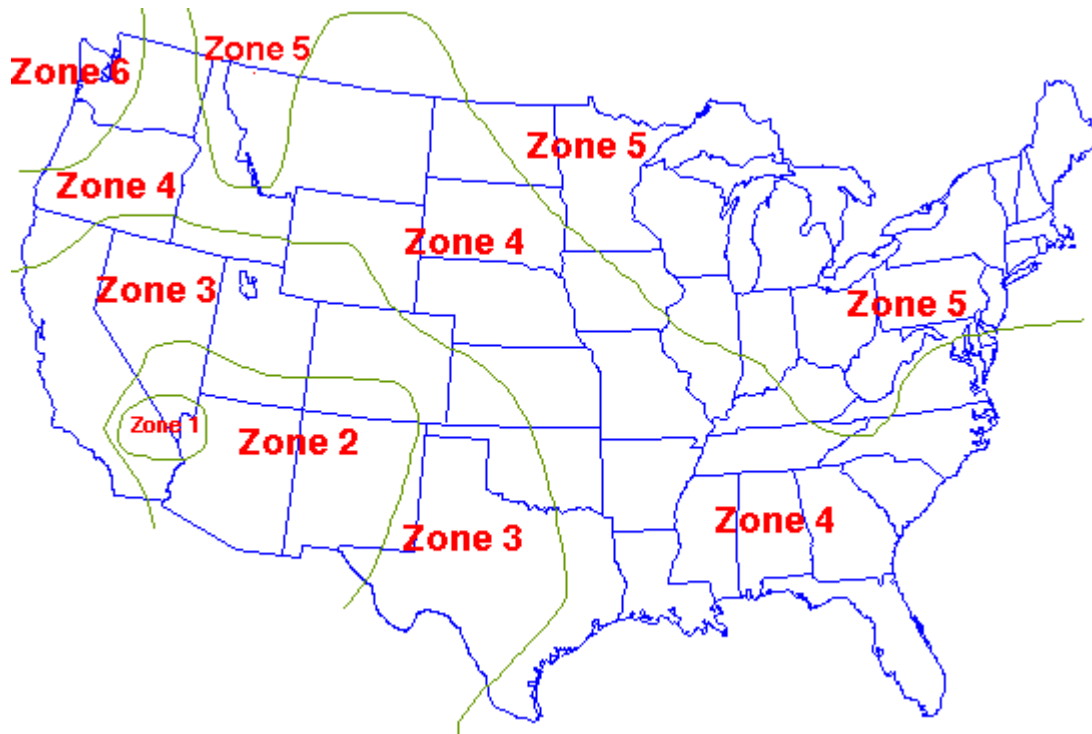
Figure 27: Solar Zone Map of the United States

http://www.wholesalesolar.com/images/grid.package_folder/insolatn.gif

(Source: Wholesale Solar)

Zone 1   6   hours

Zone 2   5.5 hours

Zone 3   5   hours

Zone 4   4.5 hours

Zone 5   4.2 hours

Zone 6   3.5 hours

Average amount of solar insulation per year

Total Energy Consumption (Quadrillion BTU)

Solar Energy Consumption
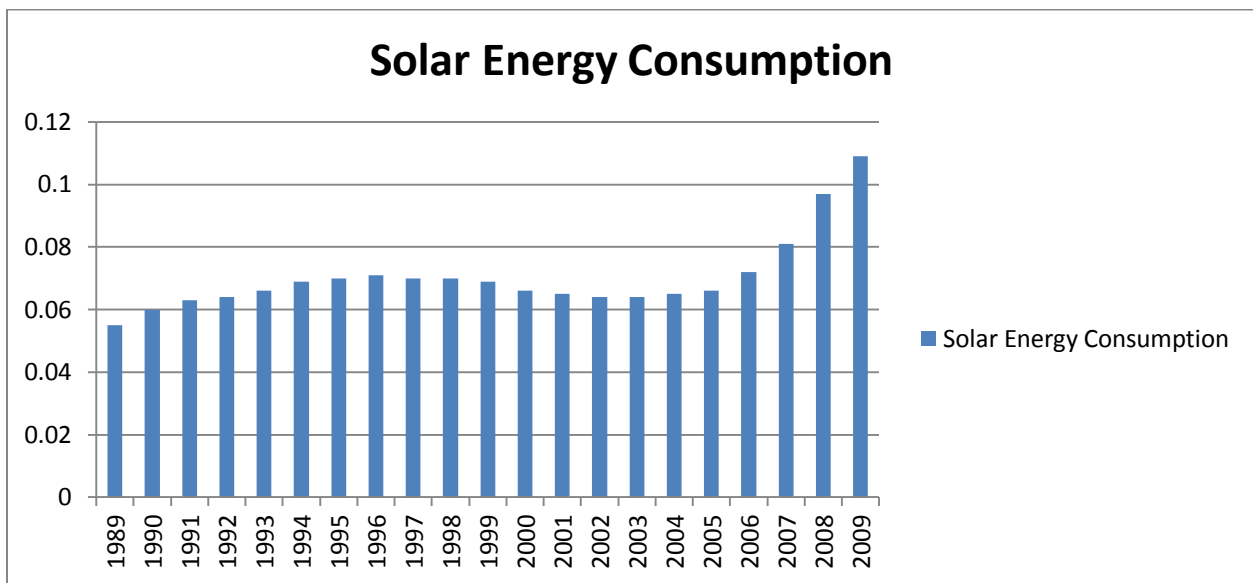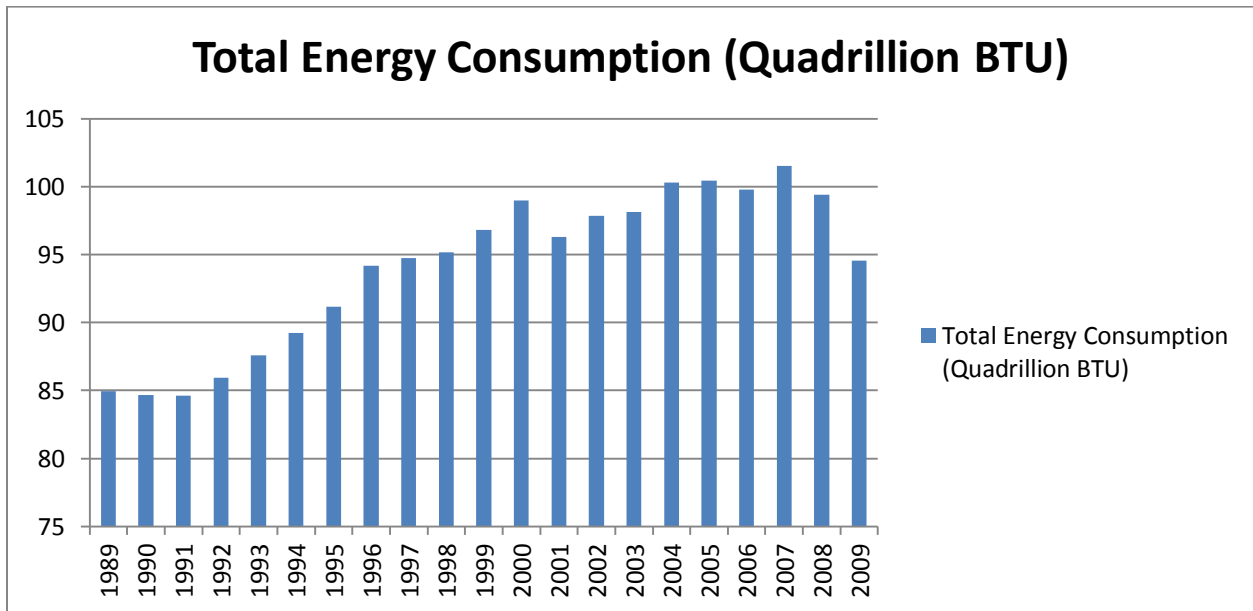
Figure 28: Solar Energy Consumption(Quadrillion BTUs) and Total Energy Consumption (Quardillion BTUs)
http://www.eia.gov/totalenergy/data/annual/txt/ptb0103.html

(Source: U.S. Energy Information Administration)

Relative to total energy consumption, solar energy consumption is miniscule. However, in recent years, solar energy consumption has increased, most likely due to the need for alternative energy resources in combination with new ways to harvest solar energy more efficiently.

Details	Surface area	Surface area in percent
Saltwater	352,103,700 km²	69.03
Freshwater	9,028,300 km²	1.77
Good land that can be farmed	44,682,307 km²	8.76
Mountains	29,788,205 km²	5.84
Covered by snow land	29,788,205 km²	5.84
Dry land	29,788,205 km²	5.84
Land doesn't have topsoil	14,894,102 km²	2.92

Table 7: Divisions of Earth's Surface Area

http://chartsbin.com/view/wwu

(Source: Chartsbin)

Clean energy potential

How much renewable energy could be developed on western public lands over 20 years

State	Solar Jobs	Wind Jobs	Geothermal Jobs	Totals
Arizona	2,424	31	50	2,505
California	15,421	1,462	4,703	21,586
Colorado	2,194	85	50	2,329
Nevada	1,701	701	2,280	4,682
New Mexico	833	199	170	1,202
Utah	1,219	256	620	2,095
Totals	23,792	2,734	7,873	34,399

Note: Figures for solar and wind are for Bureau of Land Management lands; figures for geothermal are for Bureau of Land Management and Forest Service lands. Solar outlook to 2030; wind and geothermal outlooks to 2025.

Source: Bureau of Land Management, http://solareis.anl.gov/documents/supp/Supplement_to_the_Draft_Solar_PEIS.pdf, http://windeis.anl.gov/documents/fpeis/maintext/Vol1/Vol1Ch5.pdf, http://www.blm.gov/pgdata/etc/medialib/blm/wo/ MINERALS__REALTY__AND_RESOURCE_PROTECTION_/energy/geothermal_eis/final_programmatic.Par.95063.File.dat/ Geothermal_PEIS_final.pdf

Table 8: Potential of Renewable Energy Development on Western Public Lands over 20 years

http://www.americanprogress.org/issues/green/report/2012/08/06/12002/the-vast-potential-for-renewable-energy-in-the-american-west/

Clean power creates jobs

Estimated direct jobs created from renewable energy development on western public lands over 20 years

State	Solar Jobs	Wind Jobs	Geothermal Jobs	Totals
Arizona	15,986	89	284	16,358
California	101,701	4,181	26,666	132,549
Colorado	14,469	243	284	14,996
Nevada	11,218	2,005	12,928	26,151
New Mexico	5,494	569	964	7,027
Utah	8,039	732	3,515	12,287
Totals	156,908	7,819	44,640	209,367

Table 9: Estimated direct jobs created from renewable energy development on western public lands over 20 years

http://www.americanprogress.org/issues/green/report/2012/08/06/12002/the-vast-potential-for-renewable-energy-in-the-american-west/

FIGURE 4

Bringing in billions of dollars

Potential direct investment in the renewable energy sector from development on western public lands

State	Solar investment (billions $)	Wind investment (billions $)	Geothermal investment (billions $)	Totals (billions $)
Arizona	11.3	.74	.12	11.5
California	72.0	3.5	11.7	87.2
Colorado	10.2	.20	.12	10.6
Nevada	7.9	1.7	5.7	15.3
New Mexico	3.9	.48	.42	4.8
Utah	5.7	.62	1.5	7.8
Totals	111.0	6.6	19.5	137.1

Note: Numbers may not add up exactly due to rounding.

Table 10: Potential direct investment in renewable energy sector from development on western public lands

http://www.americanprogress.org/issues/green/report/2012/08/06/12002/the-vast-potential-for-renewable-energy-in-the-american-west/

Source: University of Tennessee Howard H. Baker Jr. Center for Public Policy
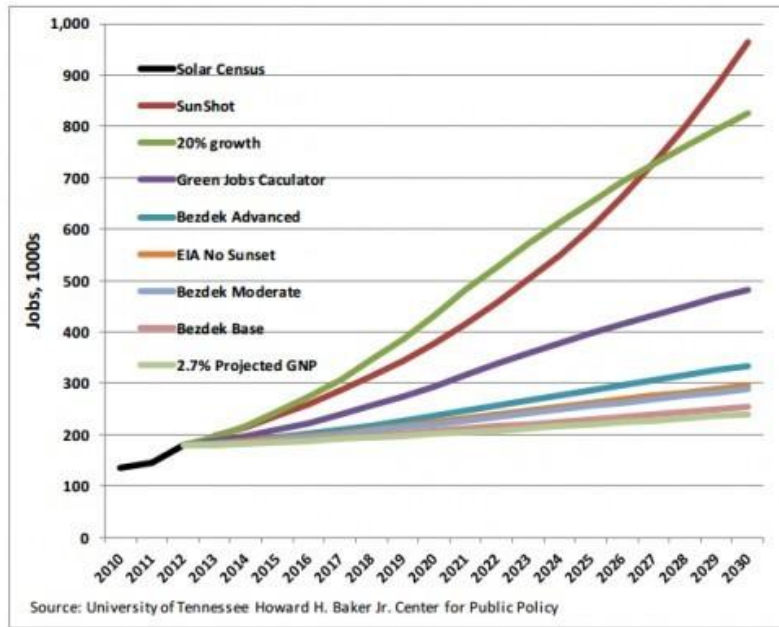
Figure A1. Employment Growth under Various U.S. Solar Growth Scenarios
Direct, Indirect and Induced

Figure 29: Employment growth under various U.S. Solar growth scenarios

http://pv.energytrend.com/research/Barber_PV_20120530.html
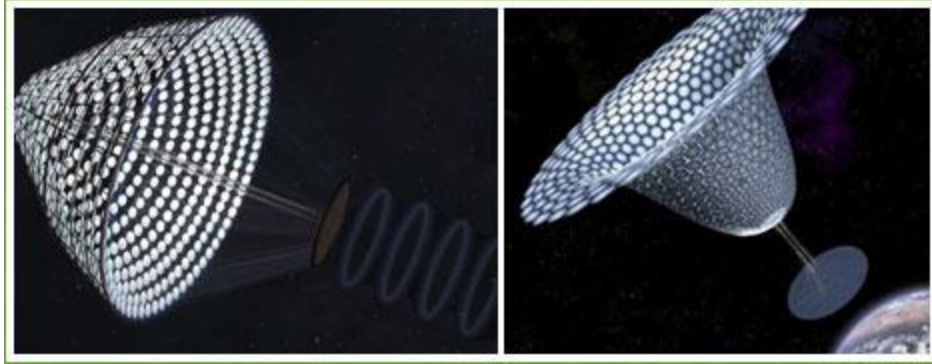
Figure 30: Concept art of petal shaped arrangement of mirrors to beam light to Earth

http://phys.org/news/2012-04-satellite-solar-power-earth.html

(Source: John Mankins)
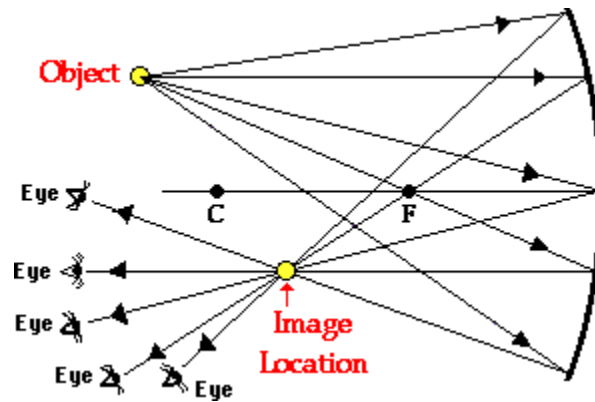
Figure 31: Ray diagram for a concave mirror

http://www.physicsclassroom.com/Class/refln/u13l3d.cfm
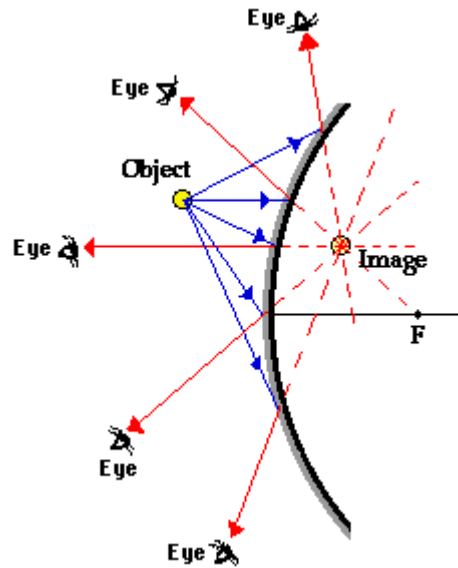
(Source: The Physics Classroom)

Chapter 8: Wind Power

Wind power is based on the idea that as the sun heats the atmosphere unevenly, the gases move around to distribute that energy across the planet. Every year the Earth has enough wind power that, if properly harnessed, it could easily replace all the fossil fuel sources we currently use. That's not to say that this would be easy to do, though. Producing traditional wind farms, which are large groups of wind turbines all kept and maintained together, one has to have good, consistent winds at a height of around 50m. It's also hard to ship the very large parts that these wind turbines are composed of, so often you need to make them nearby. This is great for the local economy, however, as it provides jobs for many people nearby. As of right now, wind turbines aren't a perfect technology, needing improvements in how they potentially store energy and can also be inconsistent due to wind speeds not staying stable. With further development, though, they could be a great weapon in the fight against the greenhouse effect, since they produce no CO_2 emissions.

There is so much wind energy that we would be downright foolish not to take advantage of it. The conservative estimates of how much energy we can capture, not just what is produced, are around 20,000 terawatt hours per year. That's 2,000 terawatt hours more than the entire world consumed in the

year 2005. These estimates also ignore the potential offshore wind energy. There is hope, though, because wind power was one of the first forces humans took advantage of, and have never stopped using.

History of Wind Turbines

For thousands of years humans have been harnessing the power of the wind. Some of the earliest recorded sail boats were found on the Nile River from around 5000 B.C. Then near 200 B.C. simple windmills were designed in China that could pump water. Simultaneously Persia and the Middle East had discovered how to use windmills to grind grain. It is a common misconception that this is essentially where windmill technology was left to molder until fairly recently, but it turns out that windmill technology was still advancing over time, even though in many areas they were replaced. During the industrialization of the 19th and 20th centuries people took windmills and turned them into wind turbines, the first windmills to produce electrical power. In the 1940's the largest such wind turbine was located in Vermont, USA and was capable of producing 1.25 megawatts when winds reached approximately 30 mph.

Types of Turbines

Today there are two different kinds of wind turbines that are used. The most common is the horizontal axis wind turbine. The second is a vertical axis turbine, which rather than having blades that look like the propellers of an airplane, has them placed vertically along the body of the structure. These vertical wind turbines have several advantages over their horizontal cousins. One is that they can be placed much closer together, because they do not slow the air that passes over them as much as traditional turbines do. In fact, horizontal turbines need to be separated by a minimum of 10 turbine diameters to work efficiently. The other major benefit is that vertical turbines do not need to be oriented toward the wind, as they can be spun from any direction. All that said, a single horizontal axis turbine will produce more power than a single vertical one, so it depends on the land area and scale you intend to build on to determine the more efficient choice.

Traditional horizontal axis turbines are relatively simple designs that use a prop designed to catch the wind and use the resulting lift, just as a plane's wing does, which spins a shaft. The shaft goes to a gearbox which increases the rate at which the shaft is rotating and feeds it into a generator. The generator is the same as any everyday generator, other than its power source, and from there wires will either go to batteries to store the electricity or directly into a transformer which is in turn connected to the power grid. Figure 33 illustrates these parts inside the turbine.

Vertical axis turbines are very similar mechanically, the real difference being that the tower and shaft are the same component. To spin it around the blades must be attached to the shaft in a way that is

reminiscent of an egg beater, a half circle with a slight helix twist in it. Just as in the horizontal turbine the shaft goes into a gearbox and from there to the generator which creates the electricity. See Figure 34 below.
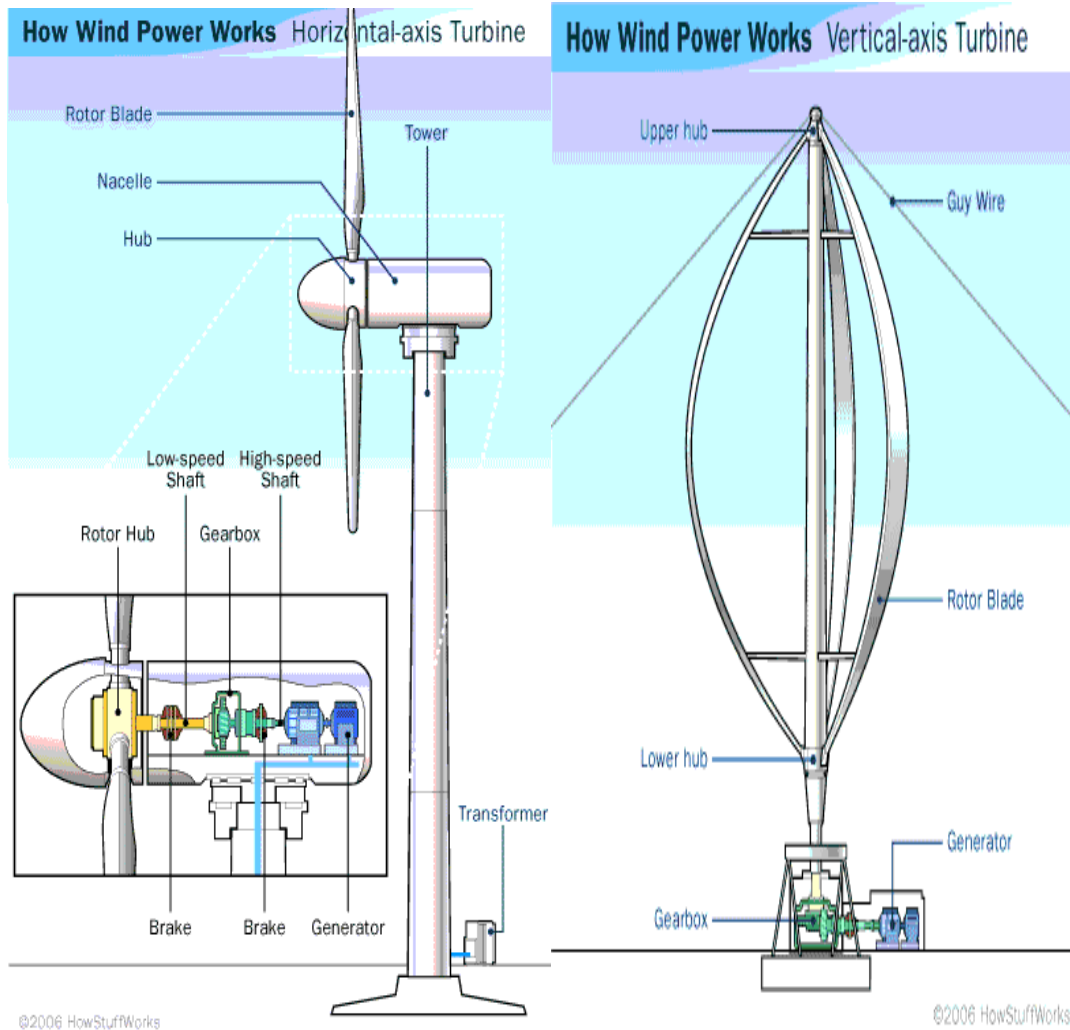
Figure 33: Horizontal Axis Wind Turbine (HAWT)   **Figure 34: Vertical Axis Wind Turbine (VAWT)**
http://science.howstuffworks.com/environmental/green-science/wind-power2.htm

(Source: How Stuff Works)

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Wind energy, although in many ways very good, also has some drawbacks. First of all, even though we can find the wind anywhere, it is only consistently strong enough to sustain a wind turbine in certain areas. The following figure is a map of the U.S. showing where the most efficient places for them are. In it you can see that there are actually quite a few areas with good, 15.7-16.8 mph sustained, winds

or better. For this reason the United States is one of the countries that stands to gain the most from the proper utilization of wind energy.

Betz Limit

The Definition of the Betz limit is that the maximum efficiency of extracting energy from the air is 59.3%. This can be shown by the following:

Definitions of Variables:

E = Kinetic Energy(J) ρ = Density (kg/m3)

m = Mass (kg) A = Swept Area (m2)

v = Wind Speed (m/s) Cp = Power Coefficient

P = Power (W) r = Radius (m)

dt/dm = Mass flow rate (kg/s) x = distance (m)

dt/dE = Energy Flow Rate (J/s)

t = time (s)

Kinetic energy of on object of mass m and velocity v is equal to work, W, in moving that object from rest to position s under a force of F:

[13] $$E \;=\; W \;=\; Fs$$

Newton's law, F=ma, therefore means that we can look at this relationship as:

[14] $$E \;=\; mas$$

Then, with the third equation of motion:

[15] $$V^2 \;=\; U^{\,2} + 2as$$

We can solve for a to get:

[16] $$a = \frac{(V^2 - U^2)}{2s}$$

With an initial velocity of zero, so U = 0, it becomes:

[17] $$a = \frac{V^{\,2}}{2s}$$

We can then substitute in the first equation to get the kinetic energy of a mass in motion:

[18] $$E \;=\; \tfrac{1}{2}\, mV^2$$

And power from wind is given by the rate of change of energy:

[19]
$$P = \frac{dE}{dt} = \tfrac{1}{2}V^2 \frac{dm}{dt}$$

The mass flow rate is:

[20]
$$\frac{dm}{dt} = \rho A \frac{dx}{dt}$$

And then the rate of change for distance is:

[21]
$$V = \frac{dx}{dt}$$

Therefore:

[22]
$$\frac{dm}{dt} = \rho A V$$

And then the final power equation can be shown as:

[23]
$$P = \tfrac{1}{2}\rho A V^3$$

We then have to determine the power coefficient, which is determined based upon particular wind turbine design. There is a Betz Limit that was calculated by Albert Betz which shows that no wind turbine can ever reach beyond 59% efficiency. This is caused in large part by the strength and durability of wind turbine parts having to meet certain requirements in order to be functional. Betz limit is explained by determining the most energy one can possibly convert from any fluid given several assumptions, which are:

1) The rotor does not possess a hub, with infinite blades without drag.

2)The flow into and out of the rotor is axial.

3)The flow is incompressible, therefore the density is constant and there is no heat transfer.

4)The rotor itself is massless and no angular momentum is imparted to the rotor or the air flow behind the rotor.

We can then calculate the greatest efficiency at all possible from a wind turbine based on power.

The mass flow rate can be given by:

[24]
$$m' = r * A1 * v1 = r * S * v = r * A2 * v2$$

Force exerted on the rotor can be written as:

[25]
$$F = ma = m\frac{dv}{dt} = m'Dv = rSv(v_1 - v_2)$$

Then we can calculate how much work is done by this force:

[26]
$$P = Fv$$

Substitute the force F above into the power equation to yield power extracted from the wind:

[27] $$P = rSv^2(v_1 - v_2)$$

Using this we can get the maximum value for efficiency E by showing:

[28] $$E = \tfrac{1}{2}m'(v_1{}^2 - v_2{}^2)$$

$$= \tfrac{1}{2}rSv(v_1{}^2 - v_2{}^2)$$

$$= \tfrac{1}{4}rSv_1 + v_2)(v_1{}^2 - v_2{}^2)$$

$$= \tfrac{1}{4}rSv_1{}^3 \left(1 - \left(\frac{v_2}{v_1}\right)^2 + \left(\frac{v_2}{v_1}\right) - \left(\frac{v_2}{v_1}\right)^3\right)$$

The result of this is that the maximum value of E, with respect to v2/v1, is 1/3.

Substituting this value results in the equation:

[29] $$P_{max} = \frac{16}{27} * \tfrac{1}{2}rSv_1{}^3$$

The power that can be obtained from a cylinder with cross sectional area S and velocity V1 is:

[30] $$P = \tfrac{1}{2}CrSv_1{}^3$$

Where the C has the maximum value of 16/27 or .593, meaning they can never exceed this percentage for efficiency.

The other important thing to keep in mind about wind power is that since you can't rely on the winds to always supply the same amount of power, one must store the energy in batteries if you want constant use. Unfortunately, though, battery technologies are not efficient enough that they could fulfill this role. This means wind energy is likely best suited to being tied directly into the current power infrastructure to supplement and reduce the use of fossil fuels, at least until battery technology is advanced enough that we can store power for when demand exceeds supply. The problem with this is that because of the generally remote locations of wind turbines, they frequently require many transmission lines be put up to deliver that power. Compared to the benefits, though, these seem to be mostly minor problems.

How Wind Power Works Wind Strength

Wind Power Class	Resource Potential	Wind Speed at 50 m (mph)
1	Marginal	12.5 - 14.3
2	Fair	14.3 - 15.7
3	Good	15.7 - 16.8
4	Excellent	16.8 - 17.9
5	Outstanding	17.9 - 19.7
6	Superb	19.7 - 24.8

—— Top-10 states for wind-energy potential factoring in environmental and land-use exclusions
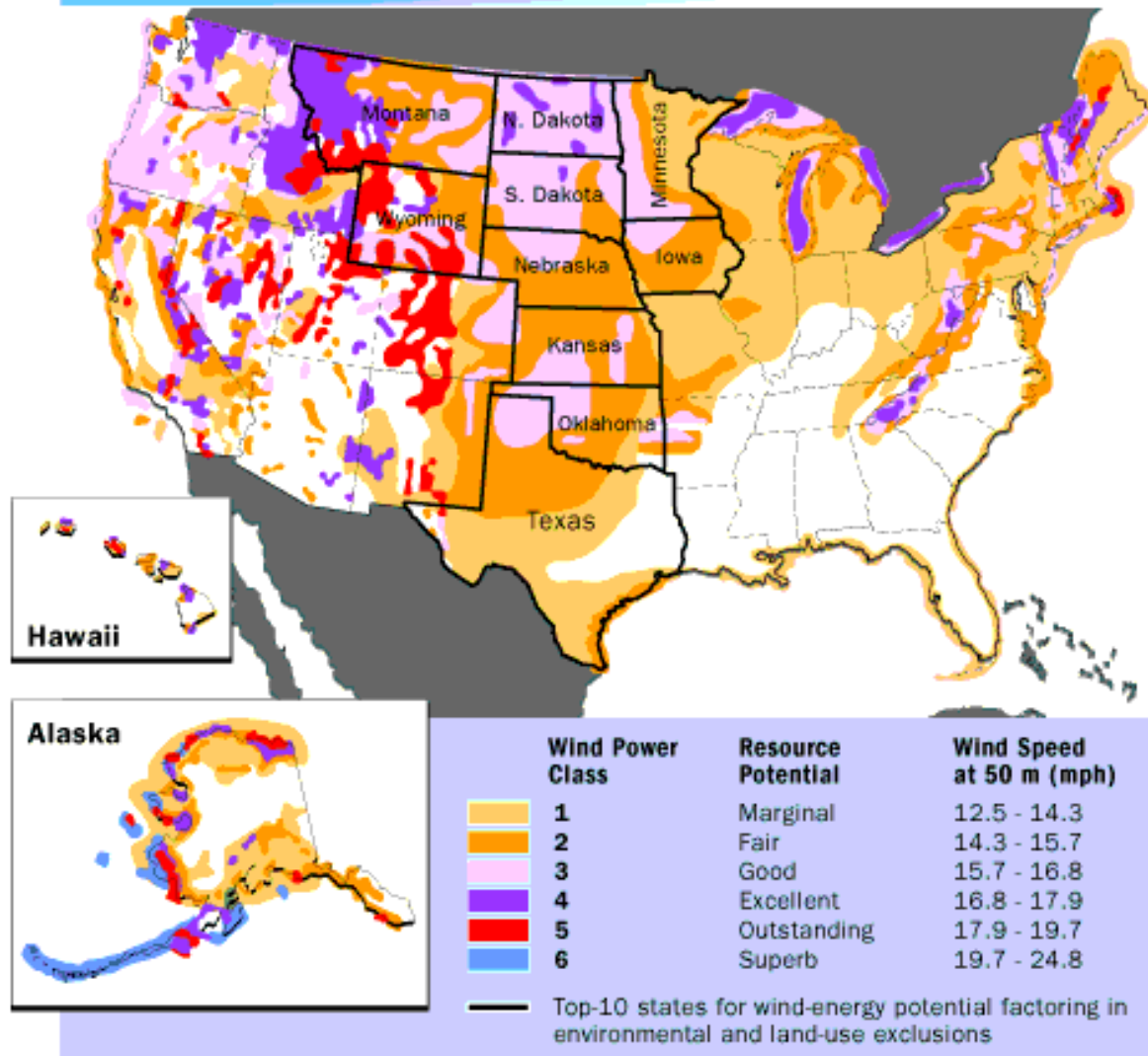
©2006 HowStuffWorks   Sources: American Wind Energy Association, U.S. DOE National Renewable Energy Laboratory

Figure 205: Map of the consistent wind speeds across the United States

http://science.howstuffworks.com/environmental/green-science/wind-power6.htm

<u>Conclusions</u>

There are many things that wind energy brings to the table that are very important for an energy source and its impact on our future. The first of these things is the simple fact that we don't put out any pollutants when creating wind energy. Every small step we take toward preventing global climate change is a valuable one and wind power could definitely help in that regard. The other major advantage it has over fossil fuels is that all of the wind power we need could be harnessed right here in the Unites States. That means all the industry related jobs would help people right here and we wouldn't have to worry

about embargos and disruption during times of conflict among other nations. This level of reliability is extremely hard to come by for current fossil fuels.

Not only is wind energy vastly superior to current fossil fuels, but it's also better than most alternative renewable energy sources. The estimated cost per kilowatt hour of nuclear, coal, natural gas, wind, solar and hydroelectric energy is shown in figure 26. As you can see, wind is vastly superior to solar power and over time the cost of fuels will make it cheaper than nuclear and coal. This means the only other energy source comparable in terms of cost is hydroelectric power, but that is severely limited by the number of places you can put a dam without damaging the local environment or displacing people living nearby.

The final great positive outcome from using wind turbines is their lack of environmental damage. Hydroelectric power requires blocking off a river and flooding vast tracts of land. Geothermal power can run out of water or steam over years, but wind turbines are harmless and with proper maintenance can last indefinitely. Some people claim they kill many birds, but compared to other normal buildings, and even cats, the numbers are insignificant. Some people also say that wind farms are noisy, but compared to most everyday noises they aren't very loud at all, especially when one accounts for how remotely located most wind farms are.

There are a few examples of major wind farms around the world. One of the more pertinent ones is the Cape Wind Project in Massachusetts. This is an offshore wind farm the Nantucket Sound off of Cape Cod. This project intends to construct 130 horizontal-axis wind turbines each with a hub heaight of 285 feet (87 meters). The blade diameters are 364 feet (111 meters). At peak generation it would be expected for the turbines to output 454 megawatts and an average output of 170 megawatts.   It is expected that this could offset close to a millions tons of CO2 each year and offset consumption of 113 million gallons (430,000 cubic meters) of oil annually. The price of construction of the wind farm is predicted to be $2.5 billion and that the electricity generated will be double the 2010 price of traditional fossil fuels. The Cape Wind Project got final government approval in 2011 and it is expected that the company will begin construction in 2013.

Another world away Denmark is also utilizing wind power and today almost 50% of the wind turbines produced around the world are from their manufacturers.   In 2008 18.9% of electricity production and 24.1% of generation capacity in Denmark was provided by wind turbines. One interesting part of this is that Denmark has somewhat modest wind speeds, only averaging 4.9 – 5.6 meters per second at a height of 10 meters on land.   Offshore, however, there are areas of 5-15 meters in depth which offer wind speeds in the range of 8.5 – 9.0 meters per second at a height of 50 meters. Based on the equations used by Denmark each of these individual turbines could reach a maximum of approximately 60% efficiency. Because of the successes so far with wind energy, Denmark is even

pushing to increase electricity generation by wind turbines to 50% of consumption. One of the newest farms intended to help reach this goal is the Anholt Offshore Wind Farm, which will be the largest wind farm in Denmark, consisting of 111 turbines with a total capacity of 400 megawatts. Construction should be completed sometime in 2013 and it will supply approximately 4% of all electricity generated in Denmark.

Wind turbines, especially vertical axis ones, are a great option for the future of the world, and the Unites States in particular. There is virtually no reason not to invest in wind technology at this point. It's cheaper than almost every alternative, the complaints people cite against it don't hold water under close scrutiny, and it has almost no negative environmental effects. At this point the only reason wind power doesn't make up much of our total power generation is because we don't have an infrastructure for it set up. However, the sooner we start building that infrastructure, the sooner we can benefit from it.

Chapter 9: Water Energy Technologies

The World Energy Council has estimated that 2 terawatts of energy can be generated by wave power. Since waves have the potential of providing a surplus of energy sources, different forms of generates have been designed to maximize energy output from different bodies of water. The most popular and known such technology is hydroelectric power. Hydropower uses running water to propel turbines, which in turn runs an electric generator to create electricity. This is considered a renewable technology since the 'fuel' that is used, water, can easily be replenished through the water cycle. The only cost that comes with a hydroelectric dam is the construction and operation of the generator facilities.

Common types of hydroelectric power plants use dams to store water from rivers or streams in a reservoir. The collected water is fed to the turbines through small canals. The electricity production can vary during the day, but is generally higher during the day. Because the generated power is low, some power plants, also known as pumped storage plants, pump the used water back into the reservoirs at night. These damns, such as the Hoover Dam in Nevada, and the Grand Coulee Dam in Washington, also meet societal needs such as irrigation, flood control and recreation.

Hydropower accounts for about 19% of electric generation. In the US, hydroelectric plants, which have the capacity of 100,000 megawatts, provide about 3.25% of the nation's total energy and about 6% of America's electricity. Hydroelectric power also makes up about 63% of renewable electricity in the US. In a current study by the U.S. Department of Energy, existing dams can provide 12,000MW of

additional capacity, and if new installations are made such that include the use of tidal current and tidal waves, hydroelectric power could provide up to 15% of America's electricity by 2030.

Other types of water energy technologies include run-of-the-river, Tidal Barrage, and the use of ocean waves. In the run-of-the-river plants, no reservoirs are created, but instead the energy flow of the river is used. Electricity is generated by the natural flow of the river, and fluctuates depending on the cycle of the river. It can be used for large scale power, but mostly kept to capabilities less than 30MW. This is popular in China, but has potential in many other countries, such as the United States.

Tidal barrages are similar to hydroelectric dams, except they are larger and are placed at the entrance of a bay or estuary. The retained water is released through the turbines which generate the electricity. In order for the barrage to work economically, the range between high and low tide must be near ten feet. The largest and oldest tidal barrage in the world is the La Rance estuary in Northern France, which was built in 1966 and has the capacity of 240MW.

There are several methods in creating electricity from waves. One of them is using the air produced by waves. Figure 36 below, represents how a water turbine can use the water's wave to generate energy.
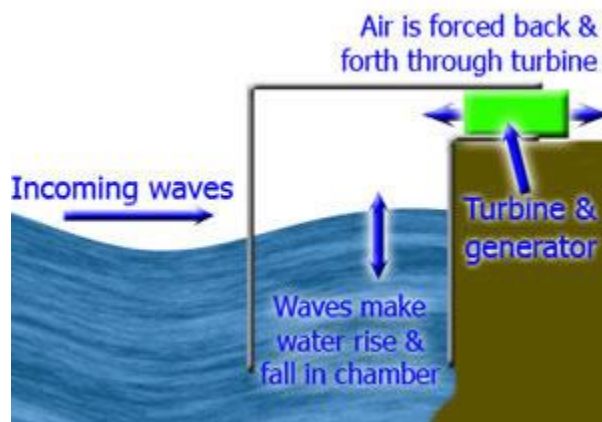
Figure 36: The Workings of a wave power station
Wave Power http://people.bath.ac.uk/as474/wavepower.html

At a wave power station, the waves cause the water in the chamber to rise and fall which causes the air in the chamber to pass in and out from the top of the chamber. This airflow will turn a turbine, which will turn an electric generator, thus creating electricity. Another method is through the use of the natural movement of the waves. Here a float on a buoy follows the up and down wave motion, causing the attached plunger to move in the same direction. The plunger's movement causes the attached hydraulic pump to change the vertical movement into a circular motion. This then drives an electric generator to produces electricity that is sent to shore through submerged cables.

While there are many advantages to using water energy, there are also many disadvantages. For example, studies have shown that large reservoirs can emit as many greenhouse gases as a fossil fuel power plant. At the beginning of a damn's life, flooded vegetation can decompose, which releases methane and carbon dioxide gases. Dams can harm the river's ecosystem, changes the water temperature, dissolve the oxygen and other nutrients in the water which can kill aquatic animals. Tidal Barrages are usually built in delicate estuary ecosystems, which can have a huge environmental impact on marine animals. Run-of-the-river is also very dependent on the flow of the water. Such things as prolonged droughts may diminish the water level in the river, which lowers electricity generation.

While using the earth's water has a few drawbacks, it is clear that it is possible to use it to produce electricity. In figure 37 below, the use of worldwide hydroelectric dams to produce electricity is seen. As was stated before, about 6% of U.S. electricity is created by hydroelectric dams. Yet in places like Norway, 99% of their electricity is created by falling water. This clearly shows that it's definitely possible to stop using fossil fuels to create our electricity.
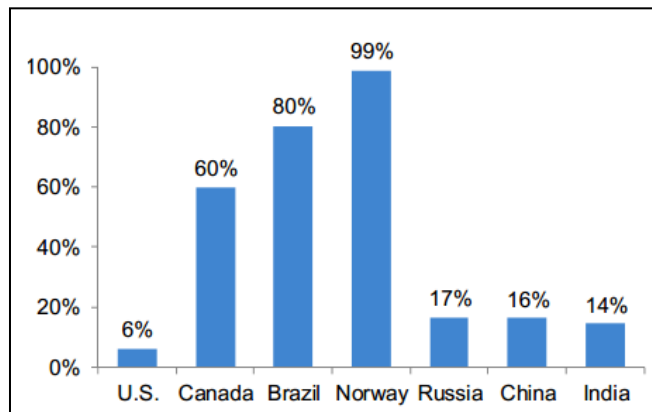
Figure 37: Percentage of electricity from hydroelectric dams
http://css.snre.umich.edu/css_doc/CSS03-12.pdf

(Source: University of Michigan)

The Bay of Fundy in Nova Scotia, Canada has one of the highest tidal ranges in the world. The Bay of Fundy has the tide spring range of 14.5 meters with an extreme range of 16.3 meters. This means about 100 billion tons of seawater moves in and out of the bay each day. With this much tidal power, engineers and scientists have been looking for different ways to harness this power into renewable energy.

The Electric Power Research Institute estimates that there are about 50,000 megawatts of energy that can be generated by the tidal force in the Bay of Fundy. Three hundred megawatts would just be

developed by the Minas Passage alone which would be enough to displace over one million tons of greenhouse gasses per year. That's like removing 200 thousand cars off the road.

There are several different turbine units that are being developed to harness the tidal energy with minimal environmental impact. Such designs can be seen in Figure 38 through 41 in the next page. At the heart of each one of these deigns is a TGU, or Turbine Generator Unit, which can be seen in Figure 38. The TGU works the same way a wind turbines work, with the foils rotating a permanent magnet generator that creates electricity. The big difference between this and the wind turbines is that water is 800 times denser than air and thus the TGU's provide more power. Each TGU has a generating peak output of about 180kW.

These TGU's can then be used in different designs. One design is seen in Figure 39 is the RivGen Power System, which is specially made to generate electricity at small river sites. They typically would be connected to diesel generators, and then turned off when the RivGen begins producing electricity. This can generate up to 50kW in a 10 foot per second river current. Other designs can be seen in Figure 40 and 41, that represent the TidGen and the OCGen Power System, which are designed to be used in water depth of 50 and 80 feet respectively.

In 2008, ORPC, or the Ocean Renewable Power Company, was the first company to generate electricity from the Bay of Fundy tidal currents without the use of dams. The reason dams are not used in the Bay of Fundy is from the fear that A beta pre-commercial version of the TidGen power system was deployed in the Bay of Fundy and met or exceeded all expectations and is the largest ocean energy device to ever be deployed in the US.

Another powerful water source of energy is the stream of the Gulf of Mexico. With a flow rate of about 8 billion gallons of water per minute, it is capable of generating between four to ten gigawatts of power, which is about the same amount of energy produced by four to ten new nuclear power plants. Just harnessing 1/1000 of the Gulf's steam available energy would power about seven million homes and business. This is equivalent to 1/3 of the electricity used in the state of Florida. These underwater turbines could generate up to four times the power that can be generated by wind turbines with the same generating capacity. As explained earlier, the turbines have about an 85% to 90% capacity factors that equal to natural gas and coal plants, but have no CO2 emissions. Each 1.2MW turbines installed would save about 10 thousand tons of CO_2 from being omitted to the air. If around ten thousand of these turbines are created by 2013-2014, it would cut down CO_2 emissions by 100 million tons and save the U.S. three billion dollars.

One of the many designs that could be implanted to harness the gulf's stream power is to have turbines over 1000feet under the surface. One of the big issues with this design is the "Cuisinart effect", which is where fish could get close to the turbines and be sliced. When this occurs, the blood could attract

other fish and the process would repeat. While this is a worry for some environmentalists, the probability of this happening is very low, since the turbines are turning so slow. With the slow momentum of these turbines, the likelihood that the fish will get caught and killed is low.

Using water as a renewable energy is one of the best and most reliable resource. With the earth covered in over 70% of water, using water as a resource for renewable energy is the most promising way to go. Unlike solar and wind energy, water energy is something that can be used day and night, and does not depend on high wind speeds.
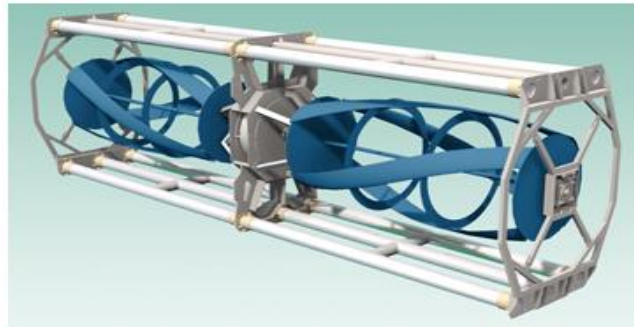
Figure 38: Turbine Generator Unit

http://www.orpc.co/orpcpowersystem_turbinegeneratorunit.aspx

(Source: Ocean Renewable Power Company)
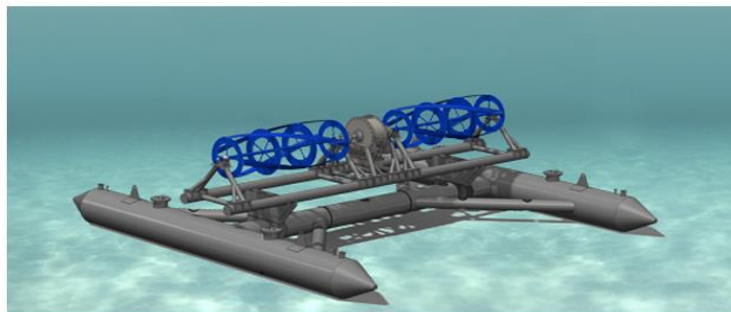
Figure 39: RivGen Power System

http://www.orpc.co/orpcpowersystem_rivgenpowersystem.aspx

Figure 40: TiGen Power System

http://www.orpc.co/orpcpowersystem_tidgenpowersystem.aspx
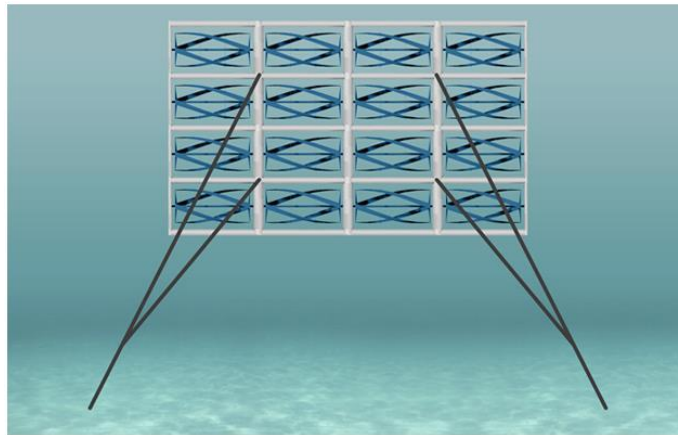
Figure 41: OCGen Power System

http://www.orpc.co/orpcpowersystem_ocgenpowersystem.aspx

(Source: Ocean Renewable Power Company)

South Korea

South Korea is one of the most promising countries for the application of the tidal energy generation. Tocardo International, which is the leading producers of hydro-power turbines, has agreed to sell its renewable energy in South Korea. It is the only company in the world that produces and sells commercially viable water turbines. These turbines are market-ready and can generate energy in any environment with flowing water such as offshore tidal currents or in-shore rivers.

Some of these turbines include the 100kW T100 turbine, the 200kW T200, which are available commercially. Other models such as the 500 kW and 1MW turbines are expected to be ready by 2013 and 2015 respectively. The T100, which can be seen in Figure 42 below, is the smallest Turbine this company has and it is ideal for river and inshore application. It operates in a minimal depth of 4 meters

and has a life expectancy of 20 years. The turbine has two blades that control a 14 pole permanent magnet and produces up to 100kW. There is currently a T100 turbine in use at the Den Oever Inshore Project site in the Netherlands. This turbine has been feeding electricity into the grid since the summer of 2008. The turbine has the capacity of 35kW and produces electricity for about 12 households. The project in the Netherlands can be seen in Figure 42.

Figure 42: T100 Turbine

http://www.tocardo.com/digi_cms/58/products.html

(Source: Tocardo International)

Figure 43: T100 Turbine in Den Oever

http://www.tocardo.com/digi_cms/44/den-oever-inshore-project.html

(Source: Tocardo International)

Another turbine is the T200, which is a medium sized turbine more suitable for inshore and near shore tidal applications. It is small enough to be attached to existing civil structures such as brides or barrages, as can be seen in Figure 44. The blade diameter for this turbine is a lot larger than the T100's and it has a 20 pole permanent magnet generator. This figure is from the Oosterschelde Inshore Project in

Oosterschelde, Netherland where five T200's are expected to be installed later this year. This project site will have the capacity of 1MW and will produce electricity for about 350 households.
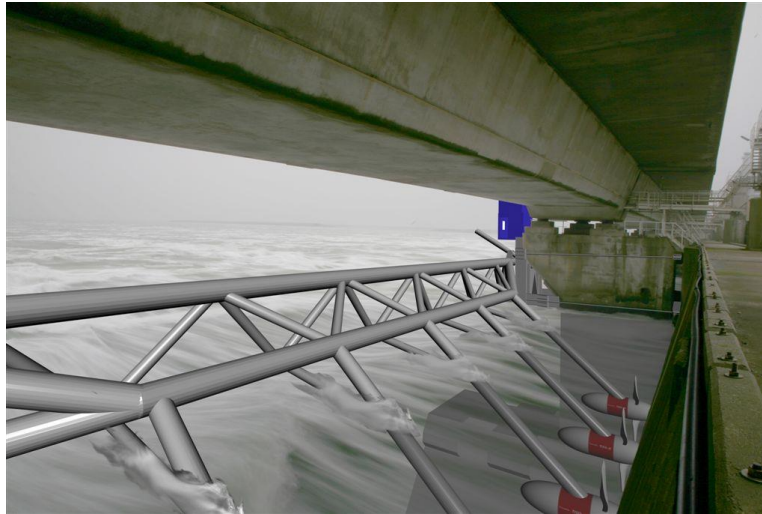
Figure 44: T200 Turbine in Oosterchelde, Nertherlands
http://www.tocardo.com/digi_cms/61/t200.html

(Source: Tocardo International)

The T500 is specially designed for offshore tidal currents and has blades that are much larger than the T200 or T100. This turbine is in its final stages of development and is expected to hit the market by 2013. The T500 can operate at depths of 5.5 to 25 meters. The last type of Turbine Tocardo is developing is the T1000, which is designed for heavy duty offshore projects. It has a rated power of about 1MW and is expected to be developed by 2015.
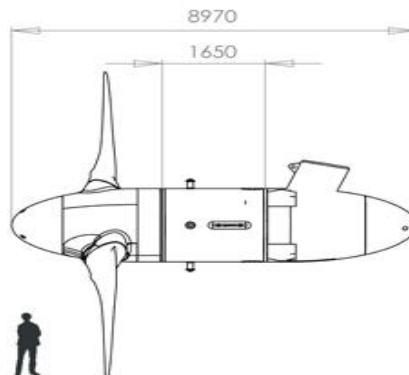
Figure 45: T500 Turbine size
http://www.tocardo.com/digi_cms/62/t500.html

(Source: Tocardo International)

KOMIPO

Two companies, Luna Energy and the Korean Midland Power Co (KOMIPO) are looking to create a colossal 300 turbine field in the Wando Hoenggan Water Way off the South Korean coast by 2015. These Turbines, as seen in Figure 46, would provide up to 300 MW of renewable energy, which is enough energy to power up to 200 thousand homes. Each turbine is a generator that provides 1MW and is about 11.5 meters in diameter. It is predicted to be a 500 million Euro dollar project, and will use the fast-moving tidal steams to turn the turbines on the sea floor. Each turbine will be about 60 feet high with a 2500 ton frame that contains a pump, generator, motor and electronics. The ecological impact of the field is expected to be less than that of tidal barrages.
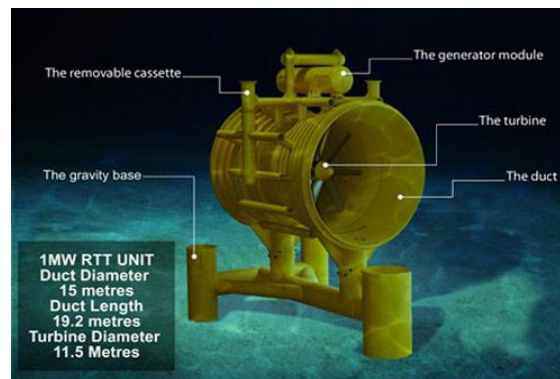
Figure 46: 1MW KMOIP Tidal Turbine

http://www1.eere.energy.gov/water/hydrokinetic/information.aspx?type=tech

(Source: U.S. Department of Energy)
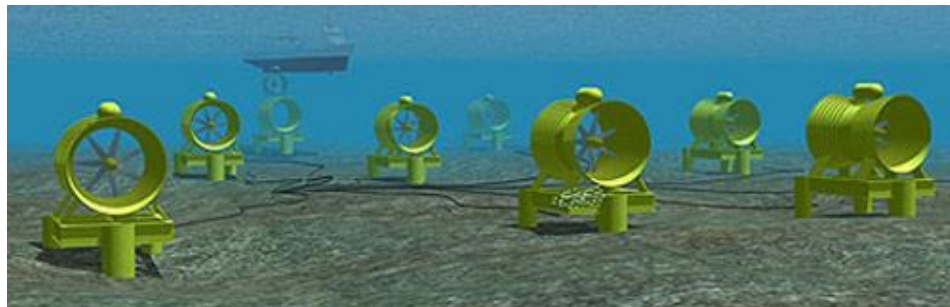
Figure 47: KMOIP Turbine Field

http://infranetlab.org/blog/tidal-turbines

(Source: Infrastructure Networks Library)

Sihwa Lake Tidal Power Station

Located about 20km south of Incheon and South Korea, this tidal power plant currently holds the highest-capacity power outage in the world. Its capacity of 254MW surpasses the previous record-holder of 240MW from the Rance Tidal Station in northwest France. In 1994 when the government attempted to create a freshwater lake, a 7.9 mile dam was created and the tidal power plant was proposed as a way of cleaning the water. This power station is expected to reduce 315,440 metric tons of CO_2 per year. This station features a sea wall that stores the water during high tide, but only generates power from incoming tides. It has a diameter of 7.5 m and was completed in early 2010. A picture of the generator turbine can be seen in Figure 48. This plant is expected to reduce the effect of CO_2 by 315,000 tons and since it began operation is early 2011, it has produced 552.7GWh of energy annually.

Figure 48: Sihwa Lake Tidal Power Station

http://wordlesstech.com/2011/04/30/sihwa-tidal-power-plant-in-ansan-near-completion/

(Source: Wordless Tech)
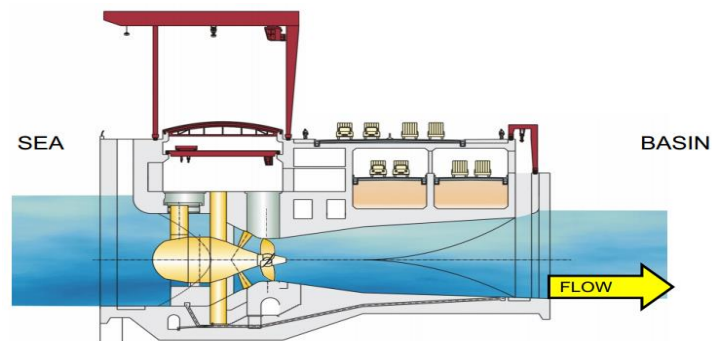
Figure 49: Sihwa Lake Tidal Station Motor

http://wordlesstech.com/2011/04/30/sihwa-tidal-power-plant-in-ansan-near-completion/

(Source: Wordless Tech)

Future Power Stations

Under the national slogan of Green Growth in South Korea, it adopted a nationwide Renewable Portfolio Standard. This standard requires utility companies to generate a certain portion of energy from renewable resource, from about 2% in 2012 to about 8% in 2020. This is why South Korea has come up with a plan of mega-scale tidal power generation. This means that off the shore of South Korea many more tidal power plants are expected to be built, like can be seen in Figure 50.
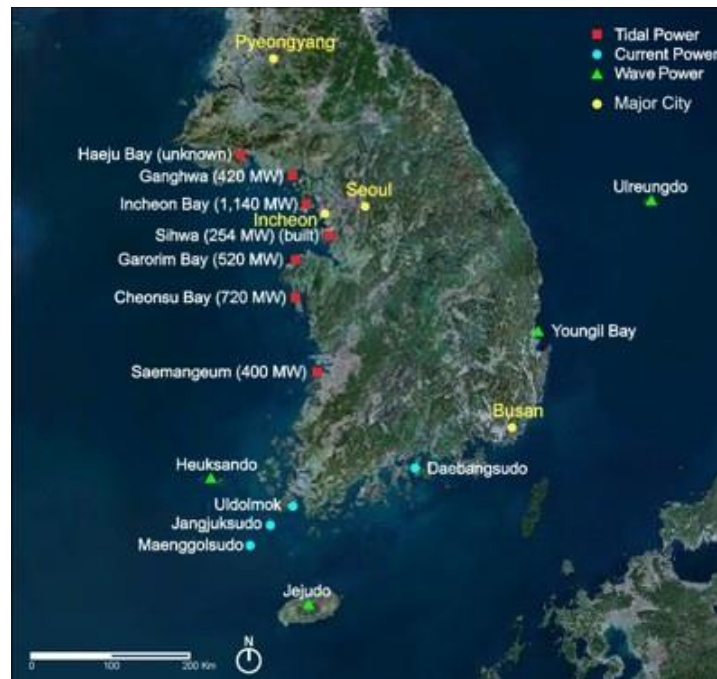
Figure 50 South Korea Plans for Tidal Power Plants
http://nautilus.org/napsnet/napsnet-special-reports/south-koreas-plans-for-tidal-power-when-a-green-solution-creates-more-problems/

(Source: Nautilus Institute)

Two of these proposed locations for the tidal plants are the Incheon bay and the Ganghwa way, better seen in the Figure 53. The Incheon Bay would have a capacity of 1,320MW, more than five times the power from the Sihwa plant. This project is expected to be equipped with 44 turbines and meet 4.5% of the nation's household electricity needs. Construction on this plant is scheduled to begin in 2014 and be completed by the end 2019. The Ganghwa Tidal Power Plant would have the capacity of 420 MW, and be 65% larger than the Sihwa plant.
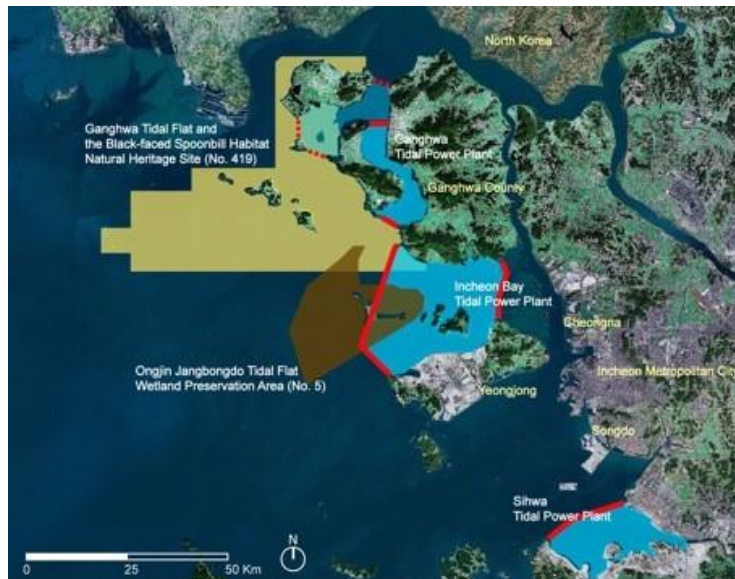
(Source: Nautilus Institute)

While there is a larger amount of renewable electricity coming from these plants, many local communities are protesting against the building of these plants. Locally, the plants could destruct ecosystems, decline local fisheries and eliminate jobs, increase the fish of flooding, and impact the natural landscape. On the National scale, it would be a large initial cost for the construction of these tidal plants, with an estimated cost of $3.4 billion. The endangered species' population could decline from the tidal processes in the Yellow Sea.

The idea of decreasing fossil fuel consumptions and use renewable energy is great, but by creating these gigantic Tidal Power Plants that could severely harm the ecosystem, and might create problems for South Korea.

While it's true that applying these larger power plants could harm the ecosystem, I think it's more important to build these power plants. It is important to start using renewable resources and to stop relying on non-renewables such as nuclear and oil. I think that while short term it might seem that this would harm the environment, long term it would help it.

90

Bay of Fundy

The Bay of Fundy is a very promising site for renewable energy. Because of its large tides that can go up to 16m in some places, it has potential to produce a large amount of tidal current energy. Chignecto Bay and the Minas Basin form two arms at the head of the Bay and have exceptional high tides. At high tide, huge volumes of water in the bay floods into the rivers, with the water racing in speeds close to 10mph. This generates rapids that are between 3 to 3.5 meters high.

Figure 52: Google image of Minas Basin and Minas Passage
http://maritimetidal.com/?page_id=38

The Bay of Fundy's surface current can reach up to 10 knots, which is equivalent to s speed of 5.1 m/s at peak surface during high tide. Each tide lasts around six hours, while high and low tides both peak for about an hour. Given that the change of tides can last for half a day, it is possible to harness the constant change and generate energy.

The Minas Passage and Minas Basin, as seen in Figure 52, have the strongest current in the Bay of Fundy running at an average current speed of 3.28m/s. The narrowest part of the Minas Passage is 4.5 to 6.5 km wide, which dumps into the Minas Basin. The Minas Basin has an even stronger current, at around 5.0m/s, and has a high tide of 14m and a low tide of 2m.

As part of this study, certain turbines where looked at to see how much power they would produce if they were placed at the Bay of Fundy. We mainly concentrated on Tocardo Turbines since it was one of the few turbines that had the necessary specifications sheets, but we also looked at Open Hydro, Marine Current Turbine, and Alstom Hydro.

TocardoTurbines

Tocardo Turbine was looked at earlier, since it is the company that has sold a few of its turbines to the South Koreans. For this study, it is theorized that the Tocardo T100 Turbine would be placed somewhere in the Bay of Fundy. Since the T100 needs at least 4m depth to work, the Minas Basin would not be ideal, even if the current has high speeds of 5m/s.

Therefore, the Minas Passage, with average water depth of 54m, would be ideal. Here with a current of 3.28 m/s, it would have a much larger probability of outputting more power.

(Source: Tocardo International)

After doing more initial research on the Tocardo Company and realizing that they have the most promising turbines, we attempted to email them to get more information about the T500 and T1000, since they are ideally the best turbines for the Minas Basin. In response to our inquiry, Bart Schuitema, the project developer at Tocardo, mentioned that since the T500 and T1000 are in development stages, there is not much information about those two turbines. He also said that the smaller turbines, like the T100 and T200, are very much like the T1000 and T500 but only have less output.

With the much bigger turbines of the T1000 and T500 unavailable, I concentrated on the T100 and its applications. According to Tocardo, a 5.5 meter blade, which is the correct blade for a rated water velocity of 3.5m/s, outputs a rated grid power of 159kWh. This is at 31.4% percentage full load capacity. According to Mr. Schuitema, Tocardo uses full load factors, which is the percentage the turbine will be running at full capacity. At 100% full load capacity, this turbine can output 505kWh.

Since the length of the Minas Passage is 12 km and the width is 4.5 km, the area where turbines could be placed is 54km^2. The turbine has a 7.6m blade diameter, plus it's recommended they have at least two meter radius. The nose to tail length of the turbine is roughly 4.25m which means that each

turbine can take up to 50m^2 of space. Now if we decided to use all the room available, that means we can have up to 1.2 million of these turbines placed in the Minas Passage.

However, this would not be practical, so if we placed around 10 turbines in the passage, it would out an average of 1.59Mwh. While it's promising, there are still other factors that need to be considered when it comes to this turbine, such as how deep it would be placed, where in the Minas Passage it would be best to be placed, and price. I inquired Mr. Schuitema about the price of a T100 and he stated that each turbine costs about €242,100 which is about 316,352.07 U.S. Dollars. This price does not include installation, foundation system, and transport. So on average, installing one turbine could cost around $400,000 which means that ten of these turbines would equal to about four million dollars. While four million seems like nothing when compared to other tidal projects, the output of this would only be 1.59MWh, compared to other projects where 4 million could produce a much higher output power.

We also inquired a bit more about the T1000, which is expected to have an output of about ten times the T100, at a rated output power of about 1MW and is currently under construction, like I stated before. It appears that this turbine would be much cheaper to buy since it's supposed to output that same amount of power as ten T100. However, with the lack of information, I'm not sure if this means that the T1000 is going to have rotor blades that are ten times the size, a bigger generator, or maybe both. Even so, installing one large turbine would be less maintenance and less expensive than installing ten smaller turbines.

Marine Current Turbine

Marine Current Turbine, or MCT which was established in 1999, is the world leader in marine current and tidal stream energy conversion. It was the company that installed the world's first commercial scale tidal turbine in 2003. This company has s specific type of turbine called SeaGen Technology.

It has two main testing locations such as SeaFlow a 300kW system in Lynmouth, Devon, and SeaGen S in Strangford Lough, NI. The SeaGen S, shows in figure 54, has twin power trains mounted on the crossbeam. This is great for water depths up to 38m and can handle currents higher than 2.4m/s.
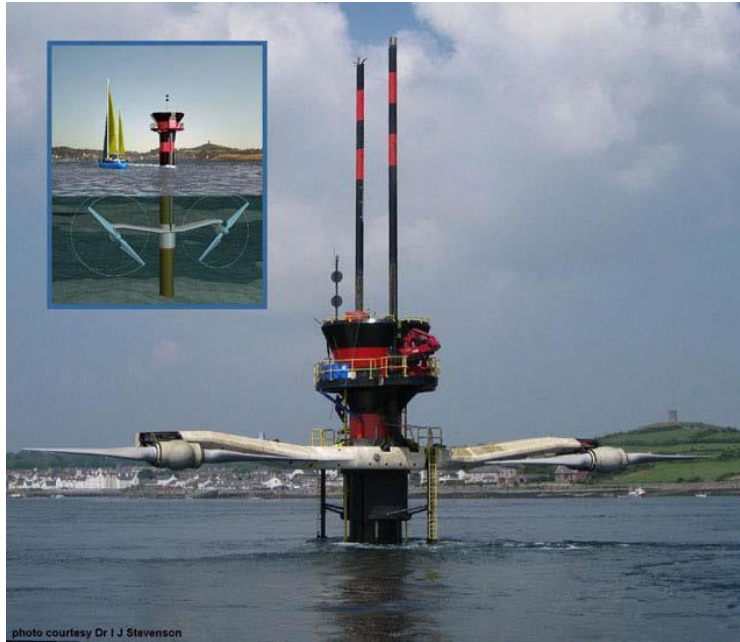
Figure 54: SeaGen Turbine

http://infranetlab.org/blog/tidal-turbines

(Source: Infrastructure Networks Library)

The SeaGen S is submerged in sea water and is driven by marine current or tidal current if velocities are high. These turbines consist of two axial rotors 15 to 20 meters across. The turbines are designed to operate in bi-directional flows allowing the blades to be pitched 180 degrees. There is a 1.2 MW system installed in Strangford Lough, Ireland that has had four years of testing and MCT is considering bringing a 2MW SeaGen S system for commercial use in the next coming years. Ideally, this turbine would work in the Minas Passage; however, the Minas Passage has a water depth of about 54m, while this turbine has a limit of 38 meters.

As of January 2008, MCT partnered with Minas Basin Pulp and Power Company to install a SeaGen U 3MW system sometime in the future. The SeaGen U has three 1MW turbines, as can be seen in figure 55. These rotors are 16 meters in diameter and be pitched 180 degrees so it will turn in both the ebb and flood tides. The turbines are currently under construction and are expected to be installed for testing sometime early in 2013.
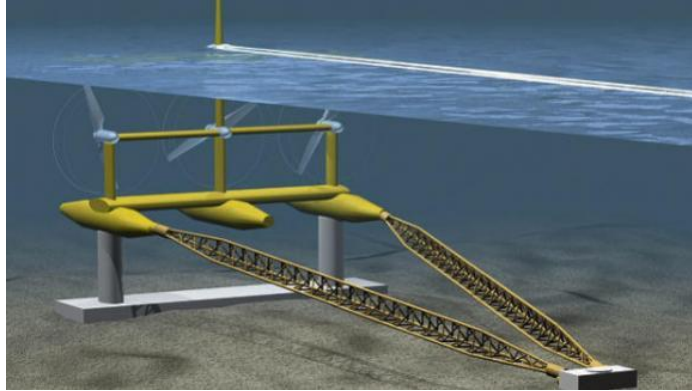
Figure 55: Proposed SeaGen U for Minas Passage

http://fern.acadiau.ca/fundy-tidal-energy-demonstration-facility.html

(Source: Fundy Energy Research Network)

Alstom Hydro

There is not much information for this company and what type of turbines it has. According to a recent article, this company partnered up with Clean Current Power Systems of Nova Scotia to install a 1MW BELUGA 9 turbine in the Minas Passage. According to its website, the BELUGA 9 has a 13m turbine outlet diameter which is designed for currents up to 9 knots, or 4.63m/s. This is a prototype and is expected to be tested first at the Minas Passage.

Open Hydro

Open Hydro, a small company stationed in Ireland, is a technology business that designs and manufactures turbines to generate renewable energy from tidal streams. One of its most popular turbines is the Open Centre turbine as seen below.

Figure 56: Open Centre Turbine

http://www.openhydro.com/techAssem.html

(Source: OpenHydro)

Open Centre is a turbine 12 blade turbine centered on a 10m diameter hole and weighs about 400 tones. Each of these units is a stand-alone generator. It would be anchored to the seafloor 200 feet below surface around five miles offshore and each unit can produce up to 2.5 MW. This is a slow moving single-piece rotor with lubricant free operation and uses a permanent magnet generator that is highly efficient inside the stator. The Open Centre turbine has been previously installed in certain places for testing, such as the French utility EDF off the coast of Brittany.

In November 2009, an Open-Centre turbine, as seen in figure 57, was deployed into the Minas Passage for a two year testing period. This testing period was to see how the turbine would fair in the Minas Passage turbulent waters. However, after only eight months, the engineers noticed there was something wrong with the turbine and decided to pull it out for forensic analysis. Due to storms and unexpected strong tides, they were not able to recover the turbine until December of 2010. At first the turbine structure appeared to be in good condition, but after further inspection, it was noticed that all 12 blades were missing. It was then towed to Dartmouth, Nova Scotia and Open Hydro said it would test the turbine to see why it failed and how to improve it. However, earlier this year in February, an article was released that this type of turbine might not be able to be improved and would not be deployed again into the Minas Passage.

Figure 57: The Open Centre Turbine deployed in the Minas Passage
http://www.openhydro.com/images.html

(Source: OpenHydro)

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Since the Open Centre turbine failed under the strong currents of the Minas Passage, it is possible that an even smaller turbine such as the T100, might not survive its turbulent waters. It could also be that the Open Centre turbine is just not the right type of turbine for the Minas Passage, and that a turbine with just two blades might fare better. There really is no right answer and the only way to know how other turbines would work is to place them in the Minas Passage for testing. The Bay of Fundy has immense tidal power potential, something that was mentioned in the early part of this paper, and to be able to safety tap into the power would go a long way into slowing the use of non-renewable resources. By using underwater turbines, it would eliminate the worry of tidal barrages, which was considered a bad choice since it could eliminate or diminish the tides. Since most of these turbines are slow in turning and have pretty big blades, they would also not have a huge impact on marine life. Overall, I believe that if the correct turbine or turbines are chosen, the Minas Passage will produce a tremendous amount of power that would put the tides of the Bay of Fundy to good use.

Chapter 10: Electric Transmission

With the advancement in technology, more and more devices are running on electricity. Electricity is a vital form of energy because it is easy to transport and be stored and still be accessible to everyone due to the power grid set up in the United States. There are two methods used in transporting electricity, High-Voltage Direct Current, HVDC, and High-Voltage Alternating Current, HVAC. HVDC is mainly used for long distances, in the range of hundreds of miles, because it is less expensive but more importantly has a better efficiency than HVAC. Per 1000km, the attenuation in HVDC is only 3% the maximum power. Due to HVDC's property of having a constant current, it can be used to stabilize problems in large power distribution networks when part of a network is down due to new loads or blackouts. Without HVDC, there may be synchronization problems when a part of a network is down and cause the entire network to fail. When two or more HVAC systems are connected and the phases are unsynchronized, HVDC can be used to increase stability while also eliminating power losses in the system.

In order to minimize power lost while transmitting, HVDC and HVAC transmission system run on high voltages. Because electricity is running through long wires that are wrapped in inductive materials, the wires are acting like conductors. Being conductive, the wires have some resistance which over time will cause the voltage to drop slightly. The lost voltage causes a loss in power in the wires. The lost power is being converted to heat energy. The following equation represents how heat loss is measured in a wire:

[31] $Q \, \alpha \, I^2 R$

The heat produced in a wire is proportional to the current squared and the resistance. Since the resistance cannot be changed because it is determined by the length of the wire, the only change is the current. The power transmitted through wires is measured by the voltage times the current:

[32] $$P = IV$$

Since both power and power lost to heat are proportional to the current, to minimize power loss, the current should be small. In order to transmit a constant wattage of power, the voltage must be high to counter the small current.

While HVDC has some benefits, there are some down sides that are fixed by using HVAC. Because HVAC has a higher efficiency when transmitting over a short distance, it is used more to distribute electricity to power consumption centers such as cities, towns and power plants. Because the transmission lines must transmit at voltages much higher than any electric appliance needs, it is easier to up and down convert the voltage in HVAC systems by using transformers.

A transformer is a device that uses inductive coupling between different numbers of windings to vary the current to create a magnetic flux in the transformers core. The varying magnetic flux occurs through a second number of windings which causes voltage to flow through the windings. The ratio between the output and input voltages is equal to the ratio of secondary to primary windings.

[33] $$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

If the voltage needs to be increased, the number of secondary windings should be greater than the number of primary windings. To decrease the voltage, the number of secondary windings should be less:

Increase Voltage: $N_s > N_p$

Decrease Voltage: $N_s < N_p$

Because HVAC and HVDC have their own benefits and faults, using both lines together in a transmission system can be beneficial. In fact, the electric power distribution grid in the United States is a combination of HVDC and HVAC. Because the transmission lines are always changing from HVDC to HVAC and vice versa, rectifiers and inverters are used to convert from one line to another. When the electricity is converted from HVDC to HVAC, power is lost. In order to have a higher efficiency, more research and development must be spent on converting from one line to another to improve the efficiency of the entire electric grid.

Chapter 11: Solar Wind Turbine

BlueEnergy SolarWind Turbine

A small company in Santa Fe, New Mexico has developed a hybrid vertical axis wind turbine that is covered with solar cells. This new design can be seen in Figure 58 below.
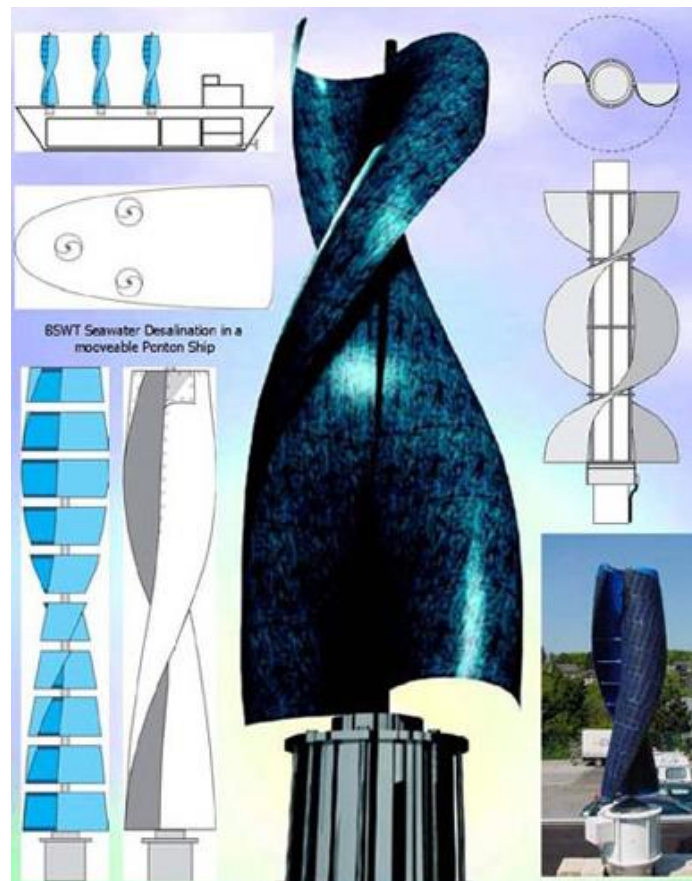
Figure 58: BlueEnergy Solar Wind Turbine
http://www.bluenergyusa.com/

(Source: Bluenergy Solarwind)

At the core of this turbine is solar cell encapsulation technology. Most solar cells are sealed behind glass, which makes them inflexible. The solar cells in the BlueEnergy Solar Wind Turbine are covered by layers of pure fluoropolymer, a flexible clear film. This encapsulation is dirt-resistant, non-reflective and impact resistant. The clear film creates a microscopic field of indentions that captures

sunlight from all angles and steers the light onto the cells without using extra optics or bulky devices. By incorporating the cells into the vanes that are mounted onto the turbine, it increases the efficiency of the turbine to 30-45% and creates electricity even when the winds are calm. Due to the double-helix shape, this turbine can catch winds as low as 4mph. It has a three-phase alternating current-synchronously permanent magnate generator. The fixed winding of the rotors is continuously activated through the magnets in the generator so that is delivers power even when the rotor is only turning at low revolutions per minute.

While this turbine is in its early stages of testing, there are a few advantages that are pretty obvious. It utilizes wind and solar energy, it is also totally soundless, it's safe for people and animals, and uses winds from all directions. Since the generator is contained at the base of the turbine it is easy to maintain, easy to monitor, and easy to replace. Since it is not as tall as other turbines, it east easier to replace and maintain the propellers.

A Payback Period Calculation for:

The Bluenergy Solarwind™ Turbine (5kw) – located in Santa Fe, New Mexico
in a breezy and sunny location, without nearby obstructions.

Annual Mean Wind Speed: **14 mph**

Predicted Electricity Output: 1,100 kWhrs / month; **13,200 kWhrs / year**; 330,000 kWhrs in 25-year lifetime

Our Average Electric Utility's Cost over the next 25 years - forecast energy inflation of 6% / year: **18 ¢ / kWhr.**

Average Annual Worth of Electricity Produced: **$2,376.**

Purchase of Bluenergy 5kW Solarwind™ Turbine, plus installation: **$35,000.**

Total cost over 25 year life *(including maintenance and 1 extra generator)*:

		Electricity cost:	
New Mexico – **Unsubsidized**	~ **$42,000.**		~ 13¢ / kWhr
New Mexico – **Rural (non-PNM)**	~ **$36,000.** (with tax credits)		~ 11¢ / kWhr
New Mexico – **PNM customer**	~ **$24,000.** (with tax and solar production credits)		~ 08¢ / kWhr

Average Payback Period:

New Mexico – **Unsubsidized**	~ **18 years** (no Fed, NM, or PNM credits)
New Mexico – **Rural**	~ **15 years** (with Fed and NM credits)
New Mexico – **PNM customer**	~ **10 years** (with Fed, NM and PNM solar credits)

Figure 59: Payback period of the Solarwind Turbine

http://www.bluenergyusa.com/SWT_Comparison.html

(Source: BlueEnergy)

As can be seen in Figure 59, this turbine has an estimated electricity output on about 1.1MWhrs/month on an annual wind speed of about 14mph. As is concluded from the numbers in the figure, the turbine would be paid back in about 15 to 18 years. Again, these are all just estimations since the prototype for this turbine has just been built is testing has also just started. However, when this is compared to just a traditional solar panel and a tradition wind turbine, these turbines comes out winning. If 500 square feet is covered by 150-Watt solar panels, it would cost about $50 thousand and have an average electricity cost of $0.23/kWr. A traditional windmill turbine that requires a tower of about 60-

140 feet high , will cost around $48 thousand and have an average electricity cost of $0.19/kWhr. Now the total cost of a Solarwind Turbine is on average $42 thousand and could have an average electricity cost of about $0.13/kwhr. This just shows how much more efficient this turbine could be if it ever made it out to market.

Model Wind Turbines

We have looked into several different model wind turbines in order to build a prototype combined wind/solar generator. This combined wind/solar generator will be used to allow us to experiment with several different types of reflective surfaces to determine how they would affect output of our system. It would also hopefully allow us to experiment with different types of blades and angles of them to see if that caused any changes. Finally it would ideally allow us to try several types of solar panels to determine if creating a tessellation of standard non-flexible panels would be better than the typically less efficient flexible panels, even though those could more easily be applied to the body of a wind turbine. For our model we have found several products that appear to meet our needs and as such I shall outline them below.

Mini Wind Turbine from kidwind.org: This is a rudimentary wind turbine kit costing approximately $36 with shipping that includes a stand, generator, blades, propeller, and alligator clips. The model is 12 inches (0.3048 m) tall with a circular base with diameter of 6 inches (0.1524 m). Model Wind Turbine from scienceguy.org: This is a step-by-step guide to constructing our own turbine. This option could potentially be cheaper, but we would need to find parts separately. Sunforce Marine Wind Turbine from northerntool.com: This is a $900 dollar model designed for marine applications. Its dimensions (Length x Width x Height) are 27 in. x 26 in. x 9 11/16 in. (0.6858 m x 0.6604 m x 0.246063 m). This option is mainly for comparison and probably will not be considered when we select parts for our prototype. Thames & Kosmos Wind Power 2.0 from amazon.com: This product costs $32.40 and includes two styles of wind turbine blades with three differing gear ratios for experimentation. With dimensions of 14.6 in. x 11.5 in. x 3.1 in (0.37084 m x 0.2921 m x 0.07874 m), the flexibility of this turbine would allow us to test more ways to improve our design. Due to the cost and flexibility of this design, this would be my recommendation for the our turbine of choice.

Choosing the Solar Panels

For our idea of creating a combination solar/wind generator we need to know whether or not the better option is to try and tessellate normal non-flexible cells or to purchase and use flexible solar cells. For this purpose I have compared those two different types of solar panels. The first thing worth noting is that flexible panels despite being much more convenient in terms of attaching them to the body of the

turbine are significantly less efficient than standard solar panels. In the most recent article I could find the record efficiency for a flexible solar panel was achieved at just 18.7%, up from 17.6%, and this was dated May 20, 2011. This means that this new technology isn't even likely to be available commercially for a few years yet. On the other hand standard solar panels have gotten up to 34% efficiency as of June 2012, a significant difference that means if the barriers to weight and tessellation could be accounted for make it a much better choice. This is still an aspect we would if at all possible like to test in our model, though. We currently know it would be much easier in terms of construction to use flexible panels, but we don't know for sure how much being wrapped tightly into a cylinder might affect their power generation. There are also still a lot of variables involving reflecting the light onto the panels themselves and we won't know for sure if one type of panel or the other might be better under those circumstances. Another important issue is the price- flexible solar panels in general are more expensive than the standard rectangular ones, something on the order $1.50/watt for standard and $4/watt for flexible paneling.

Based on previous data, the following figures compare the various ways that have been proposed to harvest solar energy:
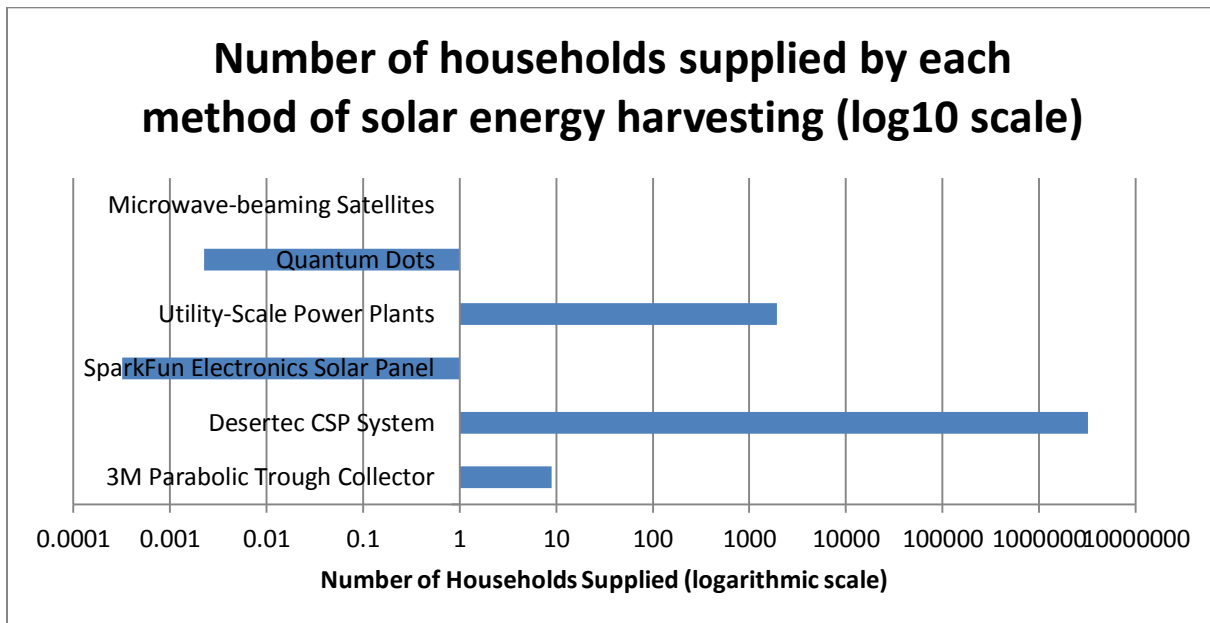

Number of households supplied by each method of solar energy harvesting (log10 scale)

Figure 60: Number of households supplied by each method of solar energy harvesting on a $\log_{10}$ scale
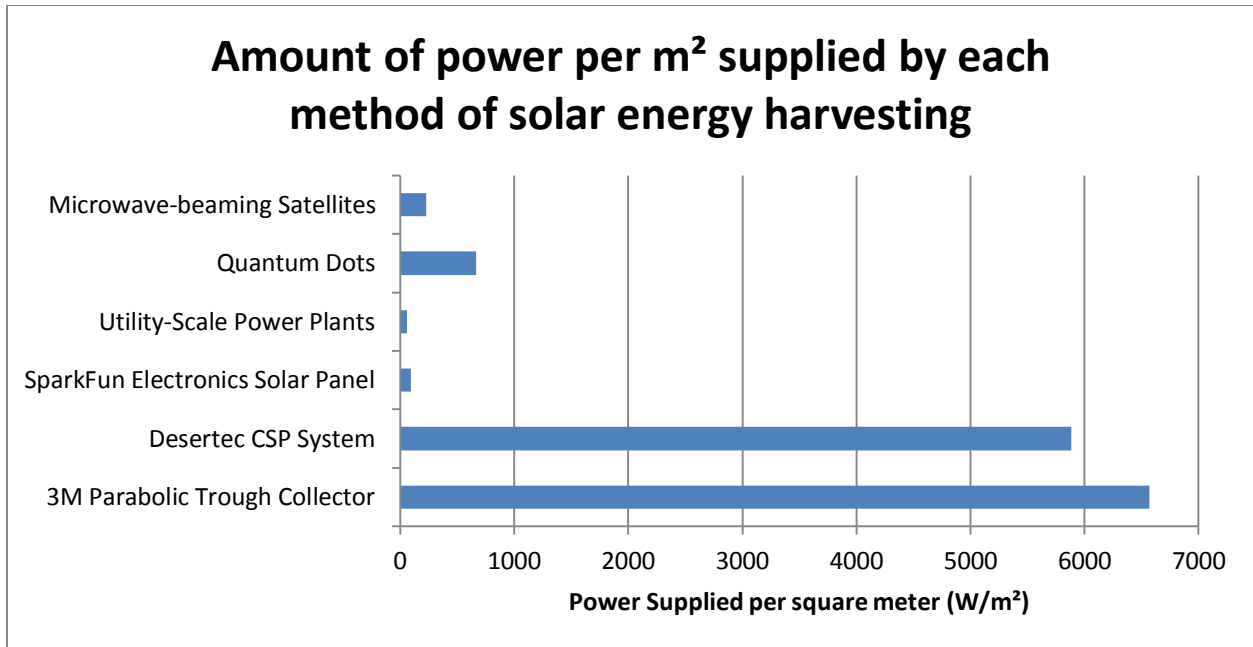
Figure 61: Amount of power square meter supplies by each method of solar energy harvesting

There are many notes to make about these figures. Figure 60 is based on the fact that typical households use around 31 kW of power, which was derived from information from the U.S. Department of Energy. The number of households each system could supply was then calculated by the specifications given of the system. For utility-scale power plants, whose values range from anywhere between 20 to 60 MW, the best case scenario of 60 MW was considered. For quantum dots, which are expected to be seven times more efficient than a typical solar panel, an estimation of seven times that of the power of a commercial solar panel (the SparkFun Electronics solar panel in this case) was used. For microwave-beaming satellites, a specification listed that the system was capable of beaming 30 kW over 1 mile. Hence, this value was used to calculate the 1 household for which the system is capable of providing energy. The reason that Figure 60 was illustrated with a logarithmic scale was because there was such a large difference between the values. Illustrating the figure in such a fashion also shows that solar panels and quantum dots in their current state are incapable of supplying even a single household with power. Figure 61 assumes values of each harvesting method, assuming each had the same amount of surface area of which to collect solar energy. From these options, the 3M Parabolic Trough Collector and the Deserte CSP system clearly produce the most power per unit area, illustrating the fact that concentrated solar power systems are much more efficient than simple photovoltaic cells. A simple comparison between the Desertec CSP system and commercial solar panels by price per household was also done. The Desertec CSP system is projected to cost 400 billion euros, or approximately $516 billion USD, whereas a SparkFun Electronics solar panel costs $60 for a 14.125" by 11.5" solar panel. If we were to use compare

the two assuming the same amount of unit surface area, the Desertec CSP system would cost $161,000 per household, and the solar panel would cost $186,000 per household. Again, a CSP system seems to be the more efficient choice.

With this conclusion, a proposal has been made, using a combination of both solar and wind power. If we were to use solar panels as the blades of a wind turbine, we could use the wind to dissipate the excess heat produced by the solar panel. In order to ensure that the optimal amount of solar energy reaches the solar panel, a series of mirrors could be ordered in such a fashion that directs the photons towards the surface of the solar panel, much similar to the CSP satellite system proposed by scientists at NASA, but without the problem of transporting parts to space and space maintenance. This idea would combine the efficiencies of solar and wind power, which would improve upon the major inefficiencies of solar power.

Choosing the Reflective Surface

Essentially, there are three main components to our design: the wind turbine, the solar panels along the cylindrical column of the turbine, and the reflective surfaces on the ground that will be used to concentrate light to the solar panels.

In order to determine the best type of reflective material to use, many options were considered. These options are: 1) the 3M Solar Mirror Film 1100, 2) thick glass mirrors, 3) thin glass mirrors, and even 4) concrete. The criteria used to determine the best reflective material to use for our application were costs (mainly production and transportation costs), durability and maintenance, albedo and reflectivity (specular reflection focusing light rather than diffuse reflection that disperses light is generally preferred), and environmental and aesthetic effects.

Typically in CSP systems, mirrors are used to reflect light to the solar panels. Thick glass mirrors have a 93.3% initial reflectance, costing anywhere between $43.20-$64.80 per m², and last anywhere from 10 to 30 years in severe outdoor environments. However, they contain 1% lead, break easily, and are relatively heavy. Thin glass mirrors have 93-96% reflectance, and cost $16.10-$43.00 per m², are relatively light weight, and are (Science Daily, 2011)copper and lead free. They too, however, break relatively easily, which could cause environmental and durability/maintenance concerns.

Concrete was considered simply for the fact that it could be that the costs for a reflective surface would be too high to implement effectively. Costing $75 per cubic yard, weathered concrete has an albedo of 0.4-0.6 and new concrete has an albedo of 0.7-0.8. According to an article by pavement.com, Increasing albedo of 1250 km of pavement by 0.25 would save $15 million per year in cooling costs, and $76 million in smog-related medical and lost-work expenses. When tested in 90°F weather, dark asphalt

had a temperature of 195°F, whereas lighter colored concrete had a termpature of 155°F, showing that lighter colored asphalt would be more ideal for our application and for the environment, lowering potential risks for overheating as well as limiting effects of rising temperatures on the Earth's surface. Lighter colored asphalt also increases safety on hightways and roadways by increasing illumination during the night. Unfortunately, due to the rough surface of concrete, its type of reflection is diffuse reflection.

The 3M Solar Mirror Film is the most appealing choice for a reflective surface for our prototype. It has a 94% reflectance with specular reflection. Still being tested, results have shown that it has had less than a 3% decline in performance since 1995. It is lead free, light weight, and flexible. For a 95 m by 1.25 m section of this film, the cost from a distributor would be approximately $3746. In a brief interview with buildaroo.com, 3M also indicated that the film would result in a cost reduction of 20-30%, as well as producing less waste, since the film does not need to be replaced, but can be renewed by placing another film over the preexisting film. However, one possible impairment to the surface would possibly be the collection of dust on the surface, which will be considered during the testing of our prototype. The following value analysis between all of these reflective materials will make it clearer as to why we selected the film.

	3M Solar Mirror Film 1100	Thick Glass Mirrors	Thin Glass Mirrors	Concrete
Cost	3	4	1	2
Durability/Maintenance	4	1.5	1.5	3
Albedo/Reflectivity	3	3	3	2
Environmental/Aesthetic Effects	3	2	1	4
Total	**13**	**10.5**	**6.5**	**11**

Table 11: Value Analysis of various reflective surfaces

The values presented for each category are essentially rankings for each product against each other, with 4 being the best and 1 being the worst. If two products have similar characteristics in one category (i.e. same reflectance), the average of the two ranks they would receive (if one were better than the other) would be taken, and both would receive that score. There is also some bias to this analysis, as some of the scores were based on information listed above, and could potentially be omitting other key aspects that were not considered.

The Design of the Reflective Surface

In designing the reflective surface, many assumptions have been made. First, we are considering a standard wind turbine, whose cylinder has a height of 80 meters, 35 of which are unobstructed by the blades, and a diameter of 15 meters. We are considering a location that is relatively flat (definitely not hills), so it is likely that current locations of wind turbines are ideal.

First, we considered the case of a flat, rectangular surface area for the reflective surface. 5 m of distance from the wind turbine to the reflective surface was arbitrarily determined to give room for any potential interference from the blades of the turbine. Assuming an angle of 45 degrees as optimal (which we would like to test this empirically with our prototype), the dimensions of the reflective surface can easily be determined by simple trigonometry and geometry. The width of the surface is simply the diameter of the wind turbine, which is 15 m. The length of the surface is simply the unobstructed section of the turbine over √2, which is approximately 24.7 m. Hence, the surface area for this rectangular surface is simply:

[33] $$Area = 24.7 \, m \, x \, 15 \, m = 370.5 \, m^2$$
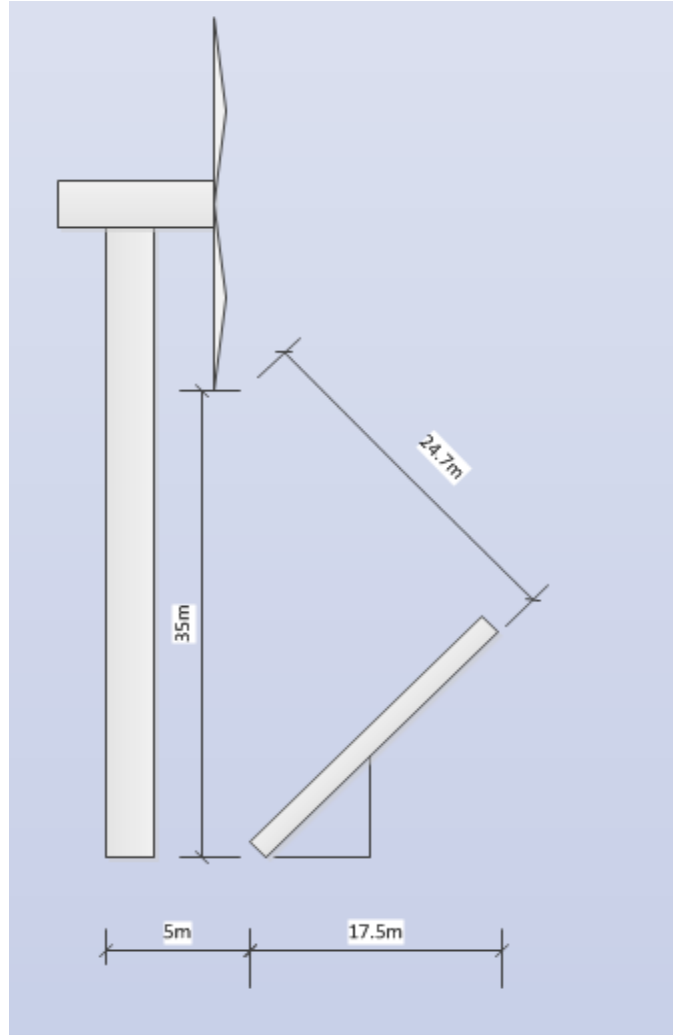
Figure 62: Schematic for Solar-Wind Turbine with rectangular reflective surfaces

We would like to cover all sides of this turbine, so presumably we would multiply this area by 4, resulting in a total surface area of 1482 m². Assuming the distributor price listed before, this would total about $46.7 thousand just for the reflective surfaces. In the visible spectrum of wavelength around 580 nm, the energy a photon can produce can be described by the equation

[34] $$E = \frac{hc}{\lambda}$$

where E is the energy each photon produces, h is Planck's constant (6.63 x 10^{-34} J•s), c is the speed of light (3 x 10^8 m/s), and λ is the wavelength (580 nm). Substituting in these numbers, the energy per photon is 3.43 x 10^{-19} J. Assuming that the number of photons that strike one square meter per second is 1.26 x 10^{22}, then 1.755 x 10^{25} photons would strike the surfaces of our proposed design every second. This equates to an output peak power of 6.02 MW. However, the amount that would actually hit the surface of

the solar panel is 94% of this output peak (since the reflectance of the material is 94%), resulting in an output peak of 5.66 MW.
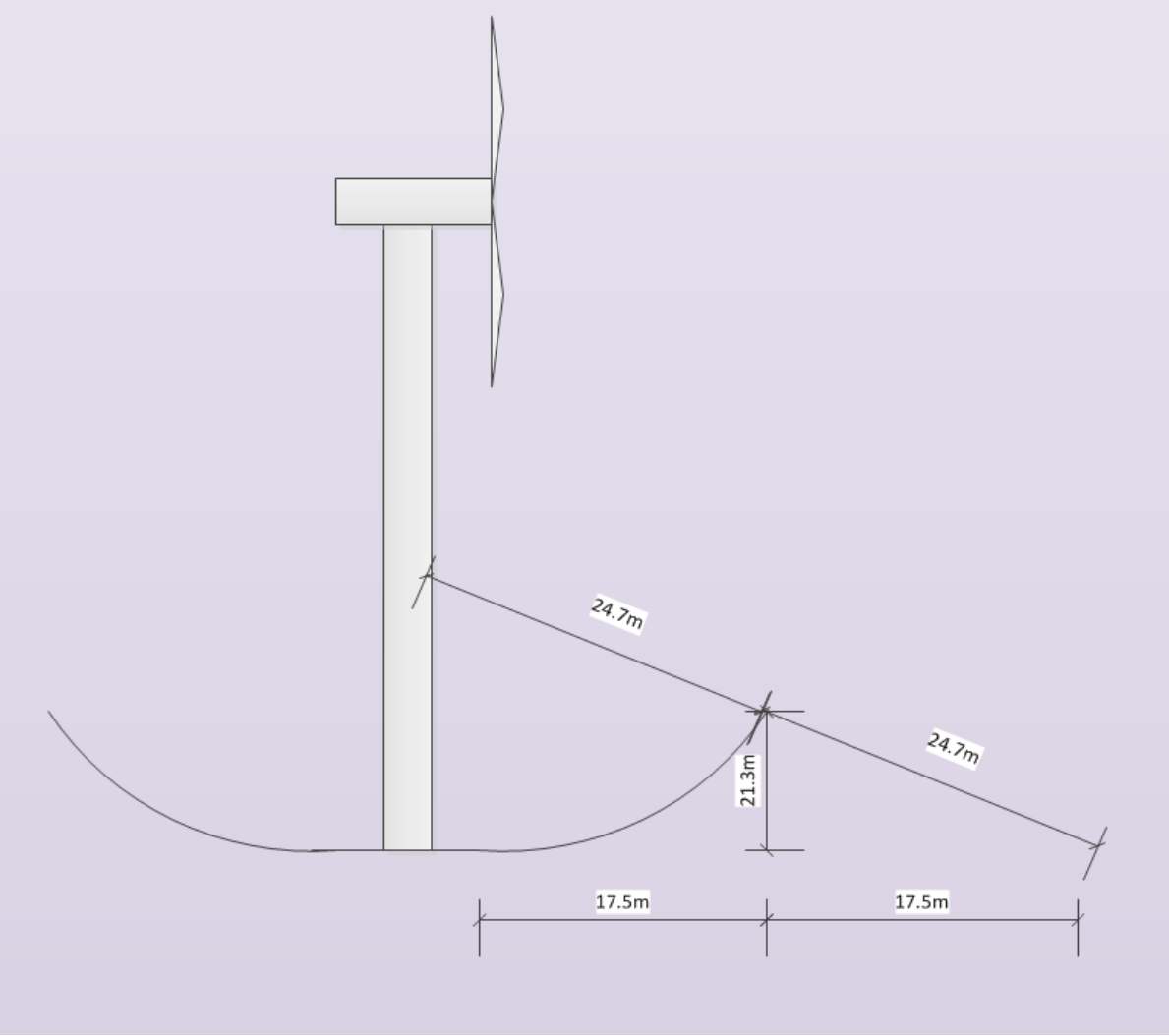
Figure 63: Schematic for Solar-Wind turbine with parabolic reflective surfaces

Figure 64: Conceptual Design of our Proposed Prototype

The case of a parabolic reflector is more mathematically involved. As this is not a typical math problem, many assumptions needed to be made. As one can see from Figure 63, some of the dimensions were assumed to be similar to that of the rectangular case. The x-axis displacement from one edge of the reflector to the other is 17.3 m, and the 45° angle distance from the turbine to the tip of the reflector is 24.7 m. Thus, using the Pythagorean Theorem, the height of the reflector would be 21.3 m. Using these numbers and assuming a simple parabolic shape, an equation for the parabola was found to be

[35] $$y = 0.06955x^2$$

To account for all sides of the system, the parabola would need to be revolved about the y-axis. To find this area, we would need to evaluate the integral for a surface of revolution:

[36] $$S_y = 2\pi \int_c^d g(y)\sqrt{1 + [g'(y)]^2}dy$$

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where S_y is the total surface area, c and d are the y limits of the integral (which in this case would be from c = 0 to d = 21.3), g(y) is the equation of our parabola solved in terms of x, and g'(y) is the derivative of this equation. Thus,

$$[37] \qquad S_y = 2\pi \int_0^{21.3} \frac{y^{\frac{1}{2}}}{\sqrt{0.06955}} \sqrt{1 + \left[\frac{y^{-\frac{1}{2}}}{2*\sqrt{0.06955}}\right]^2} \, dy = 1864.65 \; m^2$$

The resulting cost for this system would be \$58.8 thousand. 2.35 x 10^{25} photons would strike this surface per second, resulting in an output peak power of 8.06 MW. With a 94% reflectance, the output peak power hitting the solar panels would be 7.57 MW.

	Households Powered	Power per m² (W)	Size	Peak Output Power (W)	Cost (USD)
3M Parabolic Trough Collector	9	6571.09	Aperature size of 7.3 m	275 kW	N/A
Desertec CSP System	3.20E+06	5882.35	17 km²	100 GW	$516 billion
SparkFun Electronics Solar Panel	3.20E-04	95.42	0.105 m²	10 W	$60
Utility-Scale Power Plants	1935	60	1 km²	20-60 MW	N/A
Quantum Dots	0.002262443	667.94	N/A	70 W	N/A
Microwave-beaming Satellites	1	230	23 mW/cm²	30 kW/mi.	N/A

Table 12: Data various for various forms of solar energy harvesting
http://solutions.3m.com/wps/portal/3M/en_US/Renewable/Energy/Product/Films/Solar_Mirror/

(Collection of different sources)

Chapter 12: Social Impacts of Energy

Indirect Costs of Fossil Fuels

In 1994 the Clean Air Act began including mercury on its list of air pollutants, but at this time a major source of airborne mercury, coal, was left unregulated. It wasn't until 2000 that the EPA declared mercury produced by power plants a risk to public health. Under existing air-toxin regulation the power plants would have been forced to install maximum achievable control technology, which would have reduced emissions by as much as 90%, however the EPA chose to regulate mercury through a cap and trade market mechanism, which allows the buying and selling of pollution rights which aims to reduce mercury release by 70% by 2018, however Congressional Research Service predicts that this will likely actually take until 2030. A major downside to such cap and trade systems is it can extend the use of pollutants years into the future when sterner regulation could force companies to almost entirely eliminate such toxins. In addition cap and trade can create pollution "hot spots" where a poor community is forced to deal with all the toxins because a nearby facility finds it cheaper to buy their credits from a faraway place than reduce their own emissions. According to the EPA, benefits from reducing mercury emissions from power plants may be as little as $50 million a year, while the cost to the industry would be $750 million. An independent study published in the U.S. National Library of medicine estimates that proper mercury control could save $5 billion just through neurological damage caused to citizens. Part of the discrepancy between these two numbers is caused by how the EPA calculates whether that mercury is found in our population or if it comes from abroad. According to the EPA 75% of the mercury found in U.S. waterways is created abroad and as much as 70% of our mercury emissions fell on other countries or the ocean. An interesting example is that the Mount Storm power plant in West Virginia, second in the nation in mercury emissions upon its completion, was able to be fitted with scrubbers in its smokestacks and this removed much of its pollutants. These scrubbers removed sulfur, nitrogen oxides and even 95% of the mercury it was outputting at no extra operating cost.

Mercury is just one of many different pollutants generated by traditional power that ends up impacting the environment and populations unlucky enough to reside in their fallout. Another emission that causes many issues is the sulfur oxides. Predominantly this is sulfur dioxide which comes from the combustion of coal and oil as well as the purification process necessary to remove sulfur from natural gas to make it useable. Of these causes, though, coal burning is the primary contributor. Sulfur dioxide is a colorless corrosive gas that can damage both plants as well as animals. Once in the atmosphere it can also be further oxidized to sulfur trioxide which can then react with water vapor to form sulfuric acid and then it falls as acid rain. Extremely small particulates and liquid droplets can also carry the acidic sulfate ion (SO_4^{-2}) long distances in the air or deep into a person's lungs where it can be damaging- potentially causing breathing problems such as asthma over time. The acid rain itself can cost us dearly as well, as it

corrodes some materials such as marble, limestone, and bronze which are often used to create buildings and national monuments. On top of this, acid rain over time damages crops, utilities, forests and generally upsets the balance of the ecosystem itself. Because of all these factors it is nearly impossible to estimate how much damage is done in dollars by sulfurs being released into our atmosphere.

Another major health hazard generated by burning fossil fuels is the carbon oxides. Many people have heard of carbon dioxide and how it increases the greenhouse effect and generally disrupts the global climate, but there is also carbon monoxide. This pollutant is generated when you fail to burn a fuel at 100% efficiency, and is toxic to animals. Currently humans generate approximately half a billion metric tons of CO and in the U.S. 2/3 of that is from internal combustion engines. This means that CO is concentrated in heavily populated areas where the adverse effects will have the greatest impact.

Another fuel for internal combustion engines, diesel, is a large producer of many toxic pollutants. Diesel releases both particulates as well as chemicals such as benzene, dioxins, and mercury. Currently, the EPA has proposed new rules forcing the use of low-sulfur fuel and antipollution devices especially for equipment such as bulldozers, tractors, pumps, and generators. It is estimated that these new standards could prevent over 360,000 asthma attacks and 8,300 premature deaths annually. There has been a push by the industry claiming that these standards are too stringent and will cost excessive amounts, but Europe has had standards many times higher than the EPA's suggested ones for years.

There have been many disasters that have occurred from coal power plants emitting these gases. On average, for each Terawatt-hour of electricity produced from burning coal, 24.5 deaths, 225 illnesses and 13,288 minor illnesses are linked to the greenhouse gas emissions. There have been many occurrences where the greenhouse gases have affected human health. In October 1948 in the town of Donora, Pennsylvania, 20 deaths and 400 hospital admissions along with half of the 14,000 residents became sick due to atmospheric conditions trapping the greenhouses gases from a nearby power plant. Also during 1952 in London, the "killer fog" lasted for four days and almost 12,000 deaths were a result from burning coal. The overall hospital admissions rose by 43% and cases due to respiratory diseases rose by 163%. While these were severe occurrences that happened to cause major life loss and health problems, In Dublin, Ireland on September 1, 1990, the use of bituminous coal was banned and was replaced with oil. After a year from the switch, black smoke decreased by 70%. Respiratory deaths fell by 15.5% while cardiovascular deaths dropped by 10.3%. It was calculated that 450 lives were saved and hundreds of illnesses were prevented from the switch. Another study was conducted comparing areas with high greenhouse emission to areas with low emissions. In the study it was found that the high emission area had higher rates of cardiopulmonary disease, chronic obstructive pulmonary disease, hypertension, lung disease, and kidney disease.

In most of these cases, there was a choice between coal and oil. Most of the choices were price related, and did not take into consideration any health hazards. Per kilowatt-hour of energy produced, the price for coal is currently 4 cents while oil costs 10 cents. As of now, the difference of 6 cents per kwh is not that pricey. If the byproducts of coal are harmful to the community's health, paying twice as much for oil would be beneficial if lives are saved.. Another factor to look at is convenience of the fuels. Coal may be a better option for some people, but because it is not abundant in the area, the cost for transporting may cause the price to exceed the price for oil. In any case, the cheaper fuel and the less harmful one to the environment should be the one chosen to produce energy.

Political Impacts

According to a study conducted by Ruhr University, Germany totaled $130 billion in subsidies for solar energy investments; this puts Germany as one of the leading nations in solar energy investments. However, Germany plans to phase out this support within five years.
In 2011, 7.5 GW of photovoltaic capacity was installed in the nation, equivalent to 0.3% of Germany's total energy. The cost of these systems increased the average consumer's annual bill by $260. In addition, the 1.1 million solar power systems are almost useless when there is no sunlight, a fairly common scenario for Germany. Germany has the 2nd highest price in the world for electricity (with Denmark being #1), 3 times more than that of the U.S.

Implementation of solar energy does reduce carbon dioxide emissions by Germany. The expectation is that 8 million metric tons of carbon dioxide will be reduced in the next 20 years, and will cost about $1,000 per ton. However, Germany is part of the European Union Emissions Trading System, which puts a cap on the amount of emissions the entire union can produce, rather than the amount of emissions each nation can produce. Therefore, if Germany reduces emissions, other countries within the union can increase emissions. That means that by increasing costs on electricity by implementing solar power, Germany is allowing other countries to produce more emissions, allowing other countries to continue using nonrenewable sources of energy at a lower cost.

The following is data on the major oil consuming/producing nations in the world:

Rank	Country	Barrels/Day
1	Russia	10,210,000
2	Saudi Arabia	10,000,000
3	United States	9,023,000
4	Iran	4,231,000
5	China	4,073,000

Table 13: Estimates of Top 5 Nations of Crude Oil Production by Country

Rank	Country	Barrels/Day
1	United States	19,150,000
2	China	13,680,000
3	Japan	9,400,000
4	India	4,452,000
5	Saudi Arabia	3,182,000

Table 14: Estimates of Top 5 Nations of Crude Oil Consumption by Country

Rank	Country	Barrels/Day
1	United States	10,270,000
2	China	5,080,000
3	Japan	4,394,000
4	India	3,060,000
5	Germany	2,671,000

Table 15: Estimates of Top 5 Nations of Oil Imports by Country

Rank	Country	Barrels/Day
1	Saudi Arabia	7,635,000
2	Russia	5,010,000
3	Iran	2,523,000
4	United Arab Emirates	2,395,000
5	Norway	2,184,000

Table 16: Estimates of Top 5 Nations of Oil Exports by Country

From this data, it is clear that Saudi Arabia and Russia are some of the world's main contenders in the oil industry. However, if the world were to shift from oil to solar energy, there would be a shift of power on the main energy producing nations.
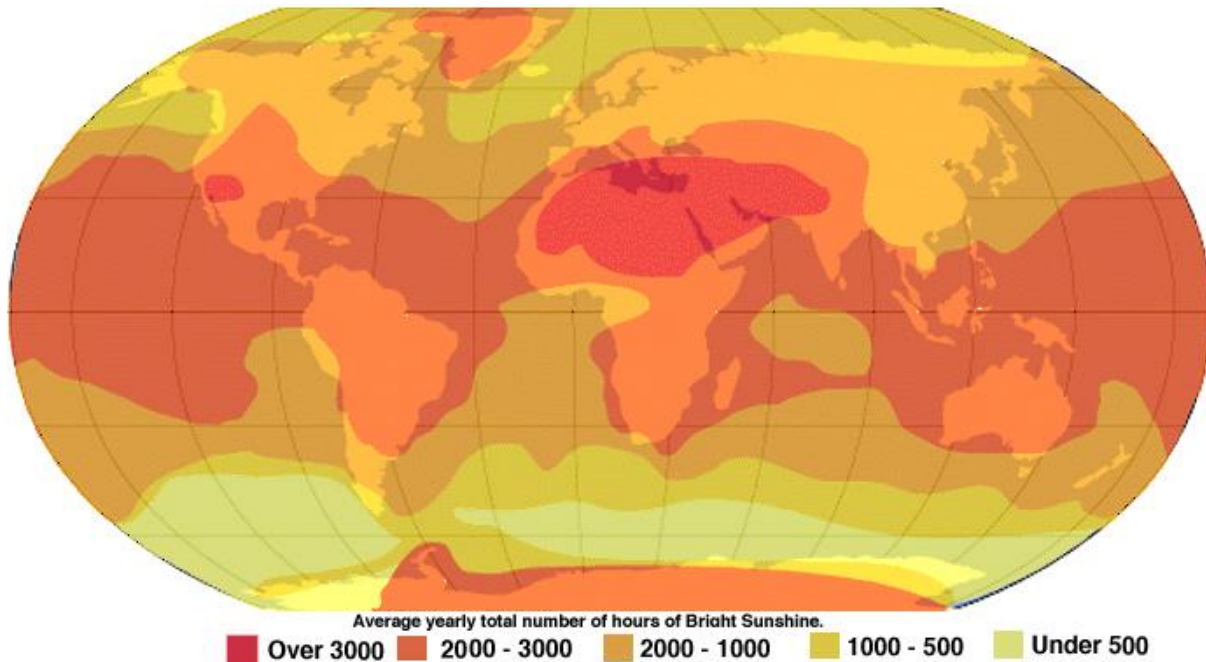
Average yearly total number of hours of Bright Sunshine.

| Over 3000 | 2000 - 3000 | 2000 - 1000 | 1000 - 500 | Under 500 |

Figure 65: Map illustrating yearly total number of hours of Bright Sunshine

From this map, it is expected that the leading energy producing nations will shift to 1) Libya and Egypt, each averaging over 3,000 hours of sunshine per year, 2) Saudi Arabia, averaging 2,000-3,000 hours of sunshine per year, and 3) Mexico and Southwestern United States (mainly Arizona), also averaging 2,000-3,000 hours of sunshine per year, but having less land area than Saudi Arabia, assuming that these nations can implement a means of solar energy harvesting.

Social Impacts

While there are many ways to harvest energy, the cheapest and most efficient energy sources are fossil fuels. Because of this, the majority of energy that is consumed by the United States and other countries around the world come from fuels such as coal, natural gas and oil. As society continues to rely on these the demand for energy will far outstrip its supply which will inevitably result in higher prices. As prices increase, it is likely that the majority of people will not be able to afford this and thus maintain their consumptions. One area this may affect is gasoline. If gasoline prices continue to increase in, it will become too costly for society to travel long distances. If this is the case, people may choose to relocate closer to their jobs to cut down on travel. If traveling to a designated work place becomes costly for many, there may be a change in how corporate America operates.

With advancements in information technology, most office jobs can be done within one's home. With traveling becoming more expensive, the majority of the work force will demand to work from home. If this indeed happens, it will alter how major corporations operate. The need for large office buildings will cease to exist because those who occupied them are now going about their business from the comfort

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of their home. It is also possible for work groups to meet through advancements in communication technologies such as Skype and Google+. Instead of having all participating party members meet in one room to discuss their work, the use of computers and cellular devices can be used to accomplish the task while everyone is located in different locations. For this to work, a high data rate must be present to stream video and audio to all participating members. Without a good connection, the video may become unclear or choppy and something may be missed.

If more and more people decide to work at home, there will be a demand for better internet connections. This will cause the cable and telecommunication companies to spend money on research and development to perfect a system where multiple users can transmit and download large amounts of information for a long period of time. These companies will also have to look into ways of accommodating the large amount of people who will access the network at any given time. While it may not be noticeable right now, if too many people decide to access the internet or cellular towers at the same time, some attempts will be dropped because the current technology has a limit as to how much it can support . If the users are constantly hogging the line, other users cannot access a line until a one becomes empty.

The Telecommunication and Cable industry will not be the only ones affected by this. The automotive company will also need to adjust. Within the past years, the automotive industry has been researching and developing alternative vehicles that run on different energy sources such as electric vehicles. If gasoline becomes too expensive to be the main energy source, the automotive industry must look into different power sources such as electricity or maybe even hydrogen to power these vehicles. If more people decide to work from home, each household may choose to have fewer cars. As of 2009, the average number of cars per household is 1.94. If a couple with jobs in different locations decides to work from home, they may likely not need two vehicles. With fewer vehicles per household, automotive sales may take a hit. Since sales are likely to go down, the price of vehicles will have to change to reflect this and stay competitive in a market where they are less critical to one's life.

In recent green energy trends, money is being spent to make almost everything energy efficient. There are more energy efficient homes, cars, computers, and other electronic device than ever before.. You might increase efficiency by increasing the number of miles per gallon a car can get or even by placing insulation in a home to keep heat from escaping. As an energy shortage looms we will, as a society, make adjustments to prevent wasting as much of it.

Since nothing is infinite, energy sources on this planet will disappear eventually even if it may take hundreds to thousands years before that occurs. As a wasteful society, we do not think about leaving lights on or other wasteful habits that use energy. Saving a little bit at a time may not seem like that much, but if it is done for a long period of time, it adds up. One of the big things we can do as a society is limit

our energy consumption. However, while it is possible for a few to consume less, it will take a lot of effort to get the entire world to follow and think more about how much energy is being wasted and how we can help to alleviate that waste.

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