March 2012

The Future of Energy IQP

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Date Submitted: March 6, 2012

Abstract

An extraordinary challenge facing modern society is the implementation of energy production infrastructure that can satisfy total demand while minimizing pecuniary cost and pollutant byproducts. Researchers are developing parallel solutions to this quandary; investigating methods of pollutant capture and reduction while simultaneously developing passive methods of harvesting energy from natural phenomena. A plethora of alternative energy sources must be utilized in conjunction with improvements in device and lifestyle efficiency in order to extend the lifetime of fossil fuels.

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Executive Summary

Modern society would not be possible without electric and mobile power. Millions of people residing in developed nations depend on affordable convenient energy. A large proportion of the population will never even consider the methods by which electricity is generated and delivered across the grid. Combustion of carbon based fossil fuel has long been utilized because of its abundance, simplicity and low overall cost. The negative aspects of fossil fuel combustion have recently started to become exaggerated because of the global scale at which they are now used. We rely too heavily on fossil fuels to stop using them outright. There are instead two courses of action that are being considered. Researchers are investigating methods by which to combust fossil fuel with fewer pollutant byproducts while simultaneously developing supplementary, passive methods of "green" energy capture. Both solution types must be examined thoroughly in order to determine the efficiency and economic feasibility of specific scenarios and technologies.

The major challenge for twenty-first century society is and will continue to be the implementation of a global energy production infrastructure that can satisfy total demand, minimize cost, produce as little pollution as possible and extend the lifetime of fossil fuels. Current energy consumption data, including the proportion of fossil fuel combustion to renewable energy use, was collected and evaluated. Recent growth and decline of specific energy sources was recorded and compared to scientific studies concerning the safety and efficiency of said methods. Corporate purchases and sales, as well as legislative hearings and grants regarding energy production and use were examined. Information was gathered regarding the advantages, disadvantages and economic feasibility of the major commercial energy production methods, as well as several promising futuristic possibilities. The culmination of this research is presented as a prediction of the roles each energy type will play in generating future power as well as their overall effect on society.

Research yielded many promising sources of sustainable, renewable energy. Many renewable energy sources are already being utilized commercially. There appears to be large amounts of energy that can be extracted from solar, wind and geothermal energy among others. All of these sources are currently being utilized to some extent and because they are renewable, they should be available for continuous future use. Certain energy sources such as nuclear fusion reactors and giant orbiting banks of solar panels are still too expensive or not sufficiently engineered to be realistically considered as a

short term replacement for fossil fuels. The primary factor driving the development of any particular renewable energy source is their cost. Many suffer from high initial infrastructure cost and will take significantly longer to be implemented at commercial scale because of the financial resources required for startup. However without investment into renewable energy sources we are destined to deplete our main source of energy very quickly and be plunged into darkness, unable to afford to power our lives. As hidden costs related to fossil fuel combustion make renewable sources more economically feasible, more research is being funded and more solutions discovered.

Introduction

Storable energy is a commodity that has penetrated every aspect of modern society. The topic of this project is one that cannot be ignored for if it is there will be severe repercussions. Environmental, social and technological barriers must be overcome in the pursuit of a future where power demand is delivered by sustainable energy sources. Energy is a necessity for all aspects of life, and thus limits the development of technology and society. Electricity and other independent means of energy capture such as the internal combustion engines provide convenience, comfort and mobility as well as a means for technological and social progress. Without sustainable production of transmittable and storable energy, all aspects of modern civilization would be devastated. Mankind would regress to a figurative dark age where development and progress cease and electronic technology has no use. However this is an issue that we have the technology and means to correct, but certain steps must be taken to ensure our energy demands are met in an environmentally friendly and efficient manner.

Finding means to generate non-polluting, efficient, sustainable energy is currently and will continue to be a predominant issue facing humanity. The largest currently used energy sources contribute to the destruction of nature, the propagation of certain cardiac and pulmonary disease, as well as causes intercontinental dependence, which has lead to social and political tension. Researching and fully utilizing passive means of energy capture will alleviate these destructive aspects and benefit mankind overall. Humanity at 2100 pertains to a combination of fields. Energy generation is achieved through heat transfer or capture of kinetic energy. Mechanical, Electrical and Civil engineers design the structures and machines that generate and store power. Economics and statistics are necessary to understand the trends in energy as well as the motives causing those trends. The Physics and Mathematics that comprises the theory of energy production will aid in understanding options and constraints. The viability of various energy sources will be deduced by examining current energy trends and concerns.

This project fulfills the IQP goals because it specifically addresses “a problem that lies at the intersection of science or technology with social issues and human needs”. This project, as a bridge between science and humanity gives an opportunity to apply the technical knowledge learned at WPI to solve practical problems. Humanity is driven forward by the advancement of technology. Supplying this power is more vital than any problem facing current and future engineers. Humanity at 2100 has the potential to contribute to the advancement of energy production and conservation. By investigating the constraints and disadvantages of all energy production methods we can provide valuable insights to improve the feasibility of alternative technologies. The project will provide better understanding of the effects of producing energy using various energy sources on humanity. It will also address what can be done to reduce the negative impacts of energy generation and capture. Researching the hidden costs of energy sources that are regarded as "cheap" may provide enough insight to alter humanity's perception of energy. A specific application to mechanical engineering is finding ways to improve the efficiency of our current power sources as well as develop new ideas to make renewable energies more plausible and how to smoothly integrate them into society.

Not only will this project help in our knowledge of current and future energies, but it will give us insight into where energy fields are headed giving us an advantage should we pursue a career in the energy field. It has also helped us build our problem solving skills, which is an essential attribute in any branch of engineering. On top of problem solving we have been able to hone our communication skills and be able to present our ideas in a clear and coherent manner. We have also been able to practice our teamwork skills, which is especially useful because in the job field it is critical to be able to work cooperatively with any group of people and do so in a professional manner. This project has also taught us to look deeper into a problem and address not just the apparent issues, but also ones that might be more difficult to recognize. Through our research we have also noticed how politics and economics are integral in engineering decisions by noticing where the money/support for a project comes from. Especially in today's world every project or idea for a project has to take in to consideration government policies and how they will affect any project.

New technologies are being developed to reduce the disadvantageous effects of energy production and provide better means to capture and store energy passively. This is a crucial project because of how quickly we are depleting the world oil supply and severe energy shortages could have many adverse effects. If we were to run out of fossil fuels it could lead to extreme economic strain while an alternative was developed to replace our dependence on these fuels. It could also cause our structured society to collapse in a fight for the remaining fuel. A shortage would cause almost all of our current technologies to become useless piles of steal and possibly lead to a new "dark age" for our oil hungry society. There are already signs of energy shortages across the world and even here in the United Sates. A scary scenario, but nevertheless one that must be resolved before it's too late.

Recent advancements of technology have allowed for greater conservation of energy due to improved efficiency, but we also have to decrease our dependency on fossil fuels and continue to move towards more renewable energies. Legislative bodies are beginning to recognize the concerns against certain means of energy generation. It is an international topic that is starting to be more recognized by countries across the world as a problem that needs immediate action and must be something all countries work together on. Many countries have joined the OECD, taking the first step, but there are many others that have yet to recognize how important this topic is. New laws and policies are being adopted to regulate and inhibit the production of energy by means that contribute to CO_2 emissions. Energy issues during the 21st century are meaningful and should be carefully studied.

The dissertation of our project would be most effective in two parts. A PowerPoint presentation containing an overview of the project and alarming statistics will be compiled and applicable mathematical models created. The second aspect of our dissemination is for the conscientious reader. Each of the group's short essays will be assembled and presented in either journal or website format. The website would be an online version of the journal and display our data in a clear and modern fashion. The website would contain pages with short essays for each energy topic as well as supplementary pages display their future impacts and how they will affect our society. It will also be important to incorporate a graphical representation of predominant energy types based on regions and where they are headed. A main focus will be on the idealized mix of both fossil fuels and renewable energies and what the true costs of their energy sources truly are. These articles will provide detailed information on current and experimental energy generation methods. The essays will explore the advantages and disadvantages of each technology as well as comment on which methods are gaining and losing popularity. The short essay format allows a reader that is particularly interested in certain portions of the PowerPoint to easily locate more detailed information on the specific topic.

Fossil Fuels

Fossil fuels are stores of carbon, the remains of ancient organic material. They manifest in petroleum, coal and natural gas. Mankind has relied on the combustion of fossil fuels for electricity and mobile power since the dawn of both technologies. Fossil fuels have and are continuing to power the industrialization, social and technological advancement of society. Modern Civilization is heavily dependent on fossil fuels. Their combustion provides 80% of the United State's electricity. The automobile is a commodity in developed nations and will soon be worldwide. Petroleum demand has an enormous impact on international relations and policy. The combustion of fossil fuels produces greenhouse gas and in some cases toxins and particulate matter. Some fossil fuels, combusting more cleanly than others, are exploding in popularity due to the decreased negative environmental effects they offer. As more efficient, passive energy technologies are developed the new, cleaner fossil fuels such as natural gas will serve as "transition fuels" and offer a cost viable alternative to coal based electricity.

The Future of Coal: Gasification and Carbon Capture

"Coal gasification to form a methane rich gas is carried out by injecting a lower aliphatic alcohol such as methanol into a coal seam, raising the temperature to cause disassociation of the alcohol and injecting water into the seam. Nascent hydrogen is produced which reacts with the coal to form methane. The product gas may also contain hydrogen and carbon monoxide which can be separated and reacted to form methanol." (Anada, 1978)

"Coal gasification allows for more efficient, cost-effective capture of CO2 from coal, which, if the CO2 is then permanently disposed of, can provide a lower carbon energy source than conventional coal use." (Antonio Herzog, James Bartis, 2007) "Without geologic storage of the CO2 produced in the conversion process, the greenhouse gas emissions from coal-based fuel would be about twice that of oil." (McKenna, 2009) CO2 emissions aren't the only environmental concern associated with mining and combusting coal. "From underground mining accidents and mountaintop-removal mining to air emissions of acidic and toxic pollution, from coal combustion, to water pollution, from coal mining and combustion rates, the conventional coal fuel cycle is among the most environmentally destructive activities on Earth." However, in the interest of controlling the effects of global warming the advantage of coal gasification is the fact that it provides a means for "capturing 85 to 90 percent of the carbon" emitted during conventional coal combustion. The captured CO2 must then be "disposed permanently in geologic reservoirs." (Antonio Herzog, James Bartis, 2007) This disposal process is still a key argument for those opposed to coal gasification as its long term ecological effects are still being investigated. Industrial scale federally funded carbon capture projects are currently taking place at fossil fuel based power plants across the country. In 2009 the U.S. legislature allocated $1.4 billion to such large scale experiments. (U.S. Department of Energy, Carbon Capture and Storage from Industrial Sources, 2009) The technology required for coal gasification has existed since the 1980s but has only recently become commercially feasible. Capital costs for IGCC plants are estimated to be twenty to forty-seven percent higher than traditional coal plants, depending on the percentage of C02 emissions captured.

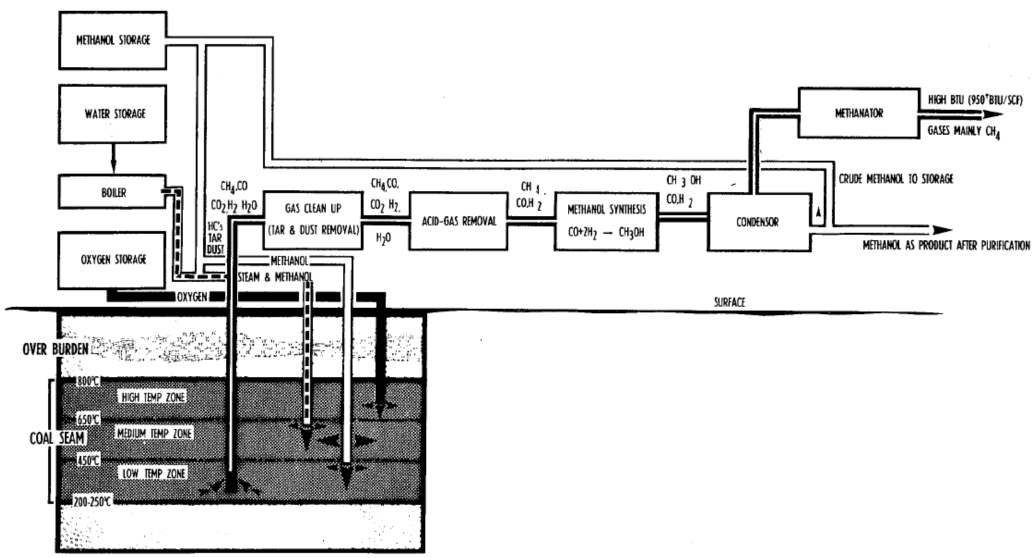


FIGURE 1 SCHEMATIC FLOW DIAGRAM FOR METHANOL-STEAM PROCESS

Figure 1: Schematic Flow Diagram for Methanol Steam Process (Anada, 1978)

"Clean coal" is also being hailed as a solution to United States foreign oil dependence. Although the majority oil imported by America comes from Canada, a serious amount of capitol streams into the Middle East from U.S. oil consumption. "OPEC revenues from oil exports are currently about $500 billion per year, and are heading higher. These high revenues raise serious national security concerns because some of the OPEC member states are governed by regimes that are not supportive of U.S.

foreign policy objectives. Oil revenues have been, and are being, used to purchase weapons." The majority of petroleum is used in "mobile power" situations. Coal derived liquids offer a potential petroleum replacement for use in heavy duty vehicles, trains, aircraft and military vehicles. The Fischer-Tropsch (F-T) process is a coal-to-liquid method that utilizes coal gasification initially. The gasified mixture consists mostly of carbon monoxide, hydrogen, and carbon dioxide. "This gas mixture is further processed to remove carbon dioxide, as well as trace contaminants, and the resulting mixture of clean hydrogen and carbon monoxide is sent to a chemical reactor where the gaseous mixture is catalytically converted to liquid products." After additional processing "a commercial F-T plant would produce a near-zero sulfur, high-performance diesel fuel for automotive applications and a near-zero sulfur jet fuel that can be used for commercial aviation applications or in military weapon systems." Unlike hydrogen fuel cells, whose implementation is hindered by cost and safety concerns, coal-to-liquids processes are "commercially ready and capable of displacing significant amounts of imported petroleum."

There are also disadvantages to this method of energy production. The coal-to-liquids cycle coupled with later combustion in a motor "roughly doubles greenhouse gas emissions" as compared to petroleum combustion. (Antonio Herzog, James Bartis, 2007) However, research indicates coal-to-liquids CO2 emissions can most likely be reduced to levels consistent with petroleum combustion in the next few years. The ultimate goal is clean affordable transportation. Coal-to-liquids processes don't contribute directly to this ideal, however they provide economic opportunity for the U.S. by relieving foreign oil demand. Their use limits potential capital flow to nations and organizations that do not support the United States. Once the technology behind the capture and geologic storage of greenhouse gas emissions from coal-to-liquid provides means for overall emissions consistent with petroleum combustion the fuel is a more intelligent alternative for U.S. mobile power users. At least this would surely be the case if the infrastructure currently existed to produce liquid coal on a commercial scale. The advocates of this technology are asking for billions of dollars from the U.S. economic stimulus program to advance coal gasification technology. (McKenna, 2009)

"Providing coal-based liquid fuel for transportation would require significant increases in coal mining activities. The U.S. transportation sector consumes fourteen million barrels of oil per day. If coal mining activities in the U.S. increase by fifty percent – an additional 580 million tons of coal mined each year – up to three million barrels of fuel per day could be produced. To achieve this, two or three new coal-to-fuel plants would need to be built each year over the next twenty years, the report says." (Alvania, 2009) In 2011 coal combustion accommodated over forty-six percent of the United States' electricity demand. (U.S. Energy Information Administration) Domestic reserves are projected to withstand another century of use, however utilizing the result of coal-to-liquid processes as a replacement for petroleum will result in even higher dependence on a resource that will inevitably run out. This petroleum replacement's use coupled with improved engine efficiency would provide necessary research time for cleaner, more sustainable mobile power sources to be developed. Ethanol produced from the biomass corn is an alternative short term domestically produced replacement for petroleum that emits less carbon dioxide, toxins and particulate matter than coal-to-liquids processes. Whether or not coal-to-liquids become commercially popular in the coming decades, the development of alternative means of power generation must remain paramount in order for a gradual and cost effective transition.

There are definite advantages associated with coal gasification in the areas of environmental protection, national security and economic stability. Serious capital is being invested in improving the efficiency and emissions of fossil fuel power plants. Such plants will be burdened with the majority of the world's power demand for the coming decades. Time and energy will be necessary to develop non-polluting, renewable energy technologies. Improvements in current technology illustrate that the environmental issues associated with fossil fuel combustion are being taken seriously and, in some areas at least, are recognized as a situation worthy of immediate action. Unfortunately conservation and pollution are not considered as important in other countries. Pollution is a global issue that must be recognized by all before quantitative progress will be realized.

Oil Sands: An Alternative Supply

Oil sands are mixtures of sediment and petroleum that occur naturally in various regions around the world. Some of the most notable deposits of oil sands are found as close to the U.S. as Alberta Canada and Venezuela, but they also occur in most other countries in much smaller quantities. Inside the United States the main concentration of oil sands are in and around Utah with an estimated 12-19 billion barrels of oil. In the Canadian and Venezuelan oil sands alone there is estimated to be more oil than in the rest of the entire world's reserves of conventional crude oil. Oil sands or tar sands, as they are commonly called, consist mainly of sand, water, clay, and bitumen.

Bitumen is “a black, oily, viscous material that is a naturally occurring organic byproduct of decomposed organic materials”. They have found traces of this material being used as early as the Neanderthals at sites where they believe it was used to fasten materials together and also used to coat boats from around 5000 B.C. Bitumen is similar to petroleum used to make gasoline and other fuels, only it needs to be separated from the other materials it is found in. The mixture of this material is usually between 1%-20% bitumen with most of the remaining material being clay. The bitumen itself is further comprised of carbon, hydrogen, sulfur, oxygen and nitrogen.

Table 1: Utah Tar Sands Estimated In-Place Resources

Deposit	**Known (MMB)**	**Additional Projected (MMB)**
Sunnyside	4,400	1,700
Tar Sand Triangle	2,500	420
PR Spring	2,140	2,230
Asphalt Ridge	830	310
Circle Cliffs	590	1,140
Other	1,410	1,530
Total:	11,870	7,330

Table 2: Breakdown of Bitumen

Carbon	83.2%
Hydrogen	10.4%
Oxygen	0.94%
Nitrogen	0.36%
Sulfur	4.8%

To mine bitumen, there are two general methods that depend on the depth of the material. If it is close enough to the surface it can simply be scooped off and processed, but deeper material must be extracted by wells similar to crude oil. Most of the valuable oil is located within 40-60 meters and a large portion can be mined by simply scooping it off the top. The material is scooped of the top and loaded into enormous trucks capable of carrying 320 tons of the material in one load reducing the amount of trips having to be made by previous and smaller vehicles.

There are other methods for mining solid bitumen from under the surface, often necessary in the cold Canadian climate. To extract the thicker material they use steam power to make the sludge less viscous, making it suitable to be pumped to the surface. One of the steam methods is to drill two wells that are horizontal to each other. In the top well, steam is pumped through and lowers the viscosity so oil seeps down to the lower well and is then extracted to the surface for refinement. There is also another method that utilizes steam, but requires only one well. This method cycles through pumping steam into the oil sands for a duration of time (several days to several weeks), then switching to extraction to recover the loosened bitumen. This process continues until the heat dissipates from below the surface and the bitumen re-solidifies underneath the ground. The bitumen material that is harvested from the ground is by nature usually 4% water and this is an extremely important fact in the refining process. This is important because if the water wasn't present in the bitumen the sand would be directly integrated into the oil, which would make the water based extraction method impossible. The bitumen is refined by adding hot water to the sand and the resulting slurry is piped to the extraction plant where it is agitated. The combination of hot water and agitation releases bitumen from the oil sand, and causes tiny air bubbles to attach to the bitumen droplets, that float to the top of the separation vessel, where the bitumen can be skimmed off. Further processing removes residual water and solids. The bitumen is then transported and eventually upgraded into synthetic crude oil. To produce a single barrel of useable oil takes about two tons of the tar sands. The oil sands in Canada differ from the oil sands in Utah because they are water wetted, while Utah's are hydrocarbon wetted and therefore the refining process will be different from the process in Canada. This is a relatively new process for the Shell Corporation and they estimate that with this process they prevent the release of over 40,000 tonnes of greenhouse gases every year.

Down in Venezuela where it is much warmer than in Canada, most of the oil can be pumped out because it is much more viscous and not frozen underground. The most common extraction method down there is to use progressive cavity pumps, which "consists of a helical rotor and a twin helix, twice the wavelength and double the diameter helical hole in a rubber stator. The rotor seals tightly against the rubber stator as it rotates, forming a set of fixed-size cavities in between. The cavities move when the rotor is rotated but their shape or volume does not change. The pumped material is moved inside the cavities."

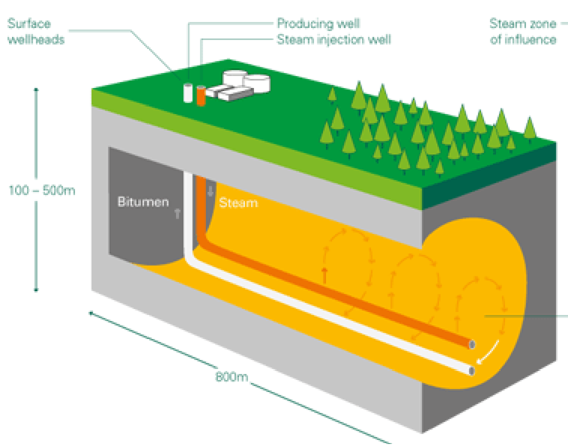


Figure 2 (Exxon Mobil, 2010)

In the Alberta oil sands alone this is an estimated 1.7-2.5 trillion barrels of oil that is either on the surface or located beneath the ground. From these oil sands there is an estimated 200,000 jobs that have been created as a result of this mining operation and billions in revenue. Canada is able to produce roughly one million barrels of synthetic oil a day from these sands and most of this oil is shipped directly to the United States. Currently this production is about 40% of Canada's production and projects for expansion are underway. In 2010 the United States imported roughly 12 million barrels per day and Canada alone supplied the U.S. with more oil per day than any other country even Saudi Arabia, Nigeria, and Libya all combined. While it may seem beneficial that we are getting a large portion of our oil from close sources and from a more stable region, there is much controversy over this expanding source of oil. A report from the EPA found that producing oil from these tar sands produces 80% more greenhouse gases than conventional oil refining. A report by Shell differs from the EPA, saying their bitumen recovery process is only 15% more carbon intensive than conventional crude oil refining (figure #5 is a chart from Shell company showing CO2 comparisons to various oil sources). Although this is a problem, if you compare oil sand usage compared to coal power plants, which generate 40 times more greenhouse gases than oil sands, it appears to be a more environmentally friendly fuel source. Concerns about the local environment and the impact of these strip-mining operations play a big role in the decision of where these oil sand mines are established.

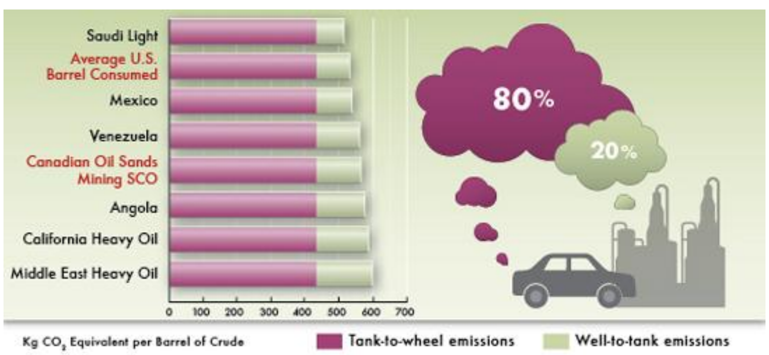


Figure 3: CO2 Comparisons (Exxon Mobil, 2010)

There is also much controversy over a proposal for a pipeline that would travel from Canada through six U.S. states because of fears that an oil spill would greatly impact thousands of resident's water supplies. This fear was heightened when last year over 800,000 gallons of oil almost spilled from an existing pipeline in Michigan. This occurrence is all too familiar with oil spills every year; many related to oil pipeline failures. President Obama has been pressured by environmentalist activist to squash another pipeline proposed to run from Canada down the Gulf Coast. The project would cost over $7 billion and would allow for approximately 830,000 barrels of oil to flow to the Gulf Coast. While there are environmental concerns regarding these oil sands, there is no doubt that as oil becomes scarcer we must utilize every outlet to continue producing oil until we are ready to completely move away from it.

To produce useable oil from these oil sands it takes a certain amount of energy and it turns out to be less than what is spent harvesting conventional crude oil. To extract a barrel of bitumen takes about 1 to 1.25 gigajoules of energy, while a barrel of crude oil take about 6.125 gigajoules to extract. This is significantly better than crude oil extraction and it is projected to be reduced to down around .7 gigajoules within a few years. Once this goal is attained it will make this resource all the more appealing and reduce the overall environmental impact of this fuel. The overall cost of the oil from the oil sands is significantly cheaper than conventional oil and is projected to be even lower in coming years. Several years ago the average cost of a barrel of bitumen was between $80-$100, but is projected to be down around $40-$60 per barrel in the near future.

As oil gets scarcer I believe we will see more of these harvesting operations in more countries around the world in order to meet our growing demand for oil. Shell has already begun to expand their oil sands operation and from their website it says, "Shell has regulatory approvals in place for Muskeg River Mine, Muskeg River Mine Expansion and Jackpine Mine, enabling production up to a total of 470,000 b/d of minable bitumen. In addition, Shell has existing licenses for 290,000 b/d of synthetic crude production at the Scotford Upgrader. Some countries may move away from oil and more into renewable energies, but in the near future there will be an ever-growing demand for oil not just in this country, but also in large developing countries such as China and India. In the next few years there will be investments of tens of billions into the oil sands in Canada alone and with conventional oil prices increasing it wouldn't be surprising to see this type of money invested in the oil sands projects.

Natural Gas: The Corporate Solution

The Outlook for Energy: A View to 2030 is an annual pamphlet released by Exxon Mobil with the purpose of illustrating the trends in energy supply, demand and environmental impact. These trends are extrapolated to estimate Earth's energy future. The 2010 edition of The Outlook examines the following two decades, predicting the global trends in power generation on the economy, transportation, standard of living, industry and environmental impact. One must be wary of bias in any article. This document is exceptionally prone to bias presentation due to the fact that it is released by a multi-national, multi-billion dollar energy giant and the subject is the future of energy. Self-preservation is the number one priority for any business. None would release a pamphlet that predicted their own demise. Exxon Mobil's *The Outlook for Energy: A View to 2030* doesn't stray from that trend. A recent buyout may explain the heavy emphasis on the advantages of natural gas.

The Outlook for Energy segregates countries by their participation in the Organization for Economic Cooperation and Development. The developmental progress and energy trends of countries that are part of this organization are very similar. Non OECD countries are growing more rapidly in population and industry. Substantial growth in electricity demand will result from growing industry, as well as from the subsequent improved standard of living. Exxon Mobil predicts eighty-five percent of the world's population to live in non OECD countries by 2030. Currently "1.4 billion people, about 20 percent of the world's population, still lack access to electricity." Exxon predicts that "through 2030, energy demand in OECD countries will change little; but demand in Non OECD countries will rise by more than seventy percent, led by China and India." It will develop to "be about seventy-five percent higher than OECD demand." Even so "by 2030 per capita use in China" is predicted "to be only one half the level of the OECD." What is occurring is a game of catch up. China and other developing economies are expected to see periods of rapid growth in power demand similar to what happened decades ago within the OECD. The difference now is the massive population of these developing countries. Even with relatively low per capita demand, the resulting total demand will be massive. Below are charts from *The Outlook* depicting electricity demand by fuel from 1980 to 2030 and the predicted average cost of various types of electricity generation in 2025.

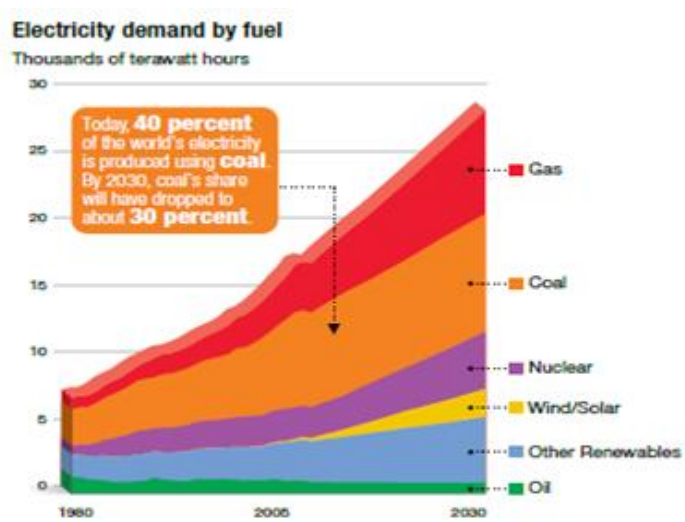


Figure 4: Electricity demand by fuel (Exxon Mobil, 2010)

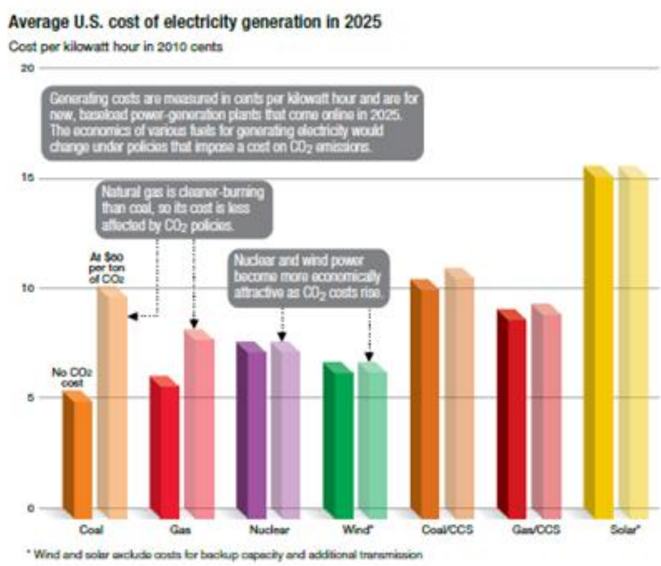


Figure 5: Average U.S. cost of electricity generation in 2025 (Exxon Mobil, 2010)

CO_2 emissions are a major concern for countries of the OECD. A number of countries have passed "carbon taxes" which charge power companies a flat rate per ton of CO_2 emissions. The cheapest fuel to burn, coal, is also the highest in carbon content. Carbon taxes seek to make cleaner energy more economical by driving up the cost of highly polluting methods. Coal burning is the predominant method of power generation in China. While the OECD drifts away from coal in the next two decades, Exxon Mobil does not predict this to occur in China. The following graphs depict energy related CO_2 emissions by region, the reduction in emissions by 2030 caused by improved efficiency and emissions per capita by region.

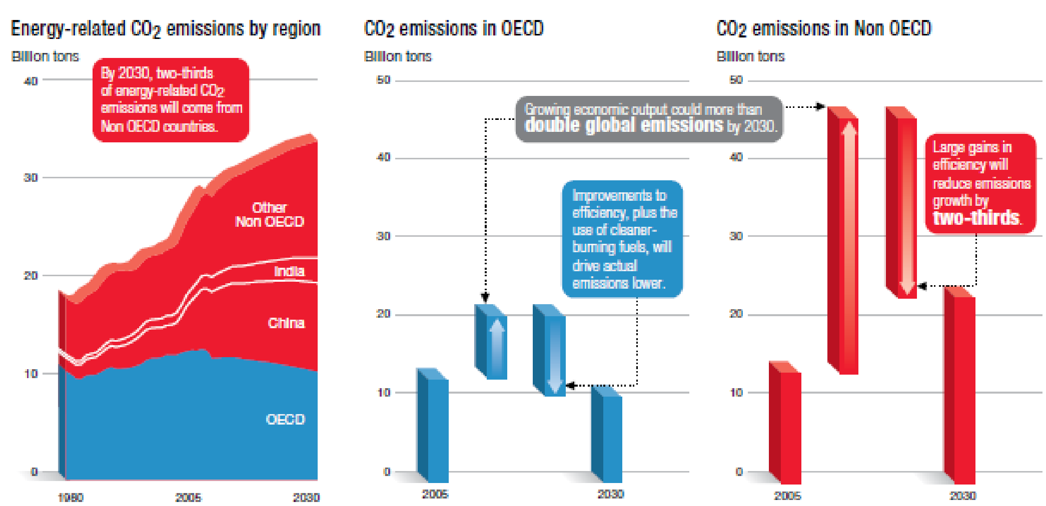


Figure 6: Energy-related CO2 emissions by region (Exxon Mobil, 2010)

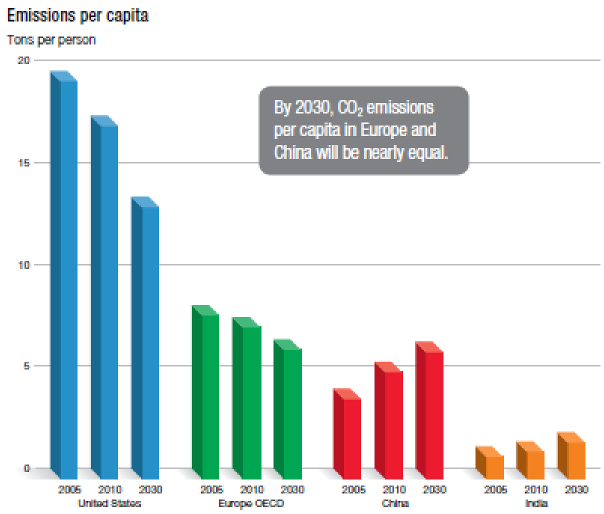


Figure 7 Emissions per capita (Exxon Mobil, 2010)

In *The Outlook,* Exxon Mobil frequently points to natural gas as a cheap abundant clean burning fuel that will remain in demand for decades to come. It is a low carbon fuel, producing sixty percent less CO_2 emissions than coal during electricity generation. The pamphlet points out that this resource is diverse; adaptable for use in power generation, steel and chemical production and as a raw material in plastics and other products. Currently eighty percent of natural gas produced in North America is conventionally drilled. Unconventional gas or gas trapped within shale rock formations is becoming economically viable for collection due to a process called hydraulic fracturing. This process requires pumping a mix of water sand and "small amounts of chemicals commonly found in dish detergents and swimming pools" into shale to bring gas trapped in pores to the well. The graph below illustrates projected natural gas demand growth from 2005 to 2030.

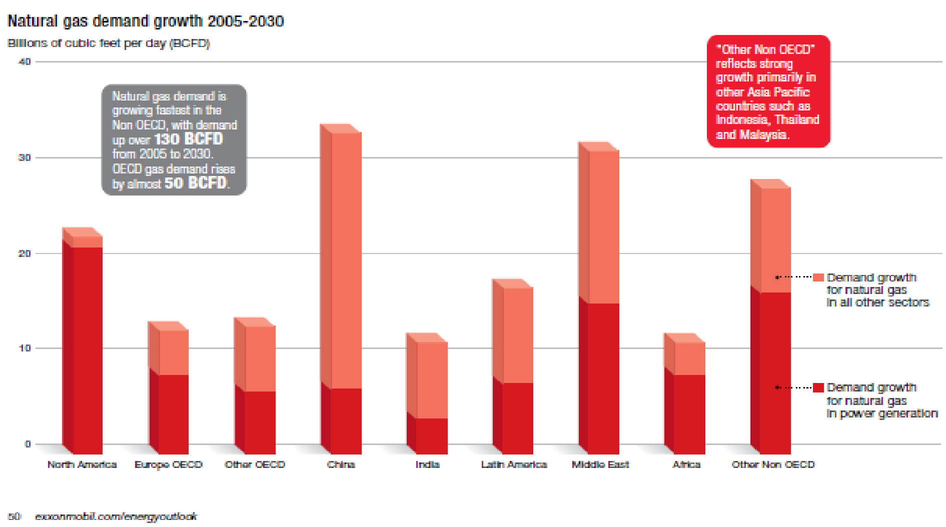


Figure 8: Natural gas demand growth 2005-2030 (Exxon Mobil, 2010)

The question to be asked is, why natural gas? Aren't zero emission technologies such as solar, wind, hydroelectric and experimental nuclear fusion more intelligent options? Natural gas may be plentiful (approximately 100 years supply at current demand has been located) but it is still a non-renewable resource and will not sustain global energy demand forever. Energy is a business and as such it is driven by money. Reducing emissions and protecting the environment are secondary goals. "Green Taxes", are currently being levied in various developed nations to balance the difference in cost of renewable and nonrenewable electricity production. These taxes require power companies to pay per ton on CO_2 emissions they generate. Natural gas is an excellent transitional fuel on the journey to clean sustainable energy. Its combustion produces less CO_2 per BTU than coal or petroleum and emits zero particulate matter. Fine particulate matter released into the air during coal and oil combustion has been found to increase the likelihood of developing lung and cardiac disease. This is one of many hidden cost associated with these "cheaper" fossil fuels. The cost of producing electricity with natural gas, $4.97 per million BTU in 2011, is comparable to coal, currently at $2.37 per million BTU and is significantly less expensive than petroleum combustion, $18.81 per million BTU. (U.S. Energy Information Administration)

Exxon Mobil wants to build confidence in natural gas because they are investing serious capitol in the technology. In December 2009 Exxon Mobil agreed to a purchase price of forty one billion dollars to buyout XTO Energy, an independent gas company that specializes in extractions of unconventional gas from shale rock formations as mentioned earlier. (Mufson, 2009) XTO utilizes hydraulic fracturing that despite being comprised of only "water, sand, and dish detergent" as described in *The Outlook* could pose environmental hazards. "The EPA is studying the effects of hydraulic fracturing"; many environmentalists point out the potential for ground water contamination. (Levine, 2009) Exxon predicts that the unconventional gas extraction from shale rock "will be the fastest growing source of global natural gas supply." Perhaps because they're the ones funding it!

Despite the recent purchase, Exxon Mobil has actually been in the gas game for decades. The company recently lost claims to leases of land in Alaska containing an estimated 9 trillion cubic feet of natural gas. The company had proposed a twenty five billion dollar pipeline construction project to pump the liquid natural gas to the US. The plan was shot down by legislators but it shows the company's determination and willingness to invest capital in the technology. (Exxon Mobil Loses Claims to Alaskan Natural Gas Reserves, 2007)

ExxonMobil is a company and as such its intent is to generate profit. Current trends of exploding population and developing superpowers drives demand for electricity on an unprecedented scale. ExxonMobil seeks to learn from its predictions, shifting toward emerging trends while simultaneously and subliminally instilling confidence in investors. As developed nations veer away from oil and coal Exxon Mobil must expand to market sectors that will continue to grow. Natural gas is presented on a pedestal in the hopes that others will believe and follow. All the while Exxon Mobil is buying in to a natural gas market that generated three hundred eighty-five billion dollars in 2008 alone. (Exxon Mobil, 2010)

Tapping Gas from Shale Rock

The abundance of clean burning natural gas has led to its acceptance as a major source of backbone energy, supplying about 22% of the total U.S. energy demand in 2008, 26.9% in 2009, and 27.1% in 2010. This trend is expected to continue for the next 20 to 30 years. EIA estimates that the U.S. has more than 1,744 trillion cubic feet of recoverable natural gas, including 211 trillion cubic feet of proved reserves while Navigant Consulting estimates that 60% of the onshore recoverable resource is recoverable unconventional gas, including shale gas, tight sands, and coal bed natural gas. Because natural gas, which is clean, reliable and cheap, can be widely used in several sectors, such as the industrial, commercial and electrical generation sectors, it is becoming more and more significant. One of the advantages of natural gas is that it is efficient and clean, comparing with oil and coal. The combustion byproducts of natural gas are mostly CO2 and water, while the combustion byproducts of coal and oil include large quantities of heavy metals, nitrogen monoxide, sulfur dioxide, particulates and more carbon dioxide. (U.S. Department of Energy, Modern Shale Gas Development in the United States: A Primer, 2009)

EXHIBIT 4: COMBUSTION EMISSIONS
(POUNDS/BILLION BTU OF ENERGY INPUT)

Air Pollutant	Combusted Source		
	Natural Gas	Oil	Coal
Carbon dioxide (CO_2)	117,000	164,000	208,000
Carbon monoxide (CO)	40	33	208
Nitrogen oxides (NO_x)	92	448	457
Sulfur dioxide (SO_2)	0.6	1,122	2,591
Particulates (PM)	7.0	84	2,744
Formaldehyde	0.750	0.220	0.221
Mercury (Hg)	0.000	0.007	0.016

Sources: EIA, 1998

Figure 9: Combustion Emissions (U.S. Energy Information Administration)

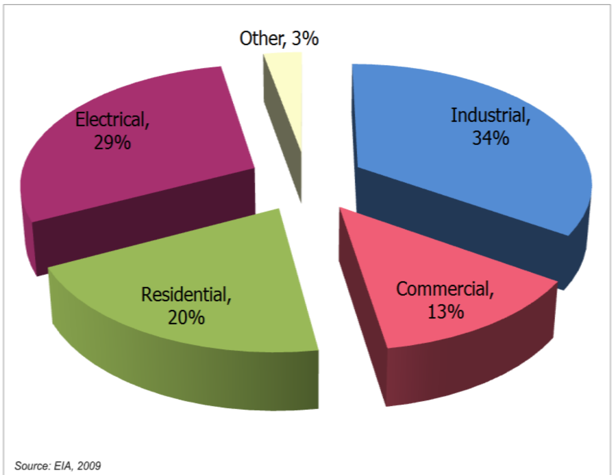


Figure 10 Natural Gas in Different Sectors (U.S. Energy Information Administration, Electric Power Annual 2009, 2010)

Although renewable energy sources are believed to be society's best choice for the future, they are not yet economical, reliable and widely available. During the next 20 years, fossil fuels will continue to supply most of our demand for energy. Since natural gas is the cleanest burning of the fossil fuels, the consumption of natural gas per year will keep increasing. (BP, 2011)

Since the domestic production from conventional reservoirs can't meet the U.S. demand for natural gas, the extraction of unconventional gas from shale rock has been developed. These unconventional gas reservoirs represent a vast, long-term supply of natural gas, much of which exists within the U.S.

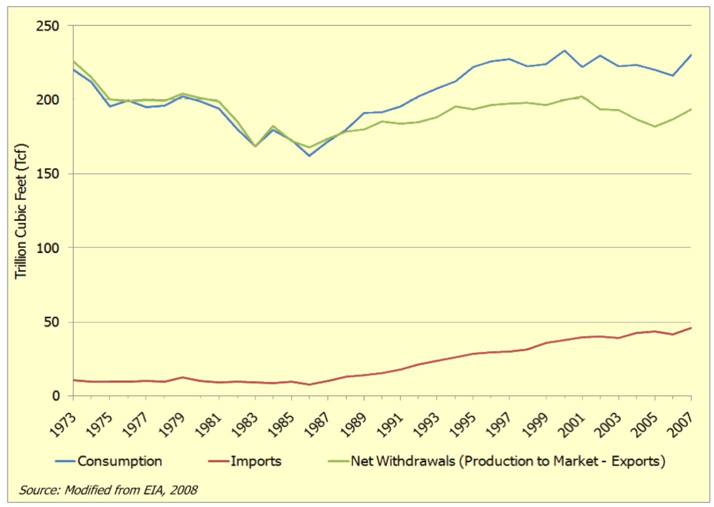


Figure 11 Imports, Consumption, New Withdrawals (U.S. Energy Information Administration)

Table 3 (U.S. Department of Energy, Modern Shale Gas Development in the United States: A Primer, 2009)

Region	Coalbed Methane (Tcf)	Shale Gas (Tcf)	Tight-Sand Gas (Tcf)	Total (Tcf)
North America	3,017	3,842	1,371	8,228
Latin America	39	2,117	1,293	3,448
Western Europe	157	510	353	1,019
Central and Eastern Europe	118	39	78	235
Former Soviet Union	3,957	627	901	5,485
Middle East and North Africa	0	2,548	823	3,370
Sub-Saharan Africa	39	274	784	1,097
Centrally planned Asia and China	1,215	3,528	353	5,094
Pacific (Organization for Economic Cooperation and Development)	470	2,313	705	3,487
Other Asia Pacific	0	314	549	862
South Asia	39	0	196	235
World	9,051	16,112	7,406	32,560

Region	Gas Resource in Fractured Shales (Tcf)
NAM–North America	3,842
LAM–Latin America	2,117
WEU–Western Europe	510
EEU–Eastern Europe	39
FSU–Former Soviet Union	627
MEA–Middle East Asia	2,548
AFR–Africa	274
CPA–Central Pacific	3,528
PAO–Asia and China	2,313
PAS–Other Asia Pacific	314
World	**16,112**

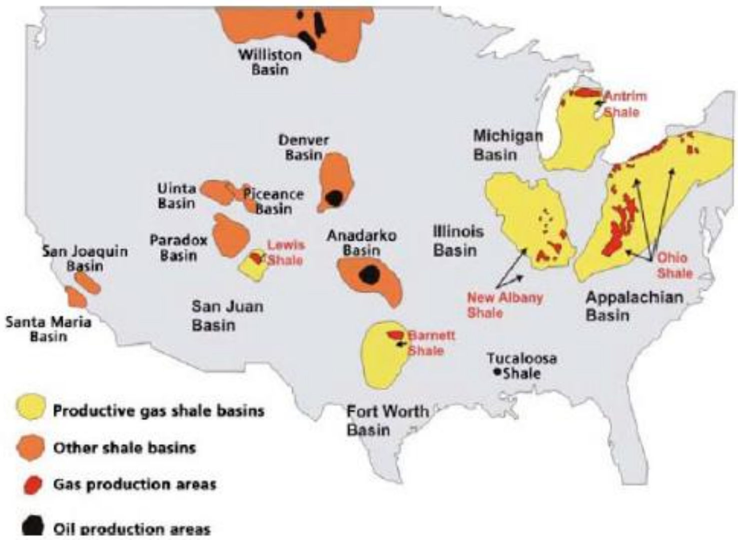


Figure 12 (National Petroleum Council Unconventional Gas Subgroup of the Technology Task Group of the NPC Committee on Global Oil and Gas, 2007)

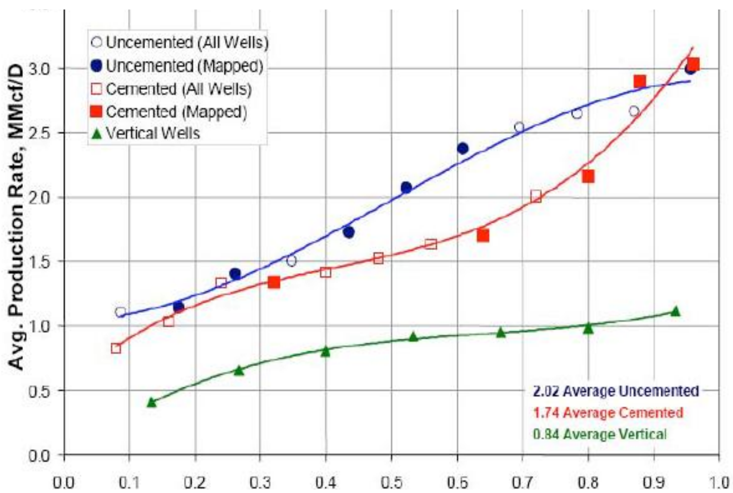


Figure 13 (National Petroleum Council Unconventional Gas Subgroup of the Technology Task Group of the NPC Committee on Global Oil and Gas, 2007)

Unconventional gas can be defined as natural gas that cannot be produced at economic flow rates or in economic volumes of natural gas unless the well is stimulated by a large hydraulic fracture treatment, a horizontal wellbore, or by using multilateral wellbores or some other technique to expose more of the reservoir to the wellbore. It has been already shown that a significant number of geologic basins around the world contain unconventional gas reservoirs, but in most countries, it is still impossible to produce gas from them because of technical limitations. However, many new technologies allow this kind of gas to be produced economically in the U.S.

Shale gas, created and stored within the shale bed, plays an important role among the unconventional gas. Current estimations predict about 16,000 trillion cubic feet of shale gas resources in fractured shale in the world. The continental United States has a wide distribution of such shale, containing large quantities of natural gas, and have funded advances in horizontal drilling and hydraulic fracturing in order to make shale gas production economical available. (National Petroleum Council Unconventional Gas Subgroup of the Technology Task Group of the NPC Committee on Global Oil and Gas, 2007)

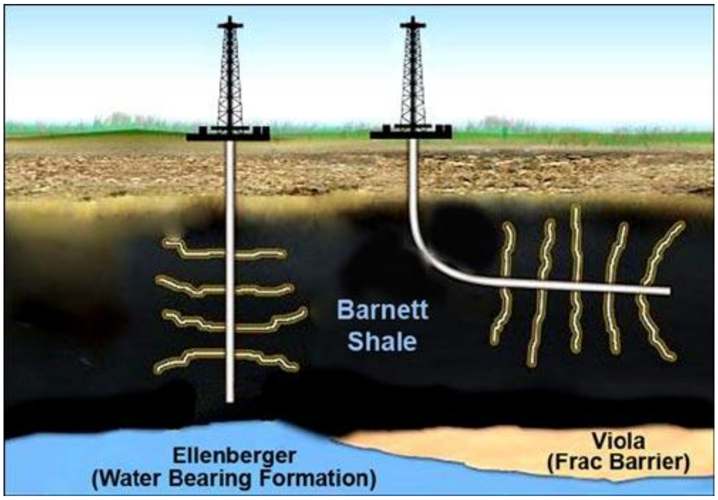


Figure 14 (EPA Tackles "Fracking" (Hydraulic Fracturing), 2011)

Horizontal drilling and multi-stage hydraulic fracturing are the primary differences between modern shale gas development and conventional natural gas development. Horizontal drilling allows an area to be developed with fewer wells than with vertical wells. Both of the processes of horizontal drilling and vertical drilling are using casing and cementing to protect fresh and treatable groundwater. With multiple wells drilled from a single pad, horizontal drilling can reduce surface disturbances and the associated impacts to public and the environment. Horizontal drilling provides more exposure to a formation than a vertical well does, and exposure to a formation creates technical advantages over vertical well drilling. The other primary difference between modern shale gas development and conventional natural gas development is hydraulic fracturing, which is the process of initiating and propagating a fracture in a rock layer by the pumping of a pressurized fracturing fluid into a shale formation in order to release shale gas from the shale to the well in economic quantities. During shale gas fracturing, a combination of casing and cement is installed between the fracture zone and ground water, but waste management and water management are still in need of developing to ensure only acceptable effects on surrounding water, air, and soil.

There are several active shales in the U.S., namely, the Barnett Shale, the Haynesville/Bossier Shale, the Antrim Shale, the Fayetteville Shale, the Marcellus Shale, and the New Albany Shalem, Among which, the Barnett Shale, located in the Fort Worth Basin of north-central Texas, is the most prominent shale gas play in the U.S., with more than 10,000 wells drilled with the technologies of horizontal drilling and hydraulic fracture treatments. (Mann, 2011)

Table 4: Comparison of Data for the Gas Shales in the United States (U.S. Department of Energy, Modern Shale Gas Development in the United States: A Primer, 2009)

EXHIBIT 11: COMPARISON OF DATA FOR THE GAS SHALES IN THE UNITED STATES

Gas Shale Basin	Barnett	Fayetteville	Haynesville	Marcellus	Woodford	Antrim	New Albany
Estimated Basin Area, square miles	5,000	9,000	9,000	95,000	11,000	12,000	43,500
Depth, ft	6, 500 - 8,500[82]	1,000 - 7,000[83]	10,500 - 13,500[84]	4,000 - 8,500[85]	6,000 - 11,000[86]	600 - 2,200[87]	500 - 2,000[88]
Net Thickness, ft	100 - 600[89]	20 - 200[90]	200[91] - 300[92]	50 - 200[93]	120 - 220[94]	70 - 120[95]	50 - 100[96]
Depth to Base of Treatable Water#, ft	~1200	~500[97]	~400	~850	~400	~300	~400
Rock Column Thickness between Top of Pay and Bottom of Treatable Water, ft	5,300 - 7,300	500 - 6,500	10,100 - 13,100	2,125 - 7650	5,600 - 10,600	300 - 1,900	100 - 1,600
Total Organic Carbon, %	4.5[98]	4.0 - 9.8[99]	0.5 - 4.0[100]	3 - 12[101]	1 - 14[102]	1 - 20[103]	1 - 25[104]
Total Porosity, %	4 - 5[105]	2 - 8[106]	8 - 9[107]	10[108]	3 - 9[109]	9[110]	10 - 14[111]
Gas Content, scf/ton	300 - 350[112]	60 - 220[113]	100 - 330[114]	60 - 100[115]	200 - 300[116]	40 - 100[117]	40 - 80[118]
Water Production, Barrels water/day	N/A	N/A	N/A	N/A	N/A	5 - 500[119]	5 - 500[120]
Well spacing, acres	60 - 160[121]	80 - 160	40 - 560[122]	40 - 160[123]	640[124]	40 - 160[125]	80[126]
Original Gas-In-Place, tcf[127]	327	52	717	1,500	23	76	160
Technically Recoverable Resources, tcf[128]	44	41.6	251	262	11.4	20	19.2

NOTE: Information presented in this table, such as Original Gas-in-Place and Technically Recoverable Resources, is presented for general comparative purposes only. The numbers provided are based on the sources shown and this research did not include a resource evaluation. Rather, publically available data was obtained from a variety of sources and is presented for general characterization and comparison. Resource estimates for any basin may vary greatly depending on individual company experience, data available at the time the estimate was performed, and other factors. Furthermore, these estimates are likely to change as production methods and technologies improve.

Mcf = thousands of cubic feet of gas

scf = standard cubic feet of gas

tcf = trillions of cubic feet of gas

= For the Depth to base of treatable water data, the data was based on depth data from state oil and gas agencies and state geological survey data.

N/A = Data not available

Green Energy

The world's current energy profile is highly dependent on fossil fuels and other non-sustainable energy sources. These sources pose the problem of finite abundance and perpetually increasing demand. To meet the energy demands of the future it is important for renewable energy to become established now. Each type of renewable energy source has its own advantages and disadvantages. Ideally a combination of several renewable sources will be used together in order to create a diverse, sustainable energy profile.

Geothermal Electricity

Currently the majority of power plants use heat as a means of creating the mechanical energy necessary to create electricity. As such geothermal energy represents a means of creating electricity without needing to make major alteration to the way electricity is generated. Conventional power plants frequently use heat in order to convert liquids to gas which then turn turbines and generate electricity. Geothermal power plants use the same system either using water or other liquids with low boiling points as a means of turning heat from the earth to create mechanical energy. The heat present inside of the earth is created from the slow decay of radioactive particles within the earth. This heat will replenish slowly as the elements continue to decay. (Union of Concerned Scientists. "How Geothermal Energy Works", 2009)

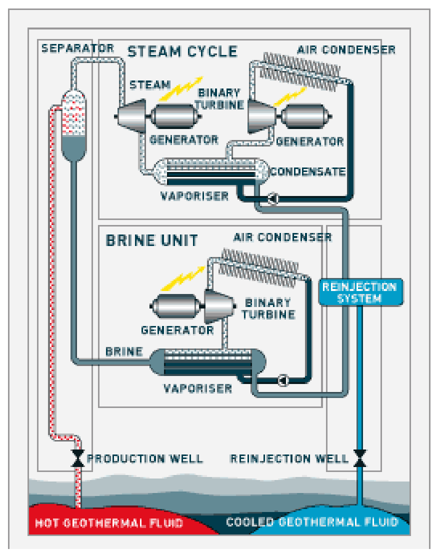


Figure 15 A generator using geothermal fluid (Mighty River Power)

Geothermal electricity is produced by using heat stored in rocks to vaporize liquids or pressurize gasses which then turn turbines that produce electricity. The least complicated method takes advantage of areas where rock formations naturally store and vaporize ground water. This vapor can be directed at turbines via pipes and returned to the earth as brine after condensing so that it can be heated again. Figure 18 shows an illustration of this process. (Mighty River Power)

Geothermal electricity is still a developing field with large-scale projects occurring as recently as 2010, in Italy, Kenya, and New Zealand. The 2010 project in Rotokawa field New Zealand has a 132 MW power plant and is currently the largest single turbine geo electric plant. (Renewable Energy World Network Editors, 2010) However, in the near future geothermal electricity may become more commonplace as Enhance Geothermal Systems are developed. Enhanced Geothermal Systems use a Binary Cycle power plant in order to access heat in rocks that would otherwise not be useable. By using water heated by the rock to flash steam a secondary fluid with a lower boiling point energy can be collected from areas that wouldn't normally have the resources or heat to generate steam. (National Renewable Energy Laboratory) By using EGS it is possible to generate large amounts of geothermal energy in areas that don't normally have access to it. A study by the US Geological Survey suggests that using EGS there is as much as 500,000 MW of electricity generating capacity in the Western US. (U.S. Geological Survey, 2008) This is about half of the electrical generating capacity of the US in 2009. (U.S. Energy Information Administration, Electric Power Annual 2009, 2010)

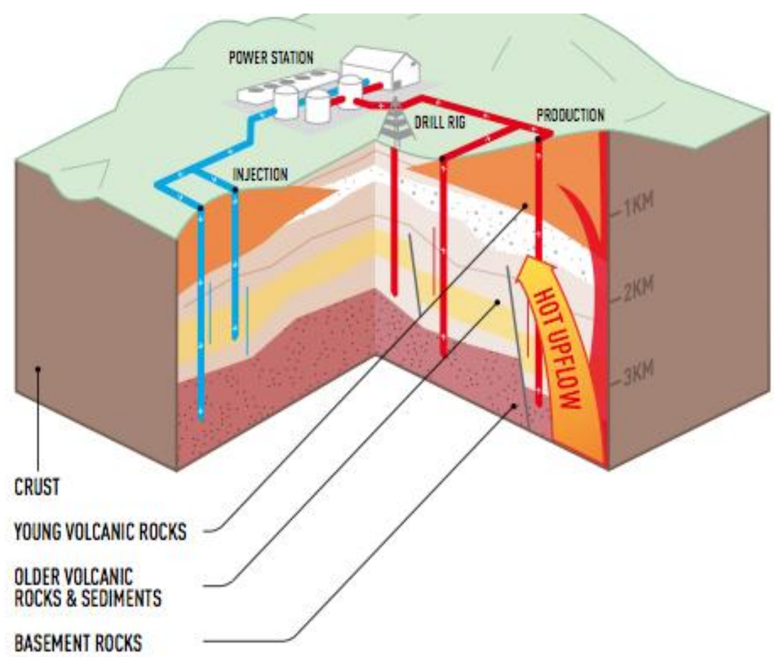


Figure 16: Diagram of a power plant accessing a geothermal reservoir (Mighty River Power)

Geothermal Electricity is a possible source of clean renewable energy in the future. With the advancement of drilling technologies and power plants that are capable of using geothermal energy without there being a preexisting liquid or vapor medium will enable geothermal energy to be more productive in the years to come.

Biofuels: Fuel from Farmland

Biofuels are energy sources that are manufactured from organisms. There are a variety of different potential sources for biofuel such as algae, corn, rapeseed, waste, and wood. Different sources have different processing requirements and can yield different types of biofuel. When discussing biofuels, the source is important as edible sources could diminish food supplies. Biofuels are looked at as a more sustainable replacement for traditional fossil fuels. While the fact that it takes significantly less time for corn to grow then for petroleum to form, there are some questions as to the sustainability of large scale biofuel production. Overuse of farmland could leach soil of nutrients, reduce food production, and put a strain on fresh water supplies in certain areas. It is also likely that an increased demand for farmable resources would cause the conversion of natural areas into farmland causing additional damage to the ecosystem. However, by implementing more sustainable practices from the beginning, such as water conservation or crop rotation it is possible to prevent these problems from arising. (Reijnders, 2006)

The development on biofuels is dependent on economic opportunities and public policy as much as it is on technological discoveries. Government policies can either help or hinder development of biofuels and much of the potential future of biofuels, at least in the EU, is affected by the research and development actions promoted by the EU or one of its component nations. Some of the main tenets of the EU energy policy are to protect the environment, to improve energy efficiency, and to secure energy supplies. The renewable nature of biofuels helps with these goals. Because of the diversity of biofuels sources there is less risk of a catastrophic loss of biofuel resources, this helps ensure energy supply security by not being dependent on specific areas or crops. Agricultural policy also affects the possible success of biofuels; policies that help make food production cheaper and more efficient would have the same benefits for biofuel production in this way significantly more benefits would arise from the same changes in policy. (A. Cadenas, S. Cabezudo, 1998) Producing ethanol from corn cost $0.60 for the equivalent of one liter of gasoline. (International Energy Agency, 2007) In the United States there are over $5.5 Billion is subsidies for biofuel production annually, this means that for every metric ton of CO_2 equivalent reduced through ethanol use it costs the U.S. spends $500 in subsidies. (Global Subsidies Initiative, 2008)

The possibility of using biofuels to supplant fossil fuels is aided by the fact that it is renewable and has a very small release of net CO_2. Because renewable resources are more evenly distributed then fossil fuels, it would create less dependence on foreign energy suppliers and spread the economic benefits amongst a larger number of countries. However, there are some problems with using it to supplant fossil fuels, one being availability of arable farmland, "According to International Energy Agency, (International Energy Agency, 2007) scenarios developed for the USA and the EU indicate that near-term targets of up to 6% displacement of petroleum fuels with biofuels appear feasible using conventional biofuels, given available cropland. A 5% displacement of gasoline in the EU requires about 5% of available cropland to produce ethanol while in the USA 8% is required. A 5% displacement of diesel requires 13% of USA cropland, 15% in the EU". (Demirbas, Progress and recent trends in biofuels, Prog Energy Combust Sci 33, 2007)

One of the problems with a large number of biofuels is that they rely on traditional agricultural forms and as such carry many of the same problems as traditional agriculture. One worry is that using land that was traditionally used for food will drive up food costs and create scarcities and create additional drain on supplies of fresh water. One of the suggested ways to counter these problems is by using algae as the basis for biofuels. Algae can be grown in atrophied water (fresh or saline) and therefore doesn't compete with arable land for food or water that could be used for plants or human consumption. Algae are also more productive than most terrestrial fuel crops meaning that the same amount of fuel could be produced more quickly, "For example, had the 67 million acres of soybeans cultivated in 2007 gone entirely to biodiesel, they would have displaced 6% of the United States' on-road petroleum diesel use; the same acreage used for algal culture would yield more than 100% of the petroleum diesel usage, even assuming modest algal productivity". Though there isn't yet comprehensive data it appears that algal-fuels may be carbon neutral. (Adey, 2009)

The various arguments for biofuels are that they tend to have a significantly lower ecological footprint then fossil fuels and are more sustainable. However, agriculture isn't necessarily a sustainable process, unless methods designed to be sustainable are used, biofuels carry the risk of depleting soil, increasing erosion, and lowering fresh water supplies, as well as reducing food supplies by competing for the same resources. However, these problems can be partially combatted by selection of crops as well as by implementing policies to prevent destruction caused by over farming. Biofuels also have an advantage in that they closely resemble the fossil fuels that they are trying to replace; some like biodiesel require that few modifications be made in order for a standard diesel engine to use them.

Others like ethanol are already being used as fuel additives. (Demirbas, Biofuels sources, biofuel policy, biofuel economy and global biofuel projections, 2008) The future of biofuels is dependent on economic and public support for changes to be made; and with the current desire to reduce carbon emissions; carbon-neutral biofuels may well become significantly more prevalent in the future.

Biofuels are a possible alternative to fossil fuel based gasoline and diesel. As one of the renewable energy sources they are distinguished by the fact that they don't generate electrical energy directly and are instead burned in traditional combustion engines to power vehicles.

The development on biofuels is dependent on economic opportunities and public policy as much as it is on technological discoveries. Government policies can either help or hinder development of biofuels and much of the potential future of biofuels, at least in the EU, is affected by the research and development actions promoted by the EU or one of its component nations. Some of the main tenets of the EU energy policy are to protect the environment, to improve energy efficiency, and to secure energy supplies. The renewable nature of biofuels helps with these goals. Because of the diversity of biofuels sources there is less risk of a catastrophic loss of biofuel resources, this helps ensure energy supply security by not being dependent on specific areas or crops. Agricultural policy also affects the possible success of biofuels; policies that help make food production cheaper and more efficient would have the same benefits for biofuel production in this way significantly more benefits would arise from the same changes in policy. (A. Cadenas, S. Cabezudo, 1998) So far use of ethanol in the U.S. has been strongly influenced by government policies, with federal incentives like the Renewable Fuels Standard, Volumetric Ethanol Excise Tax Credit, and the Small Ethanol Producer Tax Credit. The Renewable Fuels Standard requires that 36 billion gallons of renewable fuels be used in America's motor industry by 2022. (U.S. Department of Energy, Current State of the U.S. Ethanol Industry, 2010) Biomass is converted into ethanol by using enzymes to break the starch in the biomass selected into simple sugars. This can then be fermented and distilled to produce fuel grade ethanol. (International Energy Agency, 2007)

Fuel Cells for Personal Transport

Fuel cells are devices that produce electricity from hydrogen or other fuels without using combustion. They are being examined as a possible replacement for CO_2 producing combustion engines in cars and other applications. All fuel cells work in a similar manner. They use the same kind of electrochemical processes as batteries to generate electricity by the movement of electrons between an anode and a cathode during a chemical process. For example in a hydrogen fuel cell the hydrogen fuel is first fed to the anode where a catalyst separates hydrogen into positive hydrogen ions and electrons. The hydrogen ions then move through an electrolyte to the cathode to combine with oxygen producing water and heat while the electrons are forced to travel through the electrical circuit to reach the cathode generating an electrical current. (U.S. Department of Energy, Fuel Cell Basics)

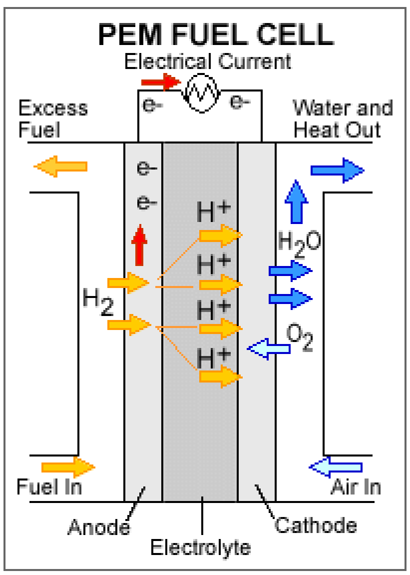


Figure 17 Diagram of a hydrogen fuel cell using a proton exchange membrane to generate electricity (U.S. Department of Energy, Fuel Cell Types)

There are a variety of types of fuel cells which use different fuels, electrolytes, cathodes, and anodes but they all function using the same basic process. Among these the proton exchange membrane (PEM) fuel cell is currently the most favored for use in cars and other portable applications because of its low startup time, low working temperature, and small size. (U.S. Department of Energy, Fuel Cell Types) However, the PEM fuel cell requires platinum as a catalyst which significantly adds to the cost of manufacturing fuel cells. Platinum also has a high sensitivity to CO poisoning making it necessary to add filters to reduce the amount of CO in the hydrogen gas, which also adds to size and expense. Fuel cells also face another major boundary which is the difficulty of transporting and storing hydrogen. Hydrogen gas has a low energy density meaning that it requires large amounts be stored to run a fuel cell in a car for long periods of time. There is also little infrastructure in place for a widespread and easy means of distributing hydrogen. One way around this problem is a new type of fuel cell call Direct Methanol Fuel Cells (DMFCs) which are powered by pure methanol mixed with steam. Because methanol is a liquid at operating temperatures and has a higher energy density than hydrogen it is better suited for portable fuel cell applications.

However, DMFC technology is still new and is less advanced than hydrogen fuel cells. (U.S. Department of Energy, Fuel Cell Challenges)

Currently fuel cells are still unable to directly compete with gasoline for use in transportation because of the difficulties associated with hydrogen and the high costs of manufacturing and use. At the moment both hydrogen fuel cells and DMFCs are much more expensive than gasoline with DMFCs costing 125 dollars per kilowatt (Meyers, Jeremy P., 2011) and PEM fuel cells costing 65 dollars per kilowatt (J. Spendelow, J. Marcinkoski, 2011) this is in comparison to automotive engines which cost approximately 30 dollars per kilowatt. (U.S. Department of Energy, Fuel Cells Technology Program: Comparison of Fuel Cells Technology) Another major problem facing fuel cells is that their durability and reliability hasn't been determined so it isn't yet possible to claim definitively that they will be able to replace other forms of electricity generation.

Table 5: Comparison of the currently available hydrogen fuel cells and their advantages and drawbacks (U.S. Department of Energy, Fuel Cells Technology Program: Comparison of Fuel Cells Technology)

Fuel Cell Type	Common Electrolyte	Operating Temperature	Typical Stack Size	Efficiency	Applications	Advantages	Disadvantages
Polymer Electrolyte Membrane (PEM)	Perfluoro sulfonic acid	50-100°C 122-212° typically 80°C	< 1kW–100kW	60% transportation 35% stationary	• Backup power • Portable power • Distributed generation • Transporation • Specialty vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up	• Expensive catalysts • Sensitive to fuel impurities • Low temperature waste heat
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90-100°C 194-212°F	10–100 kW	60%	• Military • Space	• Cathode reaction faster in alkaline electrolyte, leads to high performance • Low cost components	• Sensitive to CO_2 in fuel and air • Electrolyte management
Phosphoric Acid (PAFC)	Phosphoric acid soaked in a matrix	150-200°C 302-392°F	400 kW 100 kW module	40%	• Distributed generation	• Higher temperature enables CHP • Increased tolerance to fuel impurities	• Pt catalyst • Long start up time • Low current and power
Molten Carbonate (MCFC)	Solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600-700°C 1112-1292°F	300 kW-3 MW 300 kW module	45-50%	• Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP	• High temperature corrosion and breakdown of cell components • Long start up time • Low power density
Solid Oxide (SOFC)	Yttria stabilized zirconia	700-1000°C 1202-1832°F	1 kW–2 MW	60%	• Auxiliary power • Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte • Suitable for CHP & CHHP • Hybrid/GT cycle	• High temperature corrosion and breakdown of cell components • High temperature operation requires long start up time and limits

Ethanol is the most prevalent biofuel being used in the U.S. as it is frequently used as an additive in conventional gasoline. The U.S. is the largest producer and consumer of ethanol followed by Brazil. And with Brazil, they make up 80% of the world's ethanol production. Use of ethanol has been on the rise, with its use globally tripling between 2000 and 2009. The fact that it is able to be produced from a variety of feed stocks and can be used as an additive make it easier to phase into usage as it doesn't necessitate large scale change across the fuel industry. However, because corn is the largest source of American ethanol it constrains the price of production, in 2010 returns on ethanol were estimated to be at 30 cents per gallon, a five year low. This problem can be solved by diversifying to a number of other ethanol sources. In Brazil, for example, sugar cane is the main source of ethanol and the manufacturing costs are lessened because the sugar cane bagasse can be burned instead of natural gas. In addition to the monetary issues currently facing ethanol, energy yields are also an issue. It is only as recently as the 1990's that ethanol made the transition from taking more energy to manufacture then it produced to a small net energy gain. Since 2004 the net energy of corn ethanol has increased from 1.76 BTU's (British Thermal Units) to 2.3 BTU's for every BTU needed in the manufacturing process. Further refinements in the manufacturing ethanol could lead to small but steady gains in the energy efficiency of ethanol. (U.S. Department of Energy) The increase in the efficiency of ethanol as a fuel source is carried out by another study which showed that between 2001 and 2007 there was a 6.4% increase in ethanol yield and a 21.8% decrease in the amount of energy used. (Wu, 2007) By diversifying crops used for ethanol production to include as wide a variety of biomasses as possible (corn, sugar-beet, sugar cane, scrub grass, etc.) so that they aren't tied down to a single food price and improving manufacturing and growing efficiency it is possible to continue to increase the efficiency of ethanol production in the U.S. which in turn could reduce reliance on foreign oil and help to lower CO_2 emissions.

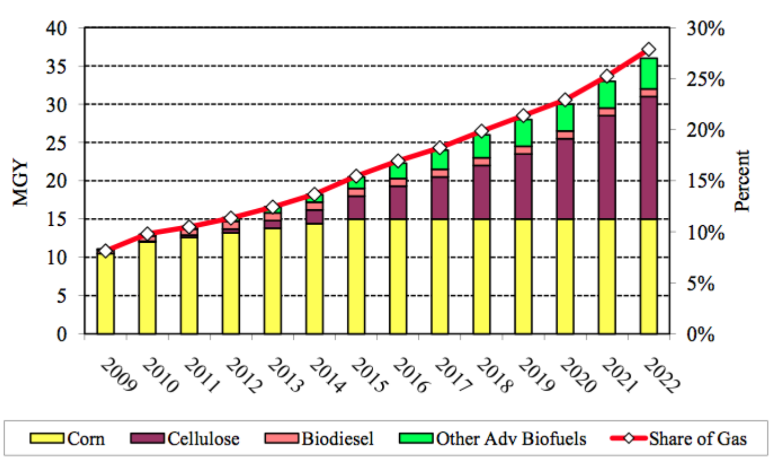


Figure 18 Renewable Fuels Standard (U.S. Department of Energy)

The likelihood of biofuel replacing oil in the long run is low. Unlike oil biofuels are limited by land availability, time spent growing crops, food prices, and weather. These serve to decrease the likelihood of their being a large enough consistent source of biofuel to replace oil. However, it is not impossible that with high yield farming techniques and the right choice of crops biofuel could serve to replace oil in a large quantity of its current applications.

Table 6: Costs and Returns of an Iowa Dry Mill Ethanol Plant (U.S. Department of Energy, Fuel Cell Basics)

	Cost per Gallon						Returns Over	
Year	Corn	Natural Gas	Other Var.	Total Var.	Fixed	Total All Costs	Variable Costs	All Costs
2005	$0.62	$0.28	$0.21	$1.11	$0.21	$1.32	$0.70	$0.48
2006	$0.80	$0.25	$0.21	$1.26	$0.21	$1.47	$1.31	$1.10
2007	$1.24	$0.25	$0.21	$1.69	$0.21	$1.91	$0.60	$0.38
2008	$1.76	$0.28	$0.21	$2.26	$0.21	$2.47	$0.39	$0.18
2009	$1.27	$0.17	$0.21	$1.65	$0.21	$1.86	$0.32	$0.11
Jan-Oct 2010	$1.32	$0.18	$0.21	$1.71	$0.21	$1.92	$0.30	$0.09

Ocean Energy: The Total Picture

Ocean energy refers to the energy derived from oceans or seas. Oceans cover about 70% of the Earth's surface and not only store energy sources like oil, coal and natural gas, but also generate thermal energy by collecting solar energy from the sun and produce kinetic energy in forms of tides, currents and waves. Several technologies including wave power, tidal power and tidal current energy, ocean thermal energy conversion(OTEC) and salinity gradient energy have been developed to harvest energy from oceans. Theoretically the ocean can provide us with a large quantity of energy. Wave power, tidal power and OTEC are some of the most developed methods of ocean energy capture and will be discussed further.

Tidal Current Energy comes from the kinetic energy of tides and can be harvested to generate electricity. All tidal effects are dependent on the earth's rotation, the positions of the moon and the sun, and the distance between the earth and the moon. The closer the moon comes to the earth, the more powerful is its effect. When the moon is at the position of perigee or the earth is at the position of perihelion, great gravitational influences and tide-raising forces are produced, and if the earth is at the position of perihelion when the moon is at the position of perigee, tides of augmented range are produced. When the moon is at perigee and the earth is at perihelion, the range of tides are larger than the range of tides when the moon is at perigee but the earth is not at perihelion and the range of tides when the earth is at perihelion but the moon is not at perigee. The types of tides in most locations are also impacted by the moon's declination. There are three daily cycles of tides: diurnal tides, semi diurnal tides and mixed diurnal tides. A diurnal tide has one high tide and one low tide occurring during a tidal day, which is about 24 hours 50 minutes. Semi diurnal tides have two high tides and two low tides each tidal day, which in most locations is the largest constituent. Mixed diurnal tides alternate based on various characteristics. Land masses and ocean basins may slow water speed, and their varied shapes and sizes affect the tides.

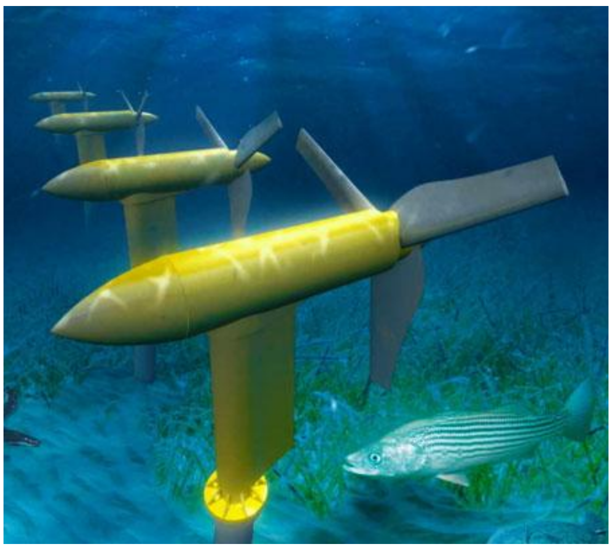


Figure 19 (An Introduction to Tidal Turbines, 2011)

Although the shape of the shoreline and ocean floor may alter tidal timing for a given location, the relationship between lunar altitude and the time of high or low tide is relatively predictable. There are two kinds of approaches to generating electricity from tidal energy. The first approach is called tidal barrage or dam method. A barrage or a dam installing gates and turbines can generate electricity from tidal energy by forcing the water through turbines. The second approach is called tidal turbine method. Tidal turbines look like wind turbines. They are arrayed underwater in rows, as in some wind farms. Close to shore in water depths of 20 -30 meters is the best locations for such tidal turbine farms. The world Offshore Renewable Energy Report 2002 – 2007, released by the DTI Renewable Energy Consulting, CO, USA, estimated that there is 3000GW of tidal energy available worldwide, however only less than 3% is located in areas suitable to be harvested to generate electricity. The tides in the Bay of Fundy, Canada are the greatest tides in the world, with amplitude that can reach 16.2m near shore. Other notable tides exist in England Severn Esturary(14.5m), France Port of Ganville(14.7m), France La Rance(13.5m),Argentina Puerto Rio Gallegos(13.3m), Russia Bay of Mezen(10.0m), and Russia Penzhinshaya Guba(13.4m) and are ideal tidal energy sources. The difference between high and low tides must be at least five meters to make it possible to harvest the kinetic energy for generating electricity. There are only about 40 sites with tidal ranges of this magnitude available on earth to harvest tidal energy for generating electricity. The largest tidal barrage type power plant is the La Rance Tidal Power Station in France. The main barrage is about

750 meters long, with an average annual output about 600GWh. The Incheon Tidal Power Station, at the Incheon Bay, South Korea, will be the new largest tidal power facility once completed in June 2017. (Skoloff, 2008)

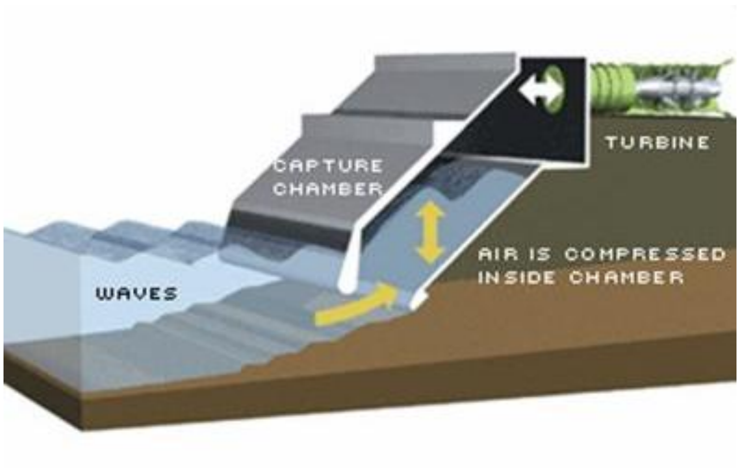


Figure 20 (Wave Power)

Wave Power is caused by wind blowing over the surface of the ocean. In many areas of the world, the wind blows periodically and produces consistent energy. The first method to harvest wave energy is to focus the waves into a narrow channel in order to increase their power, and then use them to spin turbines. The second method to harvest wave energy is through the use of an Oscillating Water Column, or OWC, to generate electricity from the rise and fall of water. This rising and falling action drives air to power an air-driven turbine. The third method to generate wave power is to use underwater pressure differences caused by waves to drive water up and down to operate a turbine. The total wave energy off the U.S. coastlines at a water depth of 60m has been estimated to be 240GW. Theoretically, we can assume an average annual capacity of about 30,000 MW from wave energy, which will meet about 33% of the energy demand. In the northeastern Atlantic, the total wave energy resource is about 290GW. In the Mediterranean basin, the total energy is about 30GW. China also has a long coastline, which is more than 14484km, so ocean energy can help to generate power there. (MacKay, 2007)

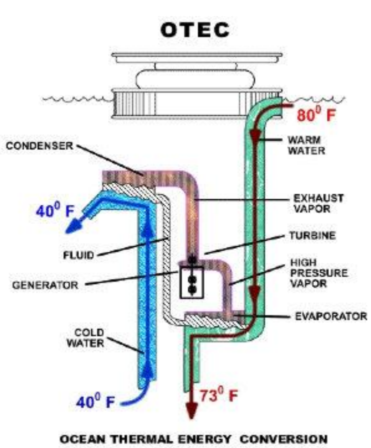


Figure 21: OTEC (Josey, 2008)

Solar energy collected by the ocean can be harvested and used to generate electricity by the Ocean Thermal Energy Conversion (OTEC) technology. Whenever the temperature difference is about 68°F between the warm surface water and the cold deep water, an OTEC system can produce energy by operating a thermodynamic cycle. There have been three fundamental types of OTEC systems designed, namely closed cycle systems, open cycle systems, and hybrid cycle systems. In a closed cycle system, warm surface water heats a low-boiling-point fluid to be vaporized, and cold deep water condenses the vapor into a liquid. Closed cycle systems rotate a turbine with the fluid to generate electricity. In an open cycle system, warm water boils in a low pressure container, and then the steam drives a water turbine to generate electricity and be condensed back into a liquid by cold deep water. In a hybrid cycle system, warm water boils in a low pressure container, and then the steam vaporizes a low-boiling-point fluid which then drives a water turbine to generate electricity. (Chen, An Indispensable Truth: Future Energy II, 2011)

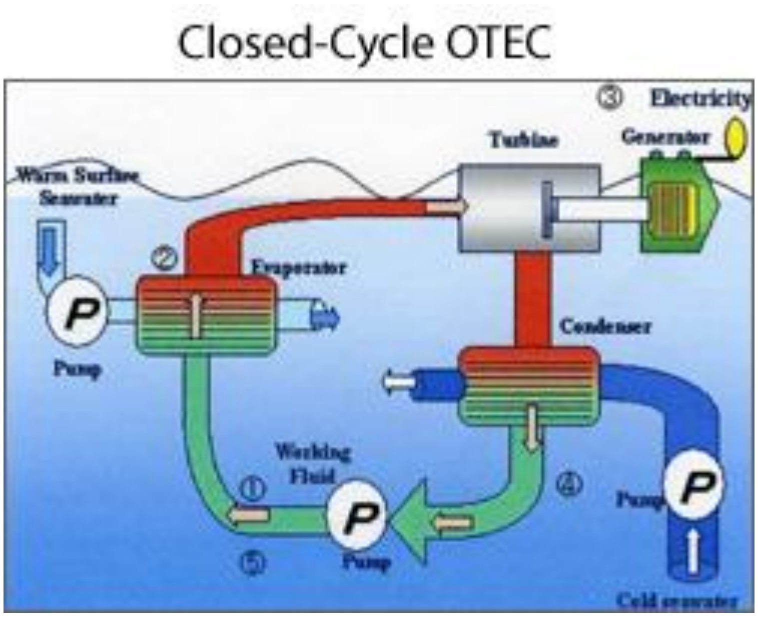


Figure 22: Closed-Cycle OTEC (Sea Solar Power)

The energy generated from the ocean is sustainable, and the energy generation technologies are also developed. However, since the cost of generating energy from the ocean is not yet competitive, some technologies are in need of further development. Monetary resources have not been available, and the environmental impacts are still unclear, only a small number of devices have been tested and evaluated, with very few designs making it to ocean testing.

Tidal Power: A Technical Evaluation

Tides are cyclic variations which are theoretically predicable because they are caused by the combination of the earth's rotation and the gravitational forces exerted by the earth, the moon and the sun. The predictability of tides makes their use as a renewable source of energy both reliable and consistent.

In order to study the tides, people build reasonable, idealized models in which relatively small impacts are ignored, and calculation is simplified. One model is for understanding tide generation. Several assumptions are made to help understand this model. Firstly, the earth is considered as a rigid spherical nucleus whose mass is spherical distributed. Then the gravitational field of the earth can be written as the gradient of the gravitational potential, and then from Poisson's equation for the gravitational potential of the spherical distributed mass we can conclude that the gravitational attraction exerted by the earth to any attracted body outside of the spherical mass distribution, which can be regarded as constructed of a collection of thin spherical shells, each one nested inside the other, is the same as if all the mass of the earth were concentrated at the center of the earth. Secondly, we assume that water covering the earth is of small depth in comparison with the radius of the earth, which means that the free surface of water is our test surface in this system. Thirdly, although the impact of the movement of the disturbing body to the water is the reason for which tides are generated, we regard the system is always in quasistatic equilibrium. Thus, it becomes easier to study the state of the free surface of the water, and then the equation of the free surface of the water is only determined by the relative positions of the components in the system.

By setting up an ideal mechanical model, we can express the total force and the tidal force acting on the unit mass at some point of the free surface of the water by the disturbing body. This gives rise to the tidal phenomena, the potential of the total force and the potential of the tidal force, which is equal to the potential of the joint gravitational field and the shape of the free surface of the water as a surface under constant pressure.

$$\overrightarrow{F} = \frac{am}{PD^3}\overrightarrow{PD} - \frac{a\mu}{EP^3}\overrightarrow{EP} - \frac{am}{ED^3}\overrightarrow{ED} + \omega^2\overrightarrow{P'P} \qquad (1)$$

$$\overrightarrow{F_{tidal}} = \frac{am}{PD^3}\overrightarrow{PD} - \frac{am}{ED^3}\overrightarrow{ED} \qquad (2)$$

$$U = \frac{am}{ED} - \frac{amEP^2}{2ED^3}(3cos^2\lambda - 1) - \frac{a\mu}{EP} - \frac{\omega^2 P'P^2}{2} \qquad (3)$$

$$U_{tidal} = \frac{am}{ED} - \frac{amEP^2}{2ED^3}(3cos^2\lambda - 1) \qquad (4)$$

S is represented by the equation:

$$\frac{amEP^2}{2ED^3}(3cos^2\lambda - 1) + \frac{a\mu}{EP} + \frac{\omega^2 P'P^2}{2} = C$$

where a is the gravitational constant, PD is the distance between the center of the sun and the test point on the surface of water, EP is the distance between the center of the earth and the test point on the surface of water, μ is the mass of the earth, ED is the distance between the center of the earth and the center of the sun, P'P is the distance between the test point and the rotational axis of the earth, ω is the angular velocity of the rotation of the earth, θ is the latitude and C is constant.

$$\eta = \frac{ma^4}{4\mu ED^3}(3sin^2\delta - 1)(3sin^2\lambda - 1) + \frac{3ma^4}{4\mu ED^3}sin2\delta sin2\lambda cos(H+\phi) + \frac{3ma^4}{4\mu ED^3}cos^2\delta cos^2\delta cos^2\lambda cos[2(H+\phi)]$$

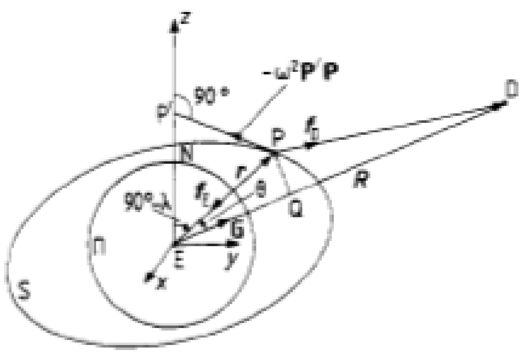


Figure 23 (Kapoulitsas, 1985)

By several complicated calculations, it is possible to find the theoretical value of the height of the tide on each point of the free surface of the water at some moment.

δ is the declination of the earth, H is the westward hour angle of the earth from Greenwich, ϕ is the east longitude of the test point, η is tidal height, and λ is the latitude of the test point. (Kapoulitsas, 1985)

With this kind of ideal model, we can satisfactorily understand how tides are generated by the combined actions of the earth, the moon and the sun. More advanced and complicated models are needed if we will study the real tides precisely, because tides are also impacted by many other factors, such as the shape of the coasts and the depth of the water. People use a Finite- Volume Coastal Ocean Model to simulate the tides in a numerical way. For every node chosen in a large area where tides are simulated, it can be written that:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - fv = -g\frac{\partial \zeta}{\partial x} - F_x$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + fu = -g\frac{\partial \zeta}{\partial y} - F_y$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial[u(h+\zeta)]}{\partial x} + \frac{\partial[v(h+\zeta)]}{\partial y} = 0$$

where x is the east direction and y is the north direction; u and v are the depth integrated east and north velocities; h is the undisturbed depth of water; ζ is the height of the free surface relative toh; g is th gravititational acceleration; t is the time; f =2πsin(latitude) is the angle the rotational plane of an ideal Foucolt's pendulum rotates once per day driven by Coriolis force;

$F_x = \kappa u \frac{\sqrt{u^2+v^2}}{h+\zeta}$ $F_x = \kappa v \frac{\sqrt{u^2+v^2}}{h+\zeta}$ where κ is the bottom friction coefficient.

Using FVCOM, the tides are then simulated with the values of u, v, and we record ζ every 1/24 of a tidal period. The amplitude and phase of the tides can then be calculated at each node by setting z = x + iy and fitting a cosine curve to the surface height. To ensure that the simulations were producing accurate results, these values were compared to measured values for the tidal phase and amplitude and the bottom friction coefficient is adjusted until the mean amplitude difference between the calculated and observed values was a minimum.

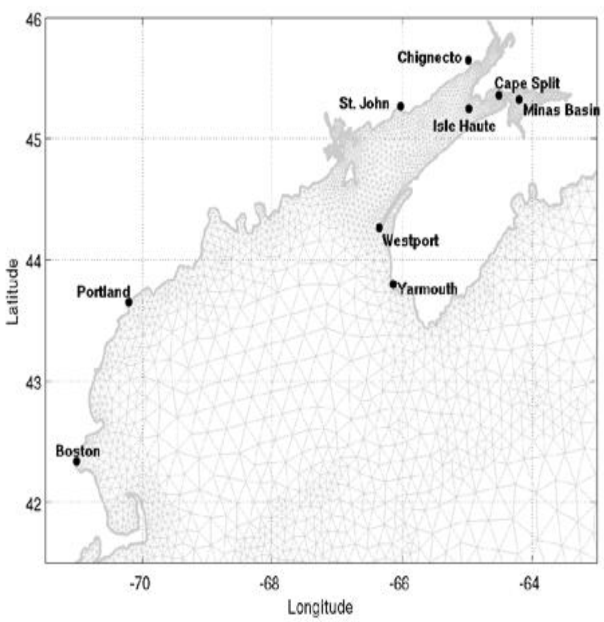


Figure 24 (McMillan & Lickley)

In the Bay of Fundy, Gulf of Maine and a region of the Atlantic Ocean, people use this model to simulate tides, and after conducting several numerical simulations, this bottom friction coefficient was chosen to be 0.0026. (McMillan & Lickley)

Technologies for harvesting tidal energy can be categorized into two groups, namely, tidal barrage, or dam method, and tidal turbine method. In tidal barrage or dam method people first use a reservoir to store water with high potential energy, captured by a barrage or dam during high tide. At low tide the gates are opened and electricity is generated as gravity pulls the water down through turbines installed along the barrage or dam, converting the potential energy into kinetic. Tidal barrage or dam systems can be operated in two modes, namely, single- basin tidal barrage mode and multiple or double basin mode. In a single basin tidal barrage mode, people use a single

Table 7 (McMillan & Lickley)

Station	Observed Amp.	Observed Phase	Modeled Amp.	Modeled Phase	Difference Amp.	Difference Phase
Boston	1.34	111	1.36	116.2	-0.02	5.2
Portland	1.33	103	1.36	106.4	-0.03	3.4
Saint John	3.04	98	3.05	97.2	-0.02	-0.8
Chignecto	4.18	103	4.27	100.4	-0.09	-2.6
Minas Basin	5.48	121	5.35	117.9	0.13	-3.1
Cape Split	-	-	4.71	107.8	-	-
Isle Haute	4.18	99	4.07	96.5	0.11	-2.5
Westport	2.20	80	2.18	79.1	0.02	-0.9
Yarmouth	1.63	63	1.66	63.1	-0.03	0.1

barrage across the estuary for power generation. Three different methods of operation of barrages, all of which allow water to flow through the barrage, have been designed to be employed with a single basin for power generation. In an ebb generation mode, electricity is generated during ebbs, while in a flood generation mode, electricity is generated during floods. The two-way generation mode, in which it is possible to generate electricity in both ebbs and floods by using bi- directional turbines, is the most advanced, since it reduces period with no generation and makes the peak power for generation to be available lower. However, this mode also required more operating and maintenance costs than the ebb generation mode and the flood generation mode. In a multiple or double basin mode, one or more basins are used to store water in order to ensure that there would always be a generation capability. Currently, there are four large tidal power stations in the world: the La Rance Plant, France, the Kislaya Guba Plant, Russia, the Annapolis Plant, Canada, and the Jiangxia Plant, China. With the highest tides in the world, the Bay of Fundy, is a good choice to tidal barrage or dam for power generation, but since there are still several issues to be decided upon, such as the environmental impacts and the limited capacity of electricity transmission there, more studies and investigations have to be made before any projects are started.

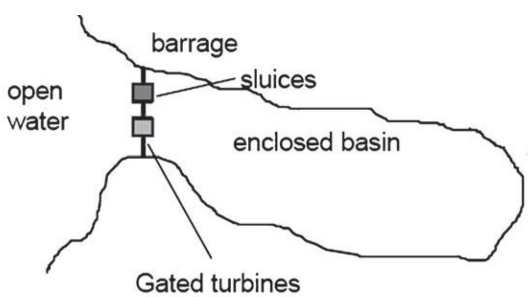


Figure 25: Single Basin Tidal Barrage System (Tushar K. Ghosh, Mark A. Prelas, 2011)

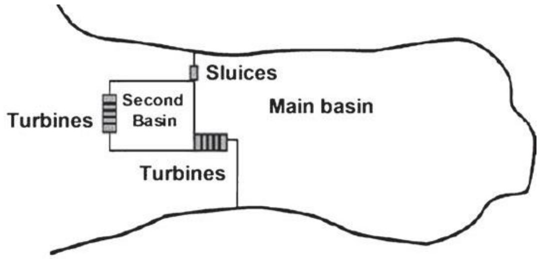


Figure 26: Double Basin Tidal Barrage System (Tushar K. Ghosh, Mark A. Prelas, 2011)

Tidal turbine method: Tide turbines are used for power generation just like wind turbines used in a wind power station. Although the tide turbines look the same as wind turbines, their working principle is different. Tide turbines harvest power by lifting or dragging water while wind turbines harvest power by lifting or dragging air. Tide turbines are made of different materials, set up in more complicated systems and have to be feasible in the intricate undersea surroundings. Although a few countries have started to pursue the use of tidal turbine method to generate power from tides, the technology still needs to be developed to make the method available. Four types of turbine have been designed for generating electricity from the tides: Horizontal Axis Turbines, Vertical Axis Turbines, Linear Lift Mechanism or Oscillating Hydroplane Systems and Venturi Based Systems. Kinds of de- signs of tidal turbines turbines are commercially available now, but more are only being tested. (Tushar K. Ghosh, Mark A. Prelas, 2011)

Ocean Current Energy Capture

In order to meet growing global energy demand new and innovative methods of power production are being researched. Renewable sources of energy that have little or no negative environmental impact are superior to coal burning and other polluting, nonrenewable methods. Researchers have recently begun to evaluate the potential of our ocean's perpetually flowing currents, tides and waves for energy production. This paper presents current research being conducted on the potential of utilizing the energy of ocean currents specifically to generate green electricity.

A major issue with wind and solar energy is the discontinuity of the energy source. Dissimilarly, ocean "currents are relatively constant and flow in one direction only." (U.S. Department of the Interior,

2006) The Gulf Stream, located "just 15 miles off Florida's coast" flows at "nearly 8.5 billion gallons per second." "The Gulf Stream is about 30 miles wide and shifts only slightly in its course" (Skoloff, 2008) Utilization of only 1/1000 of the estimated available energy produced by the Gulf Stream would provide Florida with 35% of its current electricity demand and is has equivalent power production potential of 10 nuclear plants. (U.S. Department of the Interior, 2006) The images below (figure 24) illustrate global ocean currents and a close up of those in the vicinity of the United States.

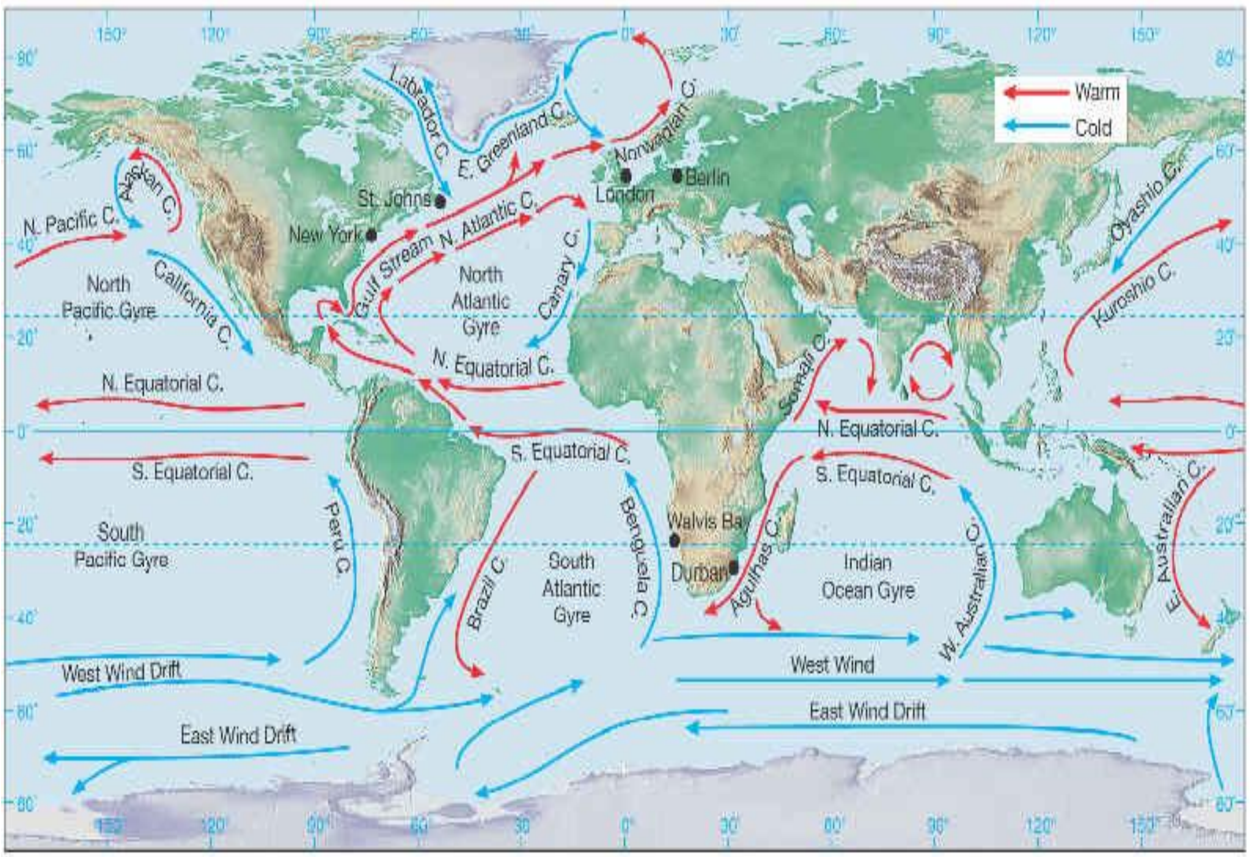


Figure 27 Ocean Currents (Zarella, 2011)

Ocean currents flow significantly slower than wind. Velocity is important to the amount of kinetic energy produced by any flow, as shown by the following equation.

Kinetic Energy = (1/2) mass* $velocity^2$

Ocean currents compensate for their lack of speed density. "Water is about 835 times denser than wind, so for the same area of flow being intercepted, the energy contained in a 12-mph water flow is equivalent to that contained in an air mass moving at about 110mph." (U.S. Department of the Interior, 2006)

Ocean current energy is a budding field. Current prototypes are just that; with no one using this technology commercially. Most work currently being conducted focuses on the amount of energy that could be extracted by these currents. One method for generating electricity from ocean currents that has already been constructed and tested is submerging turbines that utilize blades similar to that of a wind turbine to capture hydrodynamic energy. These turbines may be positioned with the rotating axis facing vertically or horizontally with respect to the surface. Posts, cables or anchors must be utilized to maintain the turbine's positioning relative to the current. One unique idea being investigated is to utilize concentrators (shrouds) to channel current into the path of a turbine, increasing the power production potential of the fluid flow. (U.S. Department of the Interior, 2006) Areas where current is strong enough could become home to clusters of such devices, similar to wind farms currently springing up around the globe.

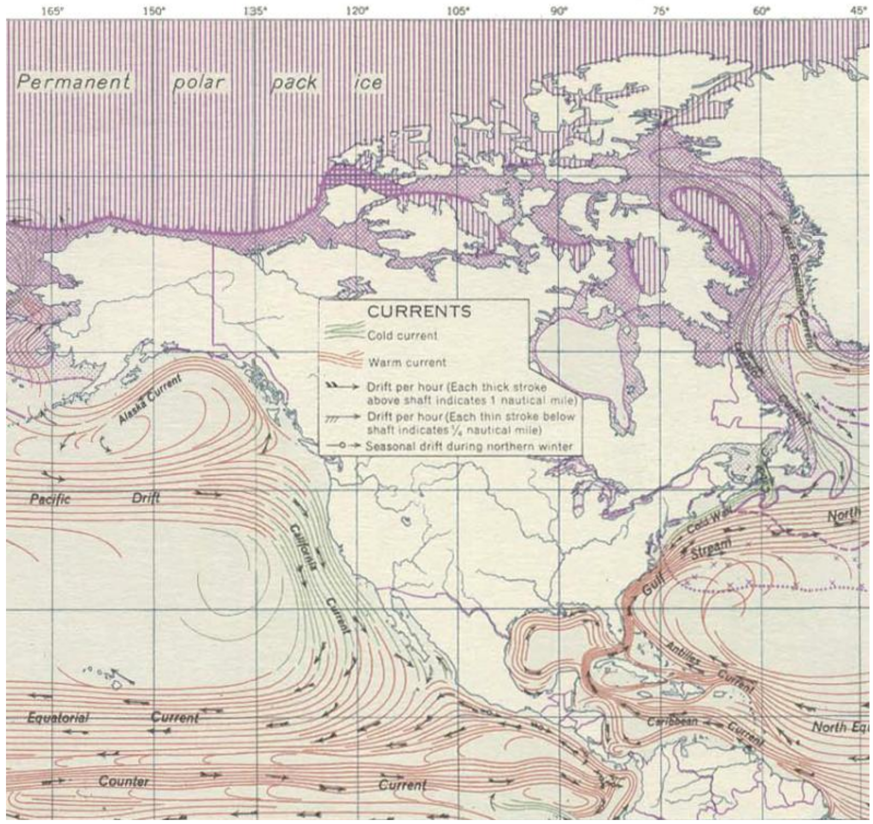


Figure 28 Ocean Currents (U.S. Department of the Interior, 2006)

There are seventeen major surface ocean currents. Deep cold water currents also exist, but pose more challenge for installation and maintenance access. These currents have been organized into the table below (figure 25) with their location, type and volumetric flow rate.

Table 8: Seventeen major surface ocean currents (The Cooperative Institute for Marine and Atmospheric Studies)

Agulhas Current	Indian	Warm	20 to 90 million m^3/s
Alaska Current	North Pacific	Warm	< 2million m^3/s
Benguela Current	South Atlantic	Warm/Cool	7 to 15 million m^3/s
Brazil Current	South Atlantic	Warm	20 to 70 million m^3/s
California Current	North Pacific	Cool	< 2million m^3/s
Canaries Current	North Atlantic	Cool	8 million m^3/s
East Australian Current	South Pacific	Warm	< 2million m^3/s
Equitorial Current	Pacific	Warm	< 2million $m^3/s1$
Gulf Stream	North Altantic	Warm	30 to 150 million m^3/s
Humboldt (Peru) Current	South Pacific	Cool	< 2million m^3/s
Kuroshio (Japan) Current	North Pacific	Warm	< 2million m^3/s
Labrador Current	North Atlantic	Cool	4 to 8 million m^3/s
North Atlantic Drift	North Atlantic	Warm	30 million m^3/s
North Pacific Drift	North Pacific	Warm	< 2million m^3/s
Oyashio (Kamchatka) Current	North Pacific	Cool	< 2million m^3/s
West Australian Current	Indian	Cool	< 2million m^3/s
West Wind Drift	South Pacific	Cool	< 2million m^3/s

The data above clearly illustrates the most energetic ocean currents are the Gulf Stream, the Agulhas Current, the North Atlantic Drift, the Brazil Current and the Benguela Current. These are located off the coasts of Florida, South Africa, Newfoundland and Brazil, making these areas most suitable for commercial scale ocean current power production.

Environmental issues with ocean current energy technology pertain to the local ecology as well as loss of space that may have been used for fishing, diving or other purposes. Ocean currents generally flow fastest relatively close to the surface. The Gulf Stream for example moves most rapidly from thirty to forty feet below the surface. While this should be enough clearance for vessels, one concern is the destruction of sea life moving through the area. One proposed technology to combat the fish chopping issue is to replace turbine blades with large parachutes that capture ocean current in one direction and then close in order to return to their original position. Other remedies include protective fences and sonar activated brakes. (U.S. Department of the Interior, 2006) Some areas that would be suitable for ocean current energy generation are currently utilized for commercial fishing. In the years to come power companies and local fisherman may battle over these limited waters. We may witness legislation that maps which areas are restricted to energy production or fishing use exclusively. "Concerns have been raised about risks from slowing the current flow by extracting energy. Local effects, such as temperature and salinity changes in estuaries caused by changes in the mixing of salt and fresh waters, would need to be considered for their potential impact on estuary ecosystems." (U.S. Department of the Interior, 2006) The law of conservation of energy tells us that energy is neither gained nor lost in a closed system. The impacts of removing energy from the ocean current system would most likely be a reduction in temperature and velocity. To what degree these changes will impact the environment is unknown and will require significant research and experimentation.

Another major hurdle for the business aspect of ocean current power production is economically viable deployment and maintenance access to submerged turbines. One company, Sustainable Marine Technologies, is designing a platform to overcome these obstacles. The device in question is called PLAT-O. It is a moored, self-buoyant, towable docking hub for up to five energy capturing devices. PLAT-O's integrated buoyancy allows it to submerge to a required depth and later return to the surface under its own power; eliminating the need for lifting equipment to be present on maintenance vessels. The prototype is anticipated to be ready for testing by 2014. (Africa News Service, 2011) Only time and research will tell how economically viable ocean current energy technology is and will be in the future.

Wind Energy: Technology and Applications

Worldwide energy consumption in 2008 was 474 exajoules, or 474*10^18 Joules. Currently eighty to ninety percent of this demand is supplied by the combustion of fossil fuels such as oil, coal or natural gas. Fossil fuels are non-renewable and their combustion releases carbon dioxide and particulate matter into the atmosphere. The Kyoto Protocol, adopted in Kyoto Japan on December 11th 1997 set targets for reduced CO2 emissions in developed nations. "Under the protocol, countries' actual emissions have to be monitored and precise records have to be kept." (United Nations Framework

Convention on Climate Change) “Green Taxation” is an emerging trend in developed nations. It involves taxing power companies per ton of CO2 emissions released. The goal of green taxes is to make other, cleaner forms of energy production more economically viable by increasing costs of dirtier technology.

Power plants generate more CO2 emissions than any other technology sector. (Exxon Mobil, 2010) Electricity generation technology is shifting its focus from maximum efficiency to maximum clean efficiency. Researchers and engineers are looking for ways to harness natural energy from the world around us. The energy generated by wind is no secret. It has been powering food production in wind mills for hundreds of years. Wind is caused by the uneven heating of the earth’s surface by the sun. Water and land absorb heat at different rates. We know from the law of conservation of energy that energy is never created or destroyed, only transferred. This means wind energy really comes from that giant power plant in the sky, the sun.

Table 9: Contrast (Al-Shemmeri, 2010)

Fuel	Calorific Value MJ/kg	CO_2 kg / kg fuel	CO_2 / Energy kg / MJ	SO_2 kg / kg fuel
Coal	26	2.361	0.091	0.018
Oil	42	3.153	0.075	0.040
Natural Gas	55	2.750	0.050	0

Wind turbines are machines that convert the wind’s kinetic energy into mechanical energy, and then electricity. The rotor with its airfoil shaped blades “aerodynamically converts the wind’s kinetic energy into mechanical through a connected shaft.” The low speed shaft’s angular velocity is controlled by a brake system which can slow and even stop the turbine if dangerously energetic winds are present. The low speed shaft’s angular speed is multiplied in a gear box and transferred to the high speed shaft which spins a generator. (Al-Shemmeri, 2010) Both low and high speed shafts, the gearbox and generator are located inside the nacelle, or

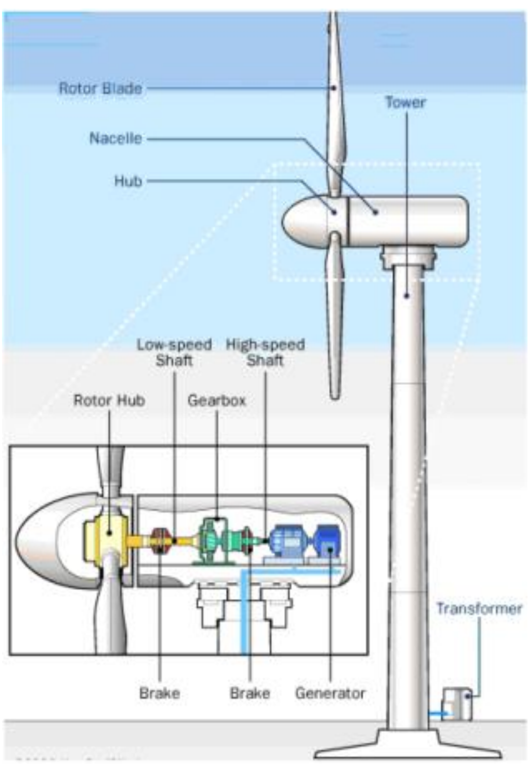


Figure 29 HAWT Turbine (Al-Shemmeri, 2010)

body of horizontal axis wind turbines. (The European Wind Energy Association) The turbine is elevated by a tower and is fixed to the ground or sea bed.

There are two distinct types of wind turbine design. The type most common for commercial power generation is horizontal axis wind turbines or HAWT. These usually utilize a two or three blade rotor. The gearbox and generator are located at the top of the tower inside the nacelle. The second type is referred to as vertical axis wind turbines or VAWT. These turbines have specially designed air foils that are capable of harnessing wind energy from any direction. VAWTs have the distinct advantage of not having to be turned into the direction of the wind. (Al-Shemmeri, 2010)

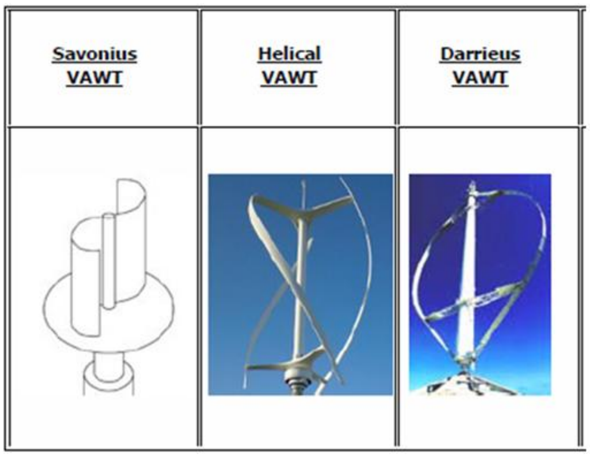


Figure 30 VAWT (Al-Shemmeri, 2010)

Where is the best location for a wind turbine farm, or collection of wind turbines in a single area? The amount of energy that can be extracted by a single wind turbine is a function of the wind velocity, blade radius and air density. (The European Wind Energy Association, Wind Directions, 2011) Wind power density is “a calculation for the effective power of the wind at a current location. (Hasnan, 2008)

- WPD = Power/Area = (1/2)ρ$*V^3$ where ρ= air density and V= air velocity (Hughes)

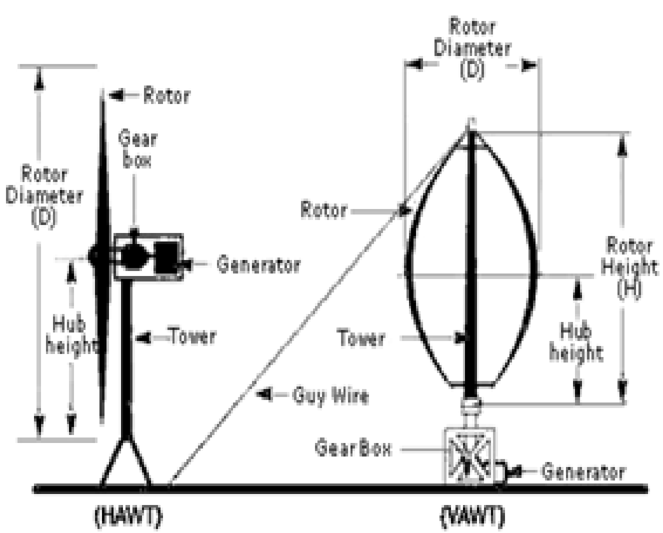


Figure 31 HAWT and VAWT (Al-Shemmeri, 2010)

Air density is inversely proportional to altitude. The most wind energy can thus be extracted from locations with low altitude and high wind speed. Several manufacturers of wind turbines have looked toward the sea for low altitude, high density wind. It is clear that velocity, being cubed in the wind power density formula is more important than density to wind power. Mountainous regions have become home to wind farms. The reliably active, high wind speeds outweigh the losses caused by high altitude and low density. The wind power density equation describes the power potential of a volume of space. The ideal wind power formula describes the amount of energy that a single wind turbine can extract from wind that is blowing through it.

- Power=C_P*(1/2)ρ*A*V^3 where ρ= air density, A=circular blade area and V = air velocity

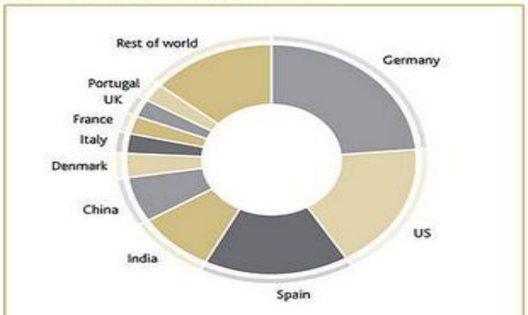
C_P is referred to as the power coefficient (or Betz coefficient). Ideal power capture is limited by the Betz coefficient, with C_P=0.59. No wind turbine will ever achieve a higher power extraction ratio than 59% of the wind power density. An abbreviated version of Al-Shemmeri proof is presented below.

- Ideal power equation comes from K.E. (P=(1/2)$\dot{m}$(V_1^2-V_2^2) with mass flow rate ($\dot{m}$= ρ*A*V_R)
- V1= air inlet speed, V2= air exit speed & VR= rotor speed=(1/2)(V1+V2)
- Substitute & differentiate with respect to V2 for quadratic equation (3V2-V1)(V2+V1)(ρ*A)/4)
- Set quadratic = 0 to find the maximum values of the quadratic equation (critical points)
- Divide out (ρ*A)/4), leaves V2=-V1 (unrealistic) and <u>V2=V1/3</u> (realistic)
- Substitute V2=V1/3 above to get P=(.5925)*(1/2)ρ*A*V^3

"Capacity Factor is an indicator of how much energy a wind turbine makes in a particular place. It is the ratio of the actual energy produced in a given period, to the hypothetical maximum possible." (Renewable Energy Research Laboratory) All power plants have a capacity factor based on physical constraints of the technology. This factor further reduces the theoretical power of wind turbines by taking factors such as maintenance time and geographical variations in wind speed and air density into account. Typical wind power capacity factors are between twenty and forty percent. Improvements in wind turbine design, such as self-lubricating components are increasing capacity factor. Hydro-electric capacity factors may be in the range of thirty to eighty percent. Fossil Fuel combustion is less affected by physical constraints and a typical plant may have a capacity factor between seventy and ninety percent. Combined cycle natural gas plants are currently limited by a capacity factor of approximately sixty percent. Capacity factor is not related to efficiency of the energy generation.

- Efficiency = Input Energy/ Useful Output Energy

TOP 10 TOTAL INSTALLED CAPACITY



	MW	%
Germany	22,247	23.6
US	16,818	17.9
Spain	15,145	16.1
India	8,000	8.5
China	6,050	6.4
Denmark	3,125	3.3
Italy	2,726	2.9
France	2,454	2.6
UK	2,389	2.5
Portugal	2,150	2.3
Rest of world	13,019	13.8
Total top 10	**81,104**	**86.2**
Total	**94,123**	**100.0**

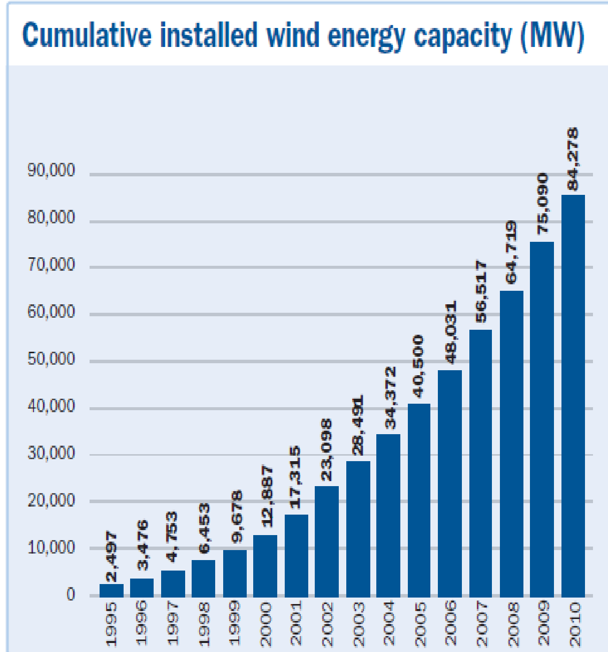


Figure 32: Installed Capacity (The European Wind Energy Association, Wind Directions, 2011)

"Wind power plants have a much lower capacity factor but a much higher efficiency than typical fossil fuel plants. A higher capacity factor is not an indicator of higher efficiency or vice versa." (Renewable Energy Research Laboratory)

Wind energy capacity describes the amount of power a single turbine can actually capture. This value is obtained for individual turbines by applying the unique capacity factor for the turbine's location to the power equation proved earlier.

- Wind Energy Capacity = Power =C_P*(1/2)ρ*A*V^3*(CF) where CF = the capacity factor

Cumulative installed wind energy capacity is a summation of the wind energy capacity of all known wind turbines worldwide. The second image breaks the worldwide wind energy capacity into countries of origin. The wind energy capacity of a wind turbine is still an idealized model for power capture. Actual power is further reduced by frictional losses in the turbine's drive train and generator. Since Power = Force*Velocity, a more accurate mathematical model for estimating turbine power could be produced by evaluating the friction forces within individual turbine components and multiplying by their respective angular speed. The sum of these products then must be subtracted from the wind energy capacity.

- P=[C_P*(1/2)ρ*A*V^3(CF)]-(F_f*ω)

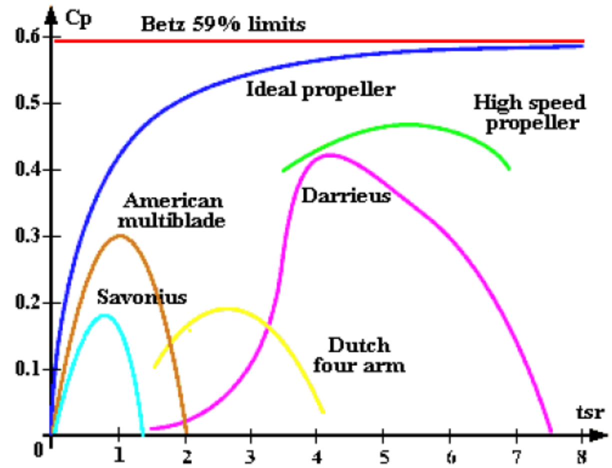


Figure 33: tsr vs. Cp (Al-Shemmeri, 2010)

Tip Speed Ratio (TSR) is crucial to wind turbine design. It is defined as "the speed of the blade at its tip divided by the speed of the wind. For example, if the tip of a rotor blade is traveling at 100 mph and the wind speed is 20mph then the TSR is 5." (Windy Nation) "If the rotor of the wind turbine turns too slowly, most of the wind will pass undisturbed through the gap between the rotor blades. Conversely if the rotor turns too quickly, the blurring blades will appear like a solid wall to the wind." The most suitable speed ratio depends on the number of blades in the rotor design as well as their geometry. Generally fewer rotor blades correspond to higher TSR. (Al-Shemmeri, 2010) Physics and fluid analysis have produced the data displayed in the graph.

Wind energy is a zero emission, reliable and completely renewable resource. It is not the final solution to our future energy demand but the advantages it presents will ensure its growth and utilization for decades to come.

Solar Cell Technology

Solar technology is powered by an almost unlimited source of energy. There has been steady improvement of photovoltaic cell efficiency in the past decades, however overall efficiency is still low. The way a solar panel works is "some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity" (Knier). Some of the most common materials used in today's solar cells is monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide. Below is diagram of a very basic solar cell.

It is a truly amazing technology, but currently some of the most efficient cells are only around 40% efficient and the price severely increases as the efficiency is increased. Even at 40% this is still a far cry from where the technology needs to be in order to make it more popular and reasonable for large-scale use. Below is a timeline of various solar cells and how they've progressed in efficiency over the past 35 years.

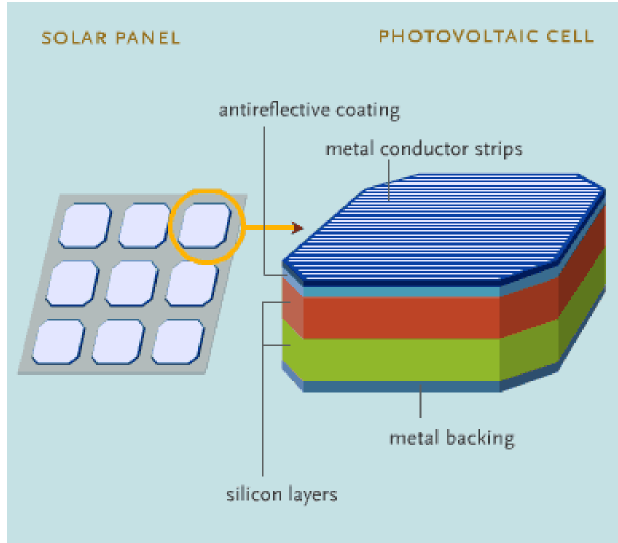


Figure 34. Diagram of a Basic Solar Cell.

There are countries around the world that are trying to utilize solar technology to cut down on their fossil fuel dependence. Countries such as Spain have been utilizing their high exposure to sun to establish solar farms in the areas that receive the most direct sunlight. Currently the United States has very little in the ways of solar power generation and remains focused on coal and natural gas.

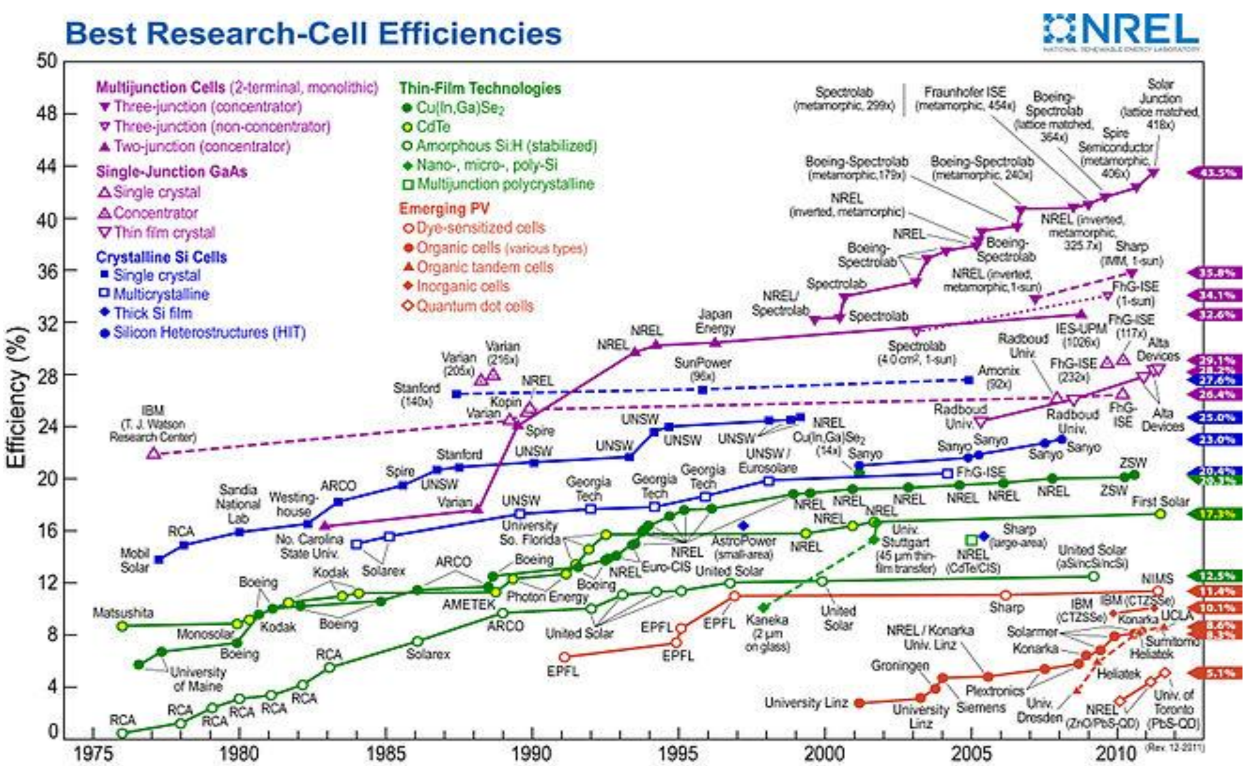


Figure 35. Change in Research-Cell Efficiencies over time.

Table 10: 2008 US Electricity Generation by Source & Weighted Average Cost Per kWh.

Energy Source	% of Total	Cost per kWh	Weighted Avg Cost
Nuclear	19.7%	$0.04	$0.008
Hydro	6.1%	$0.03	$0.002
Coal	48.7%	$0.04	$0.022
Natural Gas	21.4%	$0.10	$0.022
Petroleum	1.1%	$0.10	$0.001
Other Renewables	3.0%	$0.15	$0.005
	100%		$0.059

Solar farms have started popping up in more vacant lots across the world in areas that receive the most exposure to the suns rays. There are two main types of these farms, which are rows upon rows of photovoltaic cells and then reflective mirrors focused on a focal point. The rows of photovoltaic cells do exactly what they appear to do, which is absorb the power from sun using hundreds of cells all aimed so they can efficiently capture the suns rays. The system using the focal point uses mirrors to reflect the rays of the sun onto a relatively small area in order to boil water and then turn a turbine to produce electricity. Both systems produce electricity, but both have issues that limit their efficiency and practicality.

The system that uses the mirrors has to constantly keep each mirror as clean as possible to reduce any interference with the sunrays. In order to do this they have to be continuously be cleaned and maintained. Also because they are generally in very dry areas that receive a lot of sunlight, there is a lot of dust that makes keeping them clean all the more difficult. This is extremely time consuming to have a crew of people to constantly clean the mirrors. There is also the problem of the focal point getting to hot from the concentration of the solar rays. Due to this they can't have all the mirrors focused at exactly the same point, but spread out slightly on an area.

One solution I have developed for this specific type of solar farm would be to reverse the process. Rather than have all the photocells focused onto a focal point, have a device like a giant magnifying glass focused onto a few photocells. This would cause the suns rays to be more focused on a single point, which would mean less material needed to construct such a farm. There is still the issue of overheating of the solar cells, but utilizing units that can cool the solar cells would solve this issue and reduce any inefficiency that would be caused from overheating. Also the tower that focused the rays would have rotate with the position of the sun and likewise the solar cells would have to rotate to continue receiving the rays.

The system that utilizes the rows of solar cells has some issues as well. One being that if a solar cell is to break it first has to be found and then replaced, which can difficult when they all look the same and there are hundreds of them. Similarly these ones can overheat as well and this drives down their efficiency, which isn't all too good to begin with. One example of a specific type of solar cell and the point that its efficiency starts to reduce is the Suntech 190 W monocrystalline. This particular model is rated for -.48%, which means for every degree over 25 degrees C the maximum power is reduced by .48%. This may not seem significant, but on a typical summer day where the temperature is 45

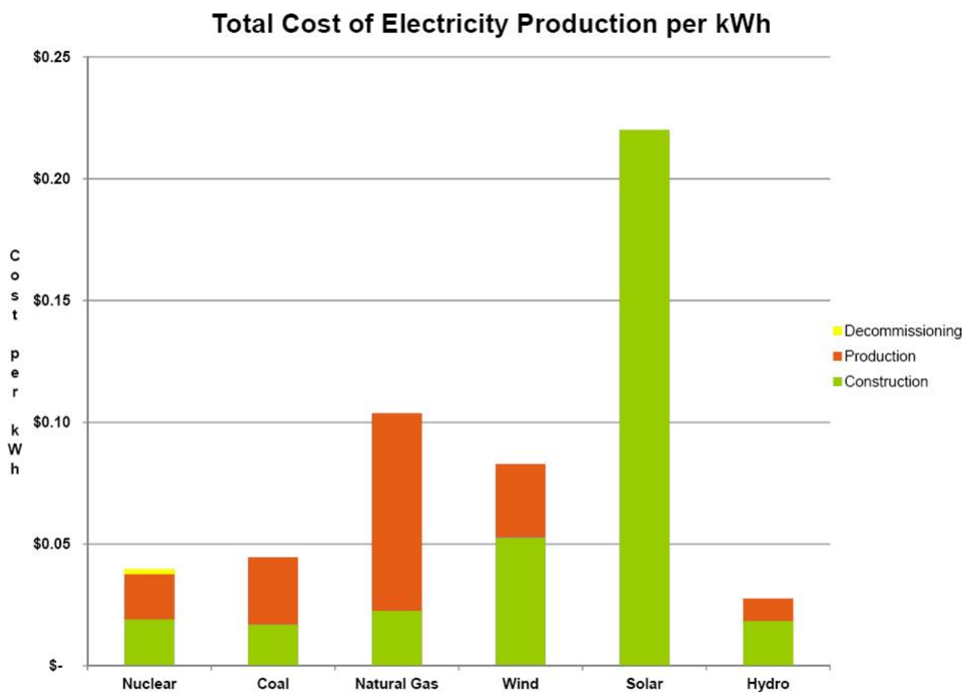


Figure 36: Total Cost of Electricity Production per kWh

degrees C the power output would be 10% less. That's a huge hit especially for a system that might only be 20% efficient to begin with.

Solar cells also have another issue, which are their high costs to manufacture. They are by far the most expensive per kWh as compared to other sources of energy as seen below (Figure 37). Eventually as time goes on and as their popularity is increased the cost to produce them will decrease. Right now for someone to get a solar powered system installed in their house can cost anywhere from $15,000-$50,000, which is a larger amount for the average citizen. The variation depends on size of the house and system as well as the grade of the solar cells. Obviously the more efficient ones (20%-40%)

cost significantly more than the less efficient systems (10%-20%). There are incentives provided from the government to encourage people to get these systems, but when you think about money from the government is still your tax money and you are still paying for it in the end. The average cost per kilowatt of solar power is around $0.25, which is much higher than the upfront cost of fossil fuels. Due to the upfront cost and long turn around period most people are hesitant to switch to solar when they can get cheaper fossil fuel power.

There are current projects that are underway that working on advancing the technology of current solar cells. Nanosolar is one company that has been working on a project to literally print solar cells onto paper. "Nanosolar grows a thin film semiconductor using a printing and annealing process that is far faster than conventional high vacuum deposition. We leverage recent advances in nanoscience to create high quality, highly uniform layers of nanoparticles dispersed through our proprietary CIGS ink" (Solar Cell, 2012). Current solar cells are said to have two main flaws and those are that they reflect up to 30% of the light that hits them and the reabsorb energy into the material, but with this advancement hopefully both would be resolved.

There is another technology being developed that would allow for solar cells to be painted onto any metallic surface. This would turn whatever is coated with the paint into a giant solar cell. The applications of this would be limitless for everything from cars to large skyscrapers. "The photovoltaic paint is made up of a layer of dye and a layer of electrolytes and can be applied as a liquid paste. Altogether the sheets of steel get four coats of solar paint- an undercoat, a layer of dye sensitized solar cells, a layer of electrolyte or titanium dioxide as white paint pigment and, finally, a light absorber or sensitizer. The excited molecules release an electron into the nanocyrstalline titanium dioxide layer, which acts as an electron collector and a circuit. The electrons finally move back into the dye attracted by positively charged iodide particles in a liquid electrolyte." (Knier)

Solar cells are currently being used in applications such as cars, satellites and on homes where they can be afforded. Solar cells are the primary source of energy for satellites because a satellite can't be constantly refueled with material such as fossil fuels and running an electrical cord to the satellite would be highly impractical. Without the solar cells we would be faced with the challenge of powering all these satellites, otherwise the communication and other resources we rely on would be impossible. Also there are never clouds in space that prevent the satellites from receiving the suns rays making it all the more ideal. Solar powered cars are one application that is still severely impractical for widespread production. The reason for this is because today's solar cars can't carry more than one passenger and if the sun isn't shining you're not going to get too far. Also the battery packs they have been using are still relatively heavy and weigh down the vehicles.

While there is still a great deal that still needs to be developed for this technology to become mainstream, there continues to be advancements every year. Sometime in the next few decades, I believe we will see a fundamental change in the way we think of energy. More and more of this technology is becoming integrated into everyday life and I don't see it slowing down anytime soon. I hope that I will see the day that this technology helps eliminate our need for any fossil fuels.

Hydrogen as a Unit of Energy Storage

Hydrogen is already starting to be used more frequently across the world as a power storage device. It is foreseen as one of the main sources power for automobiles in the near future. Hopes are to not only be able to use hydrogen in cars, but everything from computers, cell phones and homes. There are major advances taking place in this area that are showing signs of significantly advancing the widespread use of hydrogen power. Using this energy source we could potentially eliminate our dependence on fossil fuels. It is one of the most ideal sources of power because of how "green" of a technology it is. This is due to the fact that the only byproducts from hydrogen combustion are energy and water. Hydrogen is also one of the most abundant resources in the universe although it does not occur naturally on Earth as a gas, but is rather always combined with other elements in various compounds. There are hurdles that must be overcome in order to make hydrogen a viable source of energy.

Due to the fact that hydrogen doesn't occur naturally as a gas on Earth it has to be produced using a process called electrolysis. "Electrolysis is defined as splitting apart with an electric current. Decomposition of the water occurs when a direct current (DC) is passed between two electrodes immersed in water separated by a non-electrical conducting aqueous or solid electro-lyte to transport ions and completing the circuit"(5). An example of this would be the use of electrolysis to split water into hydrogen and oxygen to make hydrogen fuel ($2H2O \rightarrow 4H+ +4e- +O2$). Most of today's hydrogen is produced from natural gas although it can be derived from many other hydrocarbons. There are programs that are exploiting other renewable technologies, such as wind or solar, to power the electrolysis processes that make this process a truly green and renewable one. They are currently using the excess of these technologies to produce the hydrogen, so they don't interrupt the energy being used for powering homes and other systems. Currently most of the electrolyzer systems we use today are between 56%-73% efficient in producing hydrogen fuels. "Typical commercial electrolyzer system efficiencies are 56%–73% and this corresponds to 70.1–53.4 kWh/kg"(5).

There are currently vehicles that can and do run off of hydrogen fuel. One of the most note worthy vehicles is the NASA space shuttle. They have been using hydrogen for over thirty years and they use the byproducts of the hydrogen combustion to generate clean drinking water for the crew of the shuttle. There are also hydrogen-powered cars that have been built, but the technology isn't at the point of mass production for the public. Most of the hydrogen-powered cars in America are located out west towards California because that is where the heaviest concentration of fueling stations is located. In the United States today we use between 140-150 billion gallons of gasoline annually in order to power just our vehicles. If we were to switch to using strictly hydrogen we would need around 330 billion gallons of water to create the necessary hydrogen. Although it will not happen overnight any steps we can take towards replacing our dependency on fossil fuels will not only benefit society, but also the environment for future generations.

Back in July of 2008 there was a huge breakthrough by Chemist Daniel Nocera of MIT and Matthew Kanan of Monash University. They had discovered a new method that allowed them to remove platinum from the electrolysis process. The way they did this was by substituting cobalt and phosphates in for the expensive platinum. Platinum is currently used because of the reaction that occurs when H2 comes into contact with it. The H2 reacts with the platinum and splits into H+ ions and two e- are released and captured to do power a motor. By using this they've gone from using something that cost $1700-$2000 per ounce to something that only cost $2.25 and $0.05 per ounce. Cobalt is one of the most common elements being in the upper third according to their abundance in the Earth's crust. Of course the United States doesn't currently mine any cobalt, so we would still be dependent on foreign countries for our fuel source. The major suppliers of cobalt in the world are Zambia, Canada, Russia, Australia, Zaire, and Cuba. However this is still a huge advance towards making it realistic for the general public to utilize, because there is still the large upfront cost of the initial setup. Daniel Nocera and Matthew Kanan have reported that they were able to produce oxygen from water at room temperature in a glass jar by having a thin film of cobalt and phosphate on an electrode. Inspiration for the idea came from nature when Nocera was observing the reaction that takes place in photosynthesis, where a leaf is able to rearrange waters bonds using just sunlight. The idea would be to someday recreate this process in every house around the world to produce cheap energy. On the other side of the process there are the fuel cells, which were mainly reliant on platinum as well to re-bond the hydrogen and oxygen to produce electricity. Recently Chemist Bjorn Winther-Jensen of Monash University in Australia found an alternative to the expensive platinum by using a special polymer blend for the electrodes of the fuel cells. One of the main applications they are working towards using this technology is the mini fuel cell used for devices such as computers.

Another breakthrough that shows promise for hydrogen is the use of highly efficient nanometal electrodes. "As a material is divided into smaller and smaller particles, the three dimensional surface area per gram increases logarithmically. For example, a one gram pellet of nickel is 0.6 cm in diameter and has a surface area of 1.12 cm2, or about that of a fingernail. A 10 nm particle has a surface area of 67 m2 per gram or 27 feet on a side - a 60,000,000% increase" (6). The increased energy efficiency using this process is up to 85%. This triple nano catalyst design is 100x higher than graphite or nickel.

Hydrogen is a fuel that has the potential to revolutionize the way we look at producing energy. It is a technology that is already being used today and is showing signs of expanding in the near future. It is already being used in certain military applications to lighten the load of batteries a single soldier has to carry. The average soldier carries around thirty pounds of batteries, but using fuel cells they can reduce that burden to just five pounds. Fuel cells are also used for unmanned aircraft, watercraft and ground units and hydrogen is the best fuel to be used by the fuel cells. Fuel cells also offer the added benefit of being silent compared to the roar of Humvee engine commonly used by today's troops. With the use of fuel cells and the hydrogen to power them, there are countless applications for this technology and I believe as we continue on we will start to see more and more hydrogen powered devices integrated into our everyday lives.

However there are dangers that are associated with hydrogen that have slowed its widespread use. While the hydrogen remains safe in a sealed tank, if the tank is punctured and the hydrogen is released then it becomes a hazard. Hydrogen burns in the presence of an oxidizer such as oxygen and the flames of a hydrogen fire can be almost invisible making it all the harder to extinguish. Also if there were a leak of the gas into a closed car cabin it could cause asphyxiation because it would deprive you of oxygen. One other factor would be if it were to spill onto someone it would cause extreme frostbite almost instantly because of the low temperature of liquid hydrogen. Although these are issues that have slowed its integration into society, once we can overcome these obstacles I believe it will be a more prominent source of energy.

Nuclear Fission: The Role of Atomic Energy

Before 1945, most development of nuclear science and technology was made on the atomic bomb. By the end of the second world war in 1945, during the process of developing nuclear weapons, it was realized that nuclear energy can be used peacefully and directly, and those ideas came true as new technologies were discovered. The focus of nuclear science and technology then was moving on to harnessing nuclear energy in a controlled way to producing electricity. Since the first experimental breeder nuclear reactor to produce electricity started up in 1951 in the USA, nuclear energy has been on the process of becoming one of the primary energy sources in the world.

Nuclear energy plays the fifth largest energy production role, 5.2% of global energy consumption, following oil, coal, natural gas and hydroelectricity. While the primary energy consumption and the population of the world are both increasing in an almost linear way, we may predict that the primary energy consumption will keep on increasing almost linearly like today and nuclear energy will continue being an important role to satisfy our demand for energy.

Although the consumptions of hydroelectricity and renewable energy are growing fast during recent years, they still don't match nuclear energy. Moreover, the economic dimension of fossil fuels in each country is heavily influenced by the availability of natural resources, so nuclear energy may be one of the best choices for some countries.

The most common fissile nuclear fuel is Uranium 235, which is fuel that can be used to release energy by nuclear fission. Uranium is a relatively common element in the crust of the Earth and it is a constituent of most rocks on land and even in the sea. As a result, there are lots of known recoverable sources of Uranium, as well as unknown reserves under land and sea. Changes in costs, prices, technologies or policies, may encourage people to discover more recoverable resources of Uranium. There are more than 5,404,000 tons of known Uranium, of which most are in Australia. In 2009, 1,673,000 tons of Uranium have been discovered in Australia, and this quantity may keep on increasing in the future. This fact assures that nuclear energy may satisfy about 5% of our total demand of energy for more than half a century, even without reprocessing and recycling fuel materials or discovering new resources.

Most current technologies for providing energy are considered to be unsustainable. It is not impossible that the energy supply from nuclear fuel would be exhausted. Although safety measures are built to reduce the impact of nuclear waste on the environment and prevent any accident, the cost of nuclear energy is still low, because once a power plant is built, it usually has a long life and ongoing operating and maintenance costs are low. Moreover, it has advantages in that it produces reliable electricity without emitting carbon-dioxide into the atmosphere at the power plant level. The Kyoto Protocol emission targets call for total annual emissions in OECD countries to be reduced by about 700 million tons of carbon dioxide by 2008-2012, relative to 1990 levels. Although it becomes one of the primary energy in the world, the development of nuclear energy is always accompanied with the threat of nuclear warfare. For example, the reprocessing technologies used in a fast breeder reactor can be used to extract weapons grade plutonium. This kind of problems can be solved by developing and using new technologies to avoid the production of nuclear weapons.

Secondly, much higher level radioactive waste is produced by a nuclear power plant every day. It contains fission products and transuranic elements generated in the reactor core and accounts for over 95 percent of the total radioactivity produced in the process of nuclear electricity generation. The current method to manage higher level radioactive waste is storing the waste until its level of radiation is acceptable.

The third problem is that nuclear accidents may occur and have great impact on human-beings and the environment. Several nuclear disasters, such as Three Miles accident and Chernobyl disaster, have caused a long-time anxiety about nuclear energy. Although new technologies and more effective safety measures have helped to solve this problem, the accident occurred in Fukushima implied that more efforts on disaster prevention are still needed.

One possible solution to all these three problems above is a multinational approach. In a multinational approach, nations build power plants and corporate as partners, then use the energy together. This may be a huge project, and is heavily depended on technologies and policies, but if nuclear energy will lead the world in the future, this project can help us not only avoid nuclear warfare, effectively manage radioactive waste, and prevent nuclear accidents, but also make more area on the earth if those power plants are built in the sea. Many issues must be considered in this project. The legal and regulatory situation in countries in this multinational approach should be harmonized among the partners, the costs and liabilities to all partners in this approach should be weighed against the benefits. This kind of ideas can be found in *Spent Nuclear Fuel from Research Reactors: International Status and Perspectives* by P. Adelfang, A. J. Soares, I. N. Goldman

At last, a big problem is that it is still not sure if nuclear energy will be really competitive in the future. In fact, nuclear energy is relatively sustainable. It is still not possible to provide controlled energy by nuclear fusion, but if energy provided by nuclear fission becomes an effective, safe, acceptable option, it will help transform the current fossil fuel based energy economy to a stable and sustainable energy economy.

Issues Facing Society

Many social controversies are related to energy issues. Overpopulation will inflate the demand for resources, especially sources of electricity. Developing nations require huge amounts of energy to power factories and utilities. Fossil fuels are widely used due to their low cost of production and simplicity. The secondary costs of treating combustion related illness, responding to nuclear accidents, and funding environmental cleanup projects need to be acknowledged and quantified.

Preparing for Natural Disasters

From the common such as droughts, hurricanes, earthquakes, and tsunami's to the rarer earthquakes and geomagnetic reversal, there are a variety of possible natural disasters that could impact humanity's future. The effects and scale of these disasters vary but they always bring a certain amount of destruction and loss of life.

The effects of a natural disaster are dependent of many variables, such as preparedness and the amount of warning before the disaster occurred. Other factors that affect the amount of damage caused by a disaster are the economic development and the democracy level in the area where the disaster occurs. 80% of the deaths from natural disasters between 1964 and 2004 occurred in just 15 countries, of these 15 countries 73% are below the median GDP and 87% are below the median democracy index. The democracy index is a measure of how democratic a country is by examining electoral process and pluralism, civil liberties, functioning of government, political participation and political culture. The deadliest disasters of that period occurred in developing nations, and except for Peru had a GDP of less than $1000 at the time of the disaster, and all except India had a non-representative form of government or were at war during the time of the disaster. The type of disaster varies amongst the top ten indicating that GDP and democracy may be more important than the scale of the disaster. Due to a high correlation between the World Bank's Democracy Index and GDP make it difficult to tell whether it is one factor or the combination that is contributing to lessening the effects of natural disasters. It is also uncertain whether the correlation is because a highly economically developed democratic country is better at dealing with natural disasters or if through some quirk of global positioning the countries which experience more frequent or more deadly disasters are less democratic and less well-off economically. Although, a trend in the increase of GDP's and democracy coupled with a decrease in fatalities from natural disasters despite increased incidence suggests that there may be a causal relationship. (Wright, 2007)

In the past few decades there has been an apparent increase in natural disasters, from 78 in 1970 to 348 in 2004. Part of this trend may be that more people are now living in disaster prone regions and that recording and reporting of natural disasters has become more widespread. However, this doesn't take into account all of the increase and there is a real increase in the number of hydro-meteorological disasters (hurricanes, drought, tsunamis, flood, typhoons) over the past 25 years. Some of this may be from man-made causes like urbanization in flood prone areas and global warming. Another cause of the increase may be natural decadal cycles in the number and intensity of hurricanes as well as large-scale changes in water temperature like El Niño and La Niña. The natural cycle's may cause a decrease in the number of disasters in the future but this may be countered by increasing effects of global warming and other artificial alterations to the environment. (Than, 2005)

Geomagnetic reversal is the natural disaster with the greatest spread as it occurs simultaneously in varying degrees across the earth. Geomagnetic reversal occurs when the magnetic poles of the earth switch over a period of transition. While the difference in orientation of the magnetic field isn't in and of itself dangerous, during the transition fluctuations and regularities in the magnetic field can have numerous possible effects on the living. During the transition the magnetic field is weakened, depending on how much it is weakened the decrease in protection from cosmic radiation can cause many problems. (Shemyakin, 2009) Studies show that there is a relationship between increase in solar radiation and incidence and mortality rates of diseases and pandemics, as well as an increase in the number of heart attacks. Increases in solar radiation and changes in geomagnetic activity can also severely impact communication systems, satellites, GPS, and other electrical devices. It is also possible that a strong enough decrease in the magnetic field could let in enough solar radiation to directly harm plants and animals by exposing them to large enough amounts of radiation to cause tissue and cell damage and possibly cause cancer. Recent decreases in the strength of the magnetic field as well as an increasing rate of change may indicate that a reversal is slowly becoming imminent. Unfortunately, as the only indication of geomagnetic reversal is what can be determined from examining geological strata it is far from certain how soon the reversal will be and even more uncertain how much the magnetic field will be weakened and for how long. (Shemyakin, 2009)

The impacts of future natural disasters can drastically change the way people are forced to live both by destroying large quantities of modern infrastructure but also by requiring that people adapt around both the possibility of future disasters and the after effects of previous disasters. Disasters also effect what energy choices are available in certain areas, for instance places suffering from frequent storms are unsuitable for solar energy and if the storms are sever enough even wind energy may be unfeasible, likewise nuclear fission plants when not built with adequate safeguards could make entire areas uninhabitable.

Overpopulation and Competition

Thomas Robert Malthus' Law of Population asserts that population growth is ultimately limited by the means of subsidence. It further declares that so called "checks" are necessary to prevent human suffering when demand outpaces sustenance. Neo Malthusians continue to heed the warnings of Malthus' most famous work, *An Essay on the Principle of Population,* published in the late eighteenth century. The essay outlines a prediction of exponential population growth until an inevitable "Malthusian Catastrophe" occurs and reduces the population back to a sustainable level. Disease, ecological catastrophe or depletion of resources could individually or cumulatively be the cause of this massive decline in human population. "Malthus's observation was that, unchecked by environmental or social constraints, it appeared that human populations doubled every twenty-five years, regardless of the initial population size." Malthus' model may be represented by the equation $P(t)=P_0e^{rt}$ where P_0 is the initial population and r is growth rate or Malthusian Parameter. (McKelvey) (Kolson) (Barrows)

So what issues created by increasing population? Human presence affects the immediate ecosystem and consumes the Earth's resources. "Health hazards associated with population growth include emerging and re-emerging diseases, poor sanitation, water and food contamination and natural disasters." (Pimentel 653) Even so, experts emphasize that per capita resource consumption may be more important than absolute population. Reducing the individuals carbon footprint will scale up to tremendous conservation when applied to the entire population. (G., 1998)

Contrary to Malthus, more recent demographic research indicates population growth is a complicated formula comprised of several elements. Growth percentages vary enormously based on infant mortality rate, average life span, health education and social structure. As presented by Mark Rowe in his 2010 essay, *Safety in Numbers?,* the Earth is currently home to approximately 6.9 billion humans. We are gaining approximately 78 million people per year. Rowe asserts total population may increase to 9 billion by 2050. Another group predicts 13 billion people worldwide by 2065. “The UN Population Fund (UNFPA) reckons that about half the Earth’s biological production capacity has already been diverted to human use.” (Rowe, 2010) Human population is expected to peak around this level.

Currently, half the world population lives in cities. This statistic is projected to increase. The congestion of city life is perfect for spreading of disease. “The World health Organization (WHO) and other organizations report that the prevalence of human diseases during the past decade is rapidly increasing.”(653) Severe Acute Respiratory Syndrome (SARS) was transmitted to humans due to overcrowding and prolonged exposure to livestock in China. Air pollution poses a particularly deadly threat to city dwellers. Currently particulate matter in the air kills approximately 3 million people per year worldwide and contributes to 50% of all chronic respiratory illness. Power plants and automobile emissions are two of the worst contributors to air pollution. Both causes are centralized in cities in order to meet the demands of residents and cause these areas to be extremely polluted. “The Environmental Protection Agency’s limit for particulate matter (PM) in the air has a diameter of greater than 10µg. Los Angeles with the highest PM level in the USA, averages less than 50µg/ m^2. This statistic emphasizes the individual’s need to reduce his or her carbon footprint by utilizing green energy and transportation, especially in high congestion areas. (Pimentel, Cooperstein, & kaye, Ecology of Increasing Diseases: Population growth and Environmental degradation)

Health education and social reform are mankind’s best defense against overpopulation. Evidence of their effectiveness is displayed throughout the developed world. Many European countries are experiencing population growth rates under 1.0. The chart below shows some statistics of fertility, population growth and infant mortality rate for various countries as recorded by Rowe.

It is obvious that population growth varies proportionally with infant mortality rate and other variables associated with less-developed countries. 3.7 billion people in the world currently suffer from malnutrition. The modern family living in a developed country doesn't require an extensive family to harvest crops, herd animals, run family businesses or combat high infant mortality rates. In our increasingly global modern world it is only logical to assume less developed countries will, in time, adopt similar social expectations and family dynamics. The population extrapolations presented earlier will surely level off and even reduce back to current levels as undeveloped countries gain electricity and other modern "necessities". If Europe's fertility rate was applied to the entire world we could "easily see a population between two billion and four billion, even with a dramatic increase in life expectancy." (Rowe, 2010) (Duncan) (Pimentel, Ethical Issues of Global Corporatization: Agriculture and beyond)

Table 11: (Rowe, 2010)

Fertility Rate	Population Growth Rate	Infant Mortality Rate (out of 1000)
Niger: 7.19	USA: 0.97	Niger: 110
Liberia: 6.77	Liberia: 4.5	India: 55
UK: 1.82	UK: 0.42	UK: 4.8
China: 1.73	China: 0.58	China: 23.0

It seems an explosion of human population may not be the epidemic it appears to be. "The Human Race is a self-limiting virus." (Rowe, 2010) Health education and social reform will decrease population growth rates in underdeveloped areas as these people acquire the information and technology they need to become part of modern civilization, as cities grow and thrive issues caused by overcrowding will be addressed. Improved sanitation will be utilized to prevent unchecked propagation of disease. Application of knowledge and technology will limit malnourishment and infant mortality as well as achieve sustainable resource consumption. The knowledge and technology available in developed countries has rendered overpopulation in these locations a non-issue. The same resources must be shared with the underdeveloped areas of the world where explosive population growth is currently contributing to disease, famine and excessive competitiveness for food. It is the responsibility of the world's educated population to address this issue and aid with sex and health education. As this planet grows increasingly interconnected humanity must realize that our sustained existence depends equally on those who live half way across the globe as it does the citizens of our own nation.

The Cost of Combustion Related Illness

Fossil fuel combustion currently supplies our planet with an estimated eighty-five percent of its energy demand. The primary reason for this statistic is the fact that producing electricity from these fuels is still significantly less expensive than other renewable sources of energy. However, hidden costs such as the treatment of illnesses caused by combustion related air pollution shrink the price difference between fossil fuels and cleaner energy alternatives.

Combustion of coal and petroleum emits airborne toxins and particulate matter. Particulate matter is categorized by diameter with:

- Course: 2.5µm < Diameter < 10µm
- Fine: 0.1µm < Diameter < 2.5µm
- Ultra-Fine: Diameter < 0.1µm

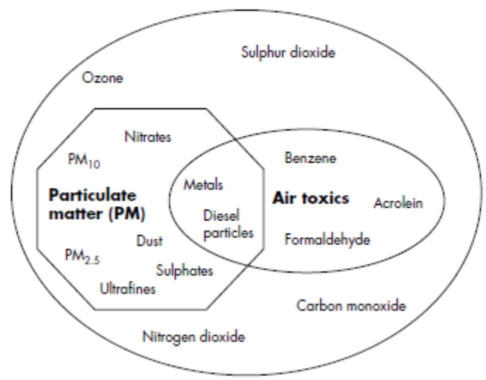
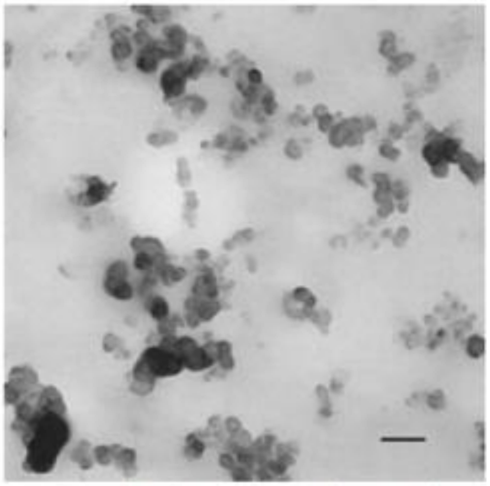


Figure 37: The air pollution mixture (Mauderly)

Fine and ultra-fine particles are the most dangerous to inhale as they penetrate deep into respiratory tissue. “Global air pollution causes nearly 700,000 deaths annually.” (Huebner, 2003) Acute and Chronic lung disease caused by air pollution affects millions and results in loss of work. Particulate matter inhalation has also been linked to cardiac disease, causing arrhythmias and heart attacks. (the issues: fossil fuel and energy use, 2006) Remaining indoors is not a viable solution because ultra-fine particles readily penetrate through walls. Newer gas and diesel engines primarily emit dangerous ultra-fine particles. Grigg reports that “in a landmark study published in 1993, Dockery and colleagues reported the findings from a cohort of 8111 adults in northeast and midwest USA followed for fourteen to sixteen years. They found that ambient levels of fine (PM2.5) particles in the most polluted cities were associated with a twenty-six percent increase in mortality from all causes compared with the least polluted (a difference in particles of 19 µg/m3), and that increased levels of fine particles were associated with increased mortality from cardiovascular disease.” “Wichmann and colleagues in Erfurt, Germany, found effects on adult mortality, both for the mass of fine particles (0.1–2.5 µm) and for the



Diesel particles sampled from an exhaust pipe, and examined by electron microscopy. Single carbonaceous ultrafine particles and aggregates of ultrafine particles are present (scale bar 100 nm).

Figure 38 (Mauderly)

number of UF particles, indicating that UF particles have a toxic effect in their own right." Infants and children are also at risk. "Woodruff and colleagues analyzed a cohort of four million USA infants born between 1989 and 1991 in 86 metropolitan areas. After adjusting for other covariates, the odds ratio for total post neonatal mortality for high exposure (versus low exposure) was 1.1." "Ritz and colleagues reported a 20% increase in preterm birth for every fifty μg increase in ambient PM10 levels during the six weeks before birth." Also, children in areas with higher levels of particulate matter are admitted to the hospital more frequently for treatment of asthma and bronchitis. (Grigg)

An EPA study conducted in 1995 concluded that residing in proximity to just one coal power plant may "double the background exposure" to Methylmercury or MeHg. This is concerning because elevated MeHg exposure may contribute to delayed childhood development. (Lipfert) The National Environmental Respiratory Center recently conducted a series of experiments regarding downwind inhalation of coal power plant emissions. They found that the frequency of health issues caused by coal combustion particulate matter was fewer than that caused by gasoline, diesel or wood burning exposure. This means that particulate matter emitted as a byproduct of coal combustion is less toxic than that emitted by these other sources. (Mauderly) "Although petrol engines emit particles, diesel engines, especially heavy duty engines, are a major emission source as they emit 100 times more particles than do petrol engines of corresponding performance." Particles emitted by diesel exhaust are classified as primary particles because they are omitted directly, and are not formed in the atmosphere. Secondary particles are sulfates formed by interactions between gas and other more benign particles.(Grigg)

ExxonMobil predicts a sixty percent rise in demand of heavy duty transportation over the next three decades. Thirty thousand new cars are currently being sold in China each month; a rapidly increasing figure. This influx of diesel engines, coupled with an exploding personal vehicle market in newly industrialized countries will be a leading contributor to lung and pulmonary illness in the coming decades. (Zaragoza, 2007) Clearly alternative means of personal and industrial vehicle propulsion will be vital to reducing particulate matter emissions.

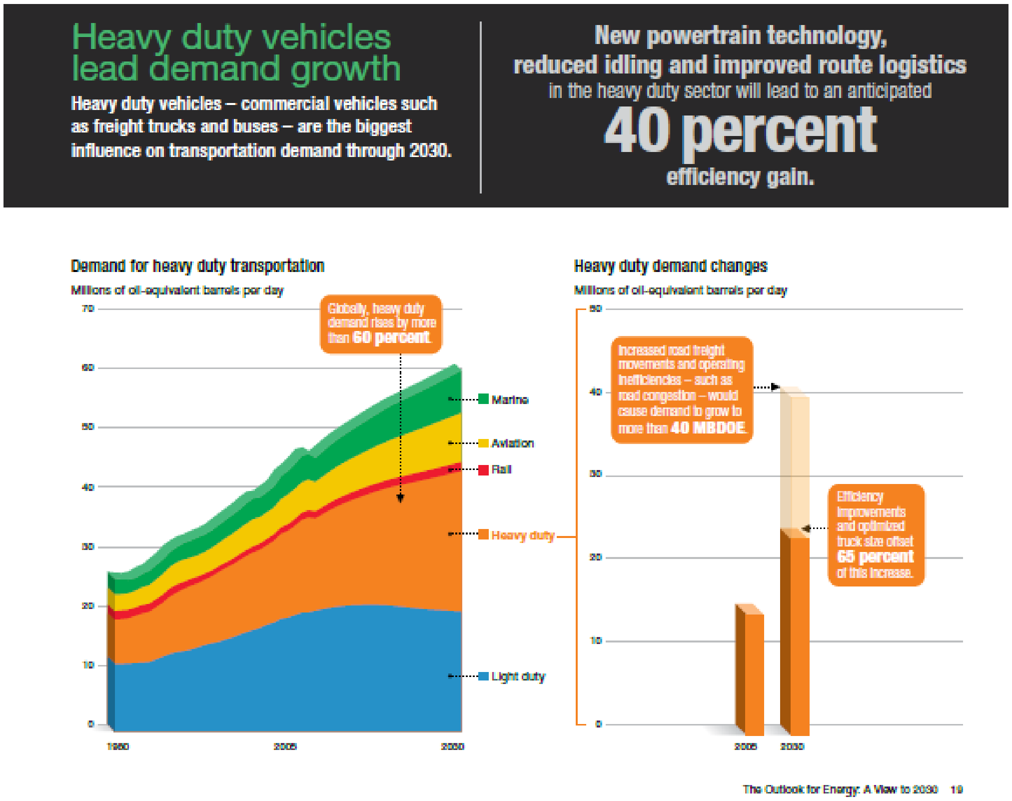


Figure 39 (Exxon Mobil, 2010)

Residents of densely populated cities are most affected by the air pollution problem due to high levels of automobile congestion. A study conducted by the Journal of the American Medical Association monitored 500,000 adults across 100 US cities for 16 years and found that "combustion-related small particles from cars, trucks, coal-fired power plants and factories increase the risk of individuals dying from lung cancer, heart attack, and respiratory failure; and the death rate increases proportionally to the density of particles." According to Fuel Economy.gov, a federal website approximately 146 million people live in countries where air pollution levels have been considered "unhealthy" since 2002. (Zaragoza, 2007) In 2011 alone the United States saw over 220,000 new lung and bronchus cancer cases. Massachusetts saw 5000 new cases. (The American Cancer Society, 2011) In 2006 Lung Cancer was estimated to have cost the United States 10.315 billion dollars in medical expenditures. (National Cancer Institute) Lung cancer accounts for more deaths than any other cancer type, with over 220,000 deaths expected for 2011. (The American Cancer Society, 2011) However, a significant and unspecified portion of these deaths are a direct result of cigarette smoking. Economists have attempted to put a price on air pollution; however it is important to note that not all air pollution comes from fossil fuel. This fact makes it difficult to reliably estimate the costs incurred by only fossil fuel related air pollutants. One study found that in the Canadian province of Ontario, air pollution results in over one billion dollars of cost in hospital admissions, emergency room visits and work absenteeism. (Huebner, 2003)

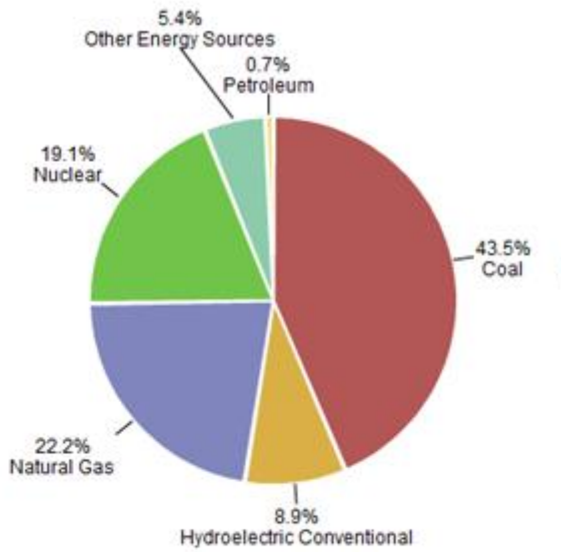


Figure 40 (U.S. Energy Information Administration)

Natural gas net electricity generation in the US increased sixty-three percent from 2000 to 2010. The cost of generating one million BTUs of energy using natural gas has increased eighty percent since 1997 from $2.76 to $4.97. Coal net electricity generation in the US decreased six percent from 2000 to 2010 even though generating one million BTUs of energy by combusting coal in 2011cost only $2.37. This is an eighty-seven percent increase from $1.27 in 1997. Despite coal remaining as the largest net generation source these figures show that conscious efforts are being made to switch to cleaner burning fossil fuels that emit no particulate matter. Petroleum's net electricity generation in the US decreased over two hundred percent from 2000 to 2010 with a 125 percent decrease between 2005 and 2006. This comes as no surprise because the cost per million BTUs of energy increased over five hundred and fifty percent, from $2.88 to $18.81, since 1997. (U.S. Energy Information Administration) It is important to note that these figures pertain solely to electricity production and not gasoline or diesel sales for use in automobiles. The rapidly increasing cost of petroleum will surely expedite the development of alternately powered vehicles. Straying away from internal combustion engines and coal combustion will greatly reduce the airborne particulate matter that is costing billions in health care annually. (National Environmental Respiratory Center)

Man-Made Disasters

Disaster is a sudden calamitous event bringing great damage, loss, or destruction. Man-made disasters, as opposed to natural disasters, are disasters resulting from human hazards, such as a badly constructed apartment block, a massive railway collision, a chemical accident, nuclear explosion, mass exodus, war, terrorism, major fire. No matter whether a man-made disaster is caused by some human designed error or is conceived, it is sometimes more destroyable than a natural disaster. As a comparison, the 2004 Indian Ocean earthquake, a terrible natural disaster, which is the third largest earthquake in recorded history, registering a moment magnitude of 9.1-9.3, cost the lives of over 130,000 people in Aceh and left more than 500,000 homeless.; while The Second Sudanese Civil War, which started in 1983 and ended with the signing of a peace agreement in January 2005, resulted in over 2 million deaths and more than 4 million people displaced between 1983 and 2005. (Gunn., 2008) (Howard K. Koh, Rebecca O. Cadigan., 2008)

One of the most famous man-made disasters is the Chernobyl nuclear accident that occurred on April 26, 1986 at the Chernobyl Nuclear Power Plant in Ukraine. Large quantities of radioactive contamination, released by an explosion and fire, spread over much of Western USSR and Europe. The disaster caused 31 immediate fatalities from Acute Radiation Sickness among the reactor staff and emergency works, nearly 4,000 deaths from excess cancers due to radiation exposure, and many other negative effects. Thousands of square kilometers were contaminated with fallout, bringing enormous costs. (Marples, 1996)

After the accident at Three-Miles Island Nuclear Generating Station and the tragedy at Chernobyl, the increase in nuclear power plant construction was ceased globally. Oil remains the world's leading fuel, at 33.6% of global energy consumption, but oil continued to lose market share for the 11th consecutive year. Since the world primary energy consumption grew by 5.6% in 2010, which was the largest increase since 1973. Oil, the consumption of which grew by 2.2% in 2010, lost market share. However, nuclear energy, which was dreamed to replace oil energy sometime, may continue to lose market share in the future, because of the Fukushima Daiichi nuclear disaster following the earthquake and tsunami on 11 March 2011. It is reported that there were serious unreported problems at the plant, so this disaster is not only a natural disaster, but a complex one, where natural and man-made forces meet. 25 years has passed since the disaster at Chernobyl, but using nuclear energy is still risky or dangerous. (Hallenbeck, 1994) However nuclear safety is constantly improving and few incidents have occurred in the years since. In fact, the disasters have pushed the development of the field of disaster management, from prevention, to planning, response and reconstruction. Disasters are being studied more deeply, widely, professionally, and scientifically. However, more efforts and supports are still needed. Unlike the disasters having been mentioned above, some disasters may not have a direct effect or impact on most human societies.

The Three Gorges Dam, a reservoir dam almost completed in 2006, is the world's largest capacity hydroelectric power station with twenty-nine 700 MW turbines and a total capacity of 20,300 MW. The expected annual electricity generation will be over 100 TWh. By August 16, 2011, the plant had generated 500 TWh of electricity. This dam, which is not only bringing a large amount of energy, but also helping to reduce carbon dioxide emission and control flooding, is really helpful to China, and even the world. On the other hand, it is causing great damage to the environment, such as biological disasters, earthquakes and landslides. It seems that the government does not really pay much attention on the environmental impact made by the Three Gorges Dam, or should we say that the government would rather continue an imperfect project than pause it. However, this kind of behaviors cannot be accepted by everybody, and it is doubtful that we, human-beings, have the right to change, control, manage, and even destroy the world to satisfy ourselves. (China Three Gorges Project Corporation)

The damages and destructions caused by the Three Gorges Dam and other projects may never be regarded as disasters, but, in fact, they are. As a result, it is possible that they will continue impacting on our world without effective preventions or recoveries.

Sustainable Solutions

The overuse of fossil fuels causes numerous unintentional effects on Earth. However, they are still irreplaceable as the world's primary source of energy. Analysis of energy supply and demand may provide an approach to discovering the optimal mix of fossil fuels, nuclear energy and renewable energy, benefiting the sustainable development of the 21st century.

Electricity Generation and Energy Supply

Several estimations show that the demand of energy will keep increasing as populations and economic activities grow. In developed countries, the scenarios generally predict a slowing population growth peaking around 2040, followed by a slow decline to the end of the century. The underdeveloped countries in Africa and Latin America are responsible for the continuing increase to 2100. The maximum population of the world is predicted to be after 2040, such numbers will a cause of a steep increase in world energy demand. At the same time, the increases of GDPs of countries, especially those of developing countries and undeveloped countries will contribute greatly to the increase of world energy demand. (Department of Economic and Social Affairs Population Division)

For different energy end-use sectors, the situation of supply and demand varies. Energy use in the residential sector accounts for about 15 % of worldwide delivered energy consumption and is consumed by households, which use different types and amounts of energy in different countries, depending on the natural resources, climate and incomes. Energy use in the commercial and services sectors, located in many different buildings for services such as health care and education, increases as populations and economies expand. Industrial sector energy demand varies among countries, mainly based on the level of economies. Industrialized economies generally have more energy-efficient industry than non-industrialized countries, whose economies generally have higher industrial energy consumption relative to the GDP. Energy used in the transportation sector includes the energy used in transferring people and goods. Growth in economies and populations are also the key factors that determine transportation sector energy demand, but increases in urbanization and personal incomes have also contributed to the increases of the energy demand in the transportation sector.

As the world's leading fuels, oil, coal and natural gas, which provide 33 percent, 29.6 percent, and 23.8 percent of the world's energy, are forecasted to remain the most significant energy sources in the following 20 years. Although we have to do our best to curb greenhouse emission, no cleaner energy can replace the role of fusil energy in the following 20 years, especially in the use in the transportation sector.

45 percent of the world's energy use is in the form of electricity now, among all the four sectors. Since electricity is widely used in people's everyday lives, not only in industries, but also in homes, offices, schools, and transportation, the demand for electric energy is increasing rapidly, by more than 80% through 2030, which is one of the largest energy problems, and, if the correlation between income and electricity is considered, will continue to be closely tied to incomes. People tried to generate more electricity by increase the efficiency of electricity generation, but it is still very inefficient. 69 percent of the fossil energy used for electricity is lost in production. The main loss is in converting heat of steam into electricity. According to the second law of thermodynamics, it is indeed impossible to generate electricity efficiently. As a result, in order to meet the rapidly increasing demand for electricity, curb greenhouse gas emissions and also keep the prices of electricity low enough, we have to pay more attention to cleaner and cheaper energy sources rather than trying to make electricity generation more efficient. There are a wide range of fuels can be used to generate electricity, from coal and natural gas, to nuclear energy and kinds of renewable energy such as hydroelectricity, wind and solar. Among those kinds of energy, coal is the most economical fuel, and it is also the leader in electricity generation which generates about 40 percent of the world's electricity. However, generating electricity from coal can emit a large amount of greenhouse gas. It is shown that, in order to get a balance between economy and environment, people will use more natural gas, from which generating electricity can emit less greenhouse gas than from coal, in the following 20 years.

The situation of the world's electricity generation and energy supply in 2030 have been roughly estimated and maybe also controlled, but the situation after 20 years is still to be greatly changed. If we see those energy problems from a higher view, we can make big plans by satisfy sustainable and environmental needs for the development during the next 100 years to solve the problem and turn them into realty as soon as possible. Surely, the solutions to the energy problem are deeply related to renewable energy originating from natural resources, which include solar energy, wind power, geothermal heat, hydropower, and biomass. Despite their sustainability, the potential for extensive utilization and appropriate application of renewable energy are limited by the some problems. (U.S. Energy Information Administration) (Exxon Mobil, 2010) (BP, 2011)

Firstly, acquirable energy capacity is fully dependent upon the geographical site. Among all the renewable energy sources, the contribution of hydropower to the worldwide electricity generation is the highest. Hydroelectric power is the simplest and most direct way to generate electricity. A hydropower system can be used to generate a few kilowatt of electricity to about 18,000MW. Hydroelectricity may provide reliable electricity, though sometimes it is also influenced by flow shortage. Although there are a number of advantages and benefits of using hydropower systems, the available sources are not enough or widely distributed to generate much more electricity for the world.

Secondly, some renewable energy sources are intermittent and not controllable. Two of the most advanced energy, solar energy and wind energy are both dominated by uncertainties. Wind- and solar-powered generating facilities, however, are heavily dependent on natural variability in wind and sun conditions, which result in much lower capacity utilization levels. As a result, they can hardly become backbone power, and even hard to provide much more electricity in the following 20 years.

Thirdly, an energy storage system is often required. The storage of some renewable energy is imperative due to the intermittent and time-dependent nature of power generation. In order to store energy for further use, people usually plan an energy storage system. However, these systems cost much and may also cause damages and dangers.

Fourthly, the environmental impacts should be considered. It has been shown that hydropower systems change the landscape and displace wildlife, and wind turbines generate low frequency noise. Other impacts may be found during the next 100 years.

It is predicted that fusil energy will keep on providing more energy and electricity, than renewable energy for at least 50 years, but new technologies may change the situation by solving the problems detailed. What more we can do to help solve those energy problems is optimization. (Tae Sup Yun, Jong-Sub Lee, Seung-Cheol Lee, Young Jin Kim, Hyung-Koo Yoon, 2011) (Chen, An Indispensable Truth: Future Energy I, 2011) (Chen, An Indispensable Truth: Future Energy II, 2011)

One good idea is to generate electricity in the ocean. The wide space on the ocean can also be used to generate electricity from solar energy or wind energy. Since oceans cover about 70 percent of the earth's surface, it is possible that many available geographical sites can be found; Technologies in energy storage, such as solar batteries and Compressed Air Energy Storage, may help to solve the problems about marine energy storage. The amount of energy stored by the oceans is enormous, which at least can meet the part of world energy demand. (Tushar K. Ghosh, Mark A. Prelas, 2011)

Realizing a Sustainable Energy Future

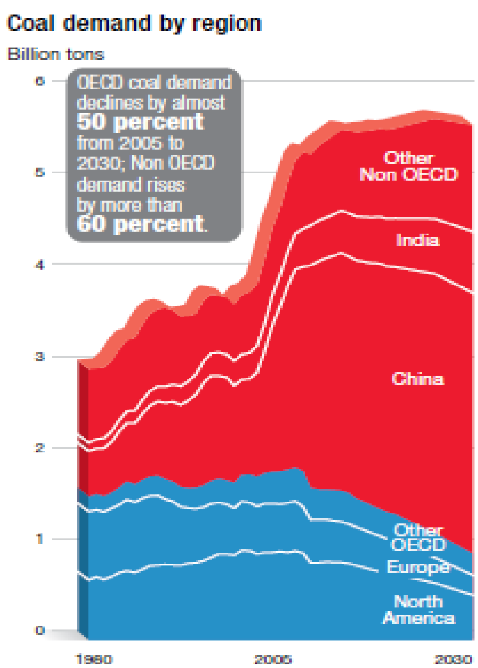


Figure 41: Coal demand by region (Exxon Mobil, 2010)

The finite amount of fossil fuels on Earth necessitates using supplementary energy sources in order to sustain future power demand. Only a certain amount of passively captured renewable energy sources may be utilized in an economically viable way and as such they will never independently meet our increasingly growing demand for energy. Fossil fuels and renewable energy sources exhibit a symbiotic relationship that is necessary for the survival of each other, as well as our modern technology based society. Renewable and non-renewable energy sources must support each other's development to maintain affordable reliable future energy production.

According to Francis Chen, author of An Indispensable Truth, human power production can be categorized into three distinct groups. "Backbone power is the primary energy source that is always there when we need it." "Green power" describes energy sources which do not pollute. "Mobile power" is defined as energy sources that "have the special requirement of transportability." **T**echnologies that belong to the "backbone power" category are capable of uninterrupted power production. Currently backbone power is primarily generated through the combustion of non-renewable fossil fuels. The figure below displays current net U.S. electricity generation by energy type. It is immediately clear that the U.S. is primarily dependent on coal for electricity generation. Coal is abundant and easy to transport. As a result it is the most inexpensive fossil fuel with a cost of $0.04 to produce one kWh of electricity in 2011. (Morgan) Research conducted by the National Academy of Sciences asserts that obtainable global coal reserves may not be as abundant as previously projected. "There is probably sufficient coal to meet the nation's needs for more than 100 years at current rates of consumption. However, it is not possible to confirm the often-quoted assertion that there is a sufficient supply of coal for the next 250 years." (Wald, 2007) Technologically developed countries are beginning to wean themselves off of coal. Total coal based electricity generation rates in the U.S. have decreased 1.35% since 2005. (U.S. Energy Information Administration) However Exxon Mobil projects heavy coal dependency over the next thirty years in developing nations. Explosive demand in these areas will increase global coal prices and further reduce the appeal of this fuel source amidst cleaner, increasingly viable alternatives. Because of the incredibly rapid economic growth occurring in China, total global electricity production by the combustion of coal will increase in the coming few decades. This market domination will not last. As alternative technology becomes more efficient and cost effective over subsequent decade's coal will slowly shift from its current role as the predominant fuel for electricity generation worldwide. Its simplicity combined with the inevitable surplus of obsolete, recycled technology and equipment will make coal the perfect initial power source of future developing nations.

Natural gas is being hailed as an excellent transitional fossil fuel due to its lack of particulate matter emission and the fact that it releases about half as much CO_2 as coal for a defined amount of heat energy. (Mouawad, 2009) Production of one kWh of electricity using natural gas cost $0.10 in 2010, about twice as much as using coal. (Morgan) "Producing electricity using a natural gas combined-cycle turbine is about thirty percent more efficient than using a

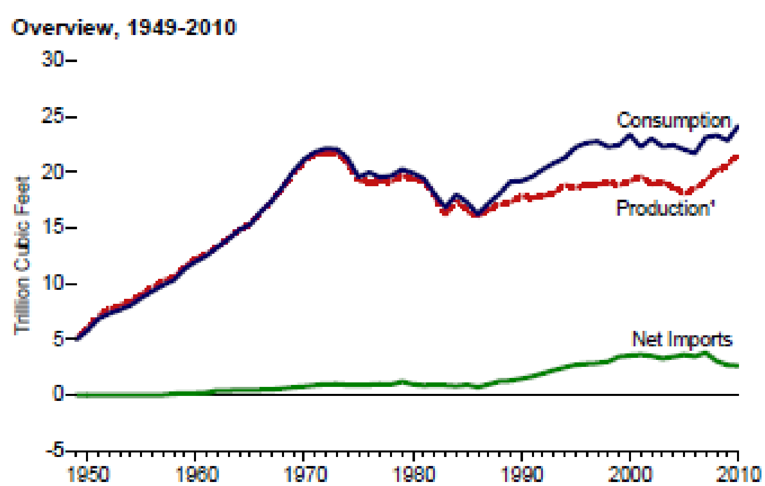


Figure 42 (U.S. Energy Information Administration)

state of the art coal plant." (Exxon Mobil, 2010) Current estimates for U.S. natural gas reserves report 2,074 trillion cubic feet of extractable gas. One cubic foot of natural gas gives off approximately 1027 BTUs when combusted. In 2010 U.S. gas consumption measured 24,133 billion cubic feet. (U.S. Energy Information Administration)

$2.074E15\ ft^3 * \frac{year}{2.413E13\ ft3}$ = 86 years of potential U.S. self sufficiency

Current U.S. natural gas demand could be met for eighty-six years with the natural gas that exists within the country's borders. This clean burning fossil fuel will provide affordable "backbone power" for developed nations in the coming decades. This on-demand power source will alleviate dependence on other fossil fuels and help extend the lifespan of all non-renewable fuel supplies. Prolonging the timeframe that humanity has to develop alternative energy sources is the main purpose of fossil fuel innovation in the coming decades.

Nuclear fission is also a commercial scale backbone power generator. Fission reactors provided 807 billion kWh of electricity generation in 2010. (U.S. Energy Information Administration) Nuclear energy experienced the third largest demand by fuel type in 2010. (Exxon Mobil, 2010) Electricity production cost using nuclear fission is on par with coal, at $0.04 per kWh. The highly technical nature of nuclear energy means there is significant room for improvements in efficiency and safety as time progresses. One major drawback of nuclear fission is the byproduct of radioactive waste that must be stored in special containment facilities for decades. Experimental nuclear fusion is occurring in labs and shows potential to provide sustained, uninterrupted atomic power without producing pesky radioactive waste. Fission is expected to see steady growth over the next three

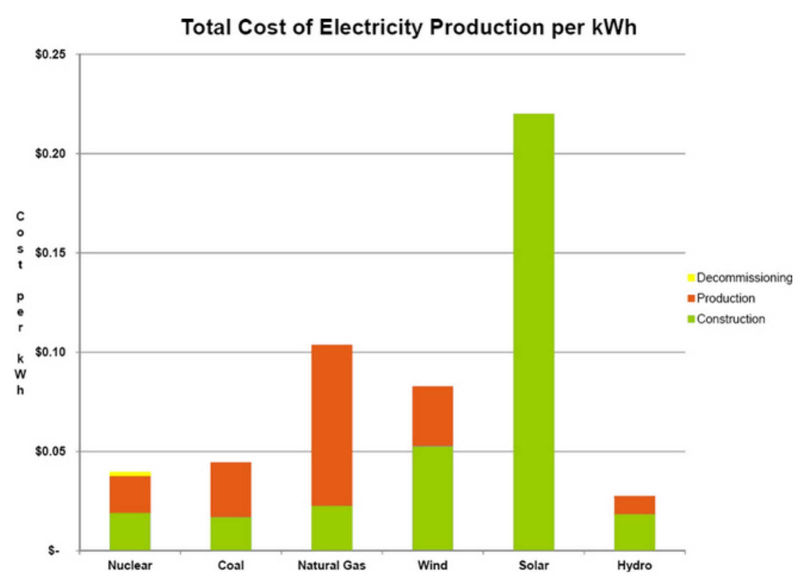


Figure 43: Total Cost of Electricity per kWh (Morgan)

decades. (Exxon Mobil, 2010) Atomic technology is too advanced to be utilized by industrializing nations. It will serve as a supplement to other fuel types in developed nations and will continue to grow steadily as improved technology makes fission reactions safer, less polluting and more widespread. Commercially viable fusion will be slow to emerge due to lack of sufficient supplies of the radioactive fuel tritium that must be harvested from the moon or other creative places.

“Green power”, Chen explains, describes energy sources which do not pollute. Green power is generated by capturing energy from naturally occurring phenomena. Energy stored in the wind, sun and tide is captured for conversion to electricity. A major issue facing most renewable energy sources is that they are intermittent and humanity’s demand for power is not. Researchers are improving methods to store energy produced during peak hours by using the excess energy to separate hydrogen from water molecules. The hydrogen is contained and later combusted to release the stored energy when it is in demand.

One green power source that does not suffer from intermittency is underwater turbine technology. Hydroelectric dams already harness the power of continuously moving water, producing electricity $0.03 per kWh, one cent less per kWh than coal. Hydroelectric power provided 31% of total renewable energy production in 2010. (Morgan) Suitable areas for hydroelectric dams are limited so they cannot fully meet energy demand. Researchers aim to capture further uninterrupted water energy from the continual and relatively stationary flow path

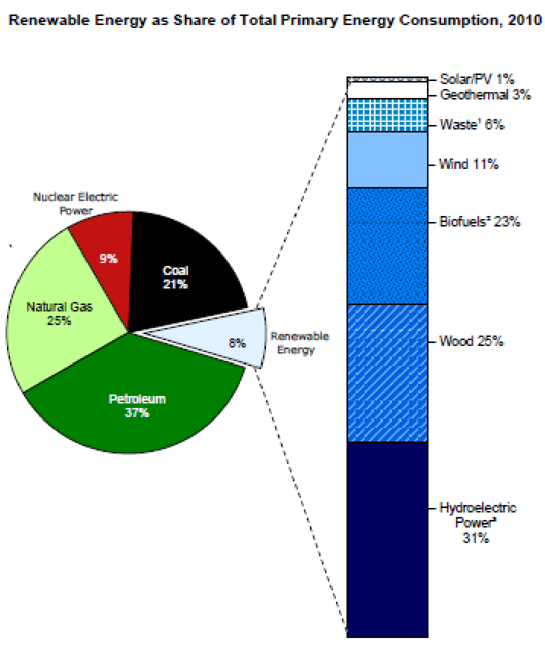


Figure 44: Renewable Energy as Share of Total Primary Energy Consumption, 2010 (U.S. Energy Information Administration, Annual Energy Review 2010, 2011)

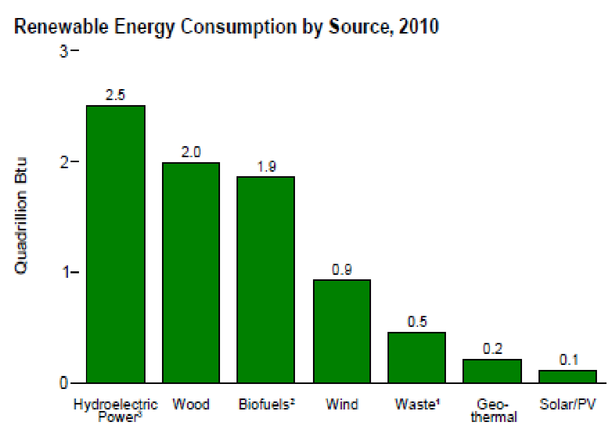


Figure 45: 2008 US Electricity Generation by Source & Weighted Average Cost per kWh (U.S. Energy Information Administration, Annual Energy Review 2010, 2011)

of the world's ocean currents. Green power must be utilized by those in its immediate vicinity. Florida can potentially meet 35% of its current energy demand by capturing energy from the Gulf Current alone. Suitable currents only exist in certain areas but they should be utilized where possible. Areas with similar advantageous phenomena should be properly developed and utilized to alleviate global reliance on backbone power. One concern with green power is that unexpected global phenomena could potentially eliminate or sufficiently alter a renewable energy source to the point of uselessness. Some researchers suggest global warming could affect the flow paths of ocean currents. This is an untested hypothesis. More research on the effects of removing energy from ocean currents must be performed before investing large amounts of capital.

Table 12: 2008 US Electricity Generation by Source & Weighted Average Cost per kWh (Morgan)

2008 US ELECTRICITY GENERATION BY SOURCE & WEIGHTED AVERAGE COST PER KWH

Energy Source	% of Total	Cost per kWh	Weighted Avg Cost
Nuclear	19.7%	$0.04	$0.008
Hydro	6.1%	$0.03	$0.002
Coal	48.7%	$0.04	$0.022
Natural Gas	21.4%	$0.10	$0.022
Petroleum	1.1%	$0.10	$0.001
Other Renewables	3.0%	$0.15	$0.005
	100%		$0.059

Developers of green power must concentrate on minimizing costs and maximizing production in the most advantageous areas. Initial funding will be necessary for construction of the infrastructure needed to collect green power on a massive scale. Localizing equipment and personnel will reduce maintenance and installation costs. Wind turbines are a prime example such a technology whose potential is currently only partially realized. Offshore wind turbines take

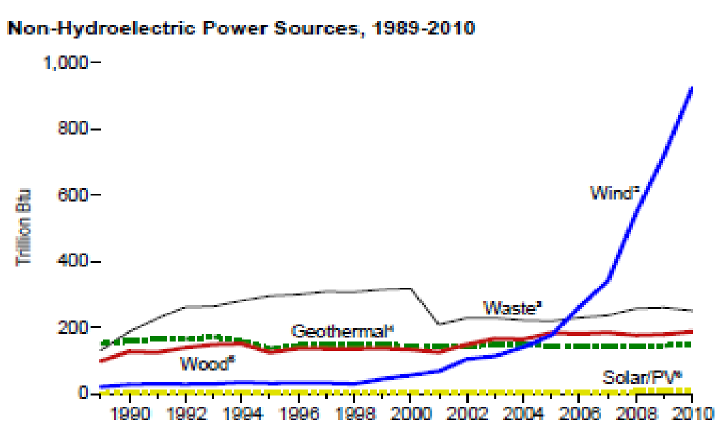


Figure 46: Non-hydroelectric Power Sources, 1989-2010 (U.S. Energy Information Administration, Annual Energy Review 2010, 2011)

advantage of higher wind speed and greater air density than their onshore counterparts, the combination contributing to thirty percent greater electricity production. Initial installation costs are thirty to fifty percent higher than on shore turbines but large scale clustering will alleviate these costs. (Offshore Wind Energy) Currently, electricity produced by wind turbine costs about $0.08 per kWh. (Morgan) The low maintenance, mechanical, passive nature of this technology results in $0.02 less cost per kWh when compared to natural gas. Possible locations for wind turbine farms are abundant and net electricity production has grown exponentially over the past decade. Wind turbines are the second largest “green power” contributor behind hydroelectric with 924 trillion BTU’s consumed in the United States in 2010. (Morgan)

The sun is the catalyst behind all other renewable energy sources. When captured directly with solar panels, it is a practically infinite source of energy. The limitations of today’s technology are hindering its potential. Solar panels are comprised of photovoltaic cells, specially designed diode banks, which capture energy directly from solar radiation in the form of electricity. There are a few issues inhibiting the growth of this energy sector. The comparatively high initial cost of solar panels has limited their utilization. Thanks to advancement in semiconductor technology, production of the diodes that are the core of a solar cell has become much less expensive over the past decade as is shown by the first figure on the previous page. In recent years the calculated cost of generating electricity with solar cells has shrunk to approximately $0.30 per kWh. (The Real Issue With Solar Energy Isn't Its Cost, 2011) This value is difficult to accurately compute because almost all of the cost is up front. In 2011 photo voltaic cells were used to produce only about 11% as much electricity as wind turbines.

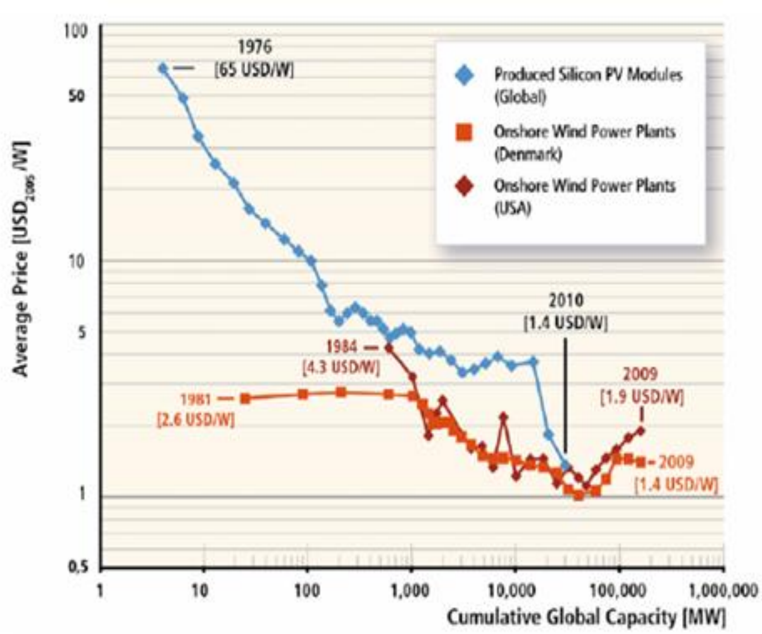


Figure 47 (The Real Issue With Solar Energy Isn't Its Cost, 2011)

Practical issues further impede solar technology. The way solar radiation is captured by diodes limits the efficiency of photovoltaic cells. The most efficient panels currently capture approximately 40% of the solar radiation that contacts their surface. Beyond this limitation is the serious issue of intermittency. Solar panels are normally ground based and only receive radiation during daylight hours. Cloud cover can also easily halt the production of a solar power plant. These plants must be located in areas with the most suitable weather conditions in order to generate electricity per kWh on comparable scale to other renewable sources. Some home owners have begun installing solar panels on the roofs of their homes in order to reduce their electric bill. This is a significant commitment as a typical home installation can cost anywhere from fifteen to fifty thousand dollars based on efficiency. Desert residents seem a viable candidate; however they may soon long for a small wind turbine instead, as solar panels must be continually cleaned of radiation absorbing dust or else suffer significant decrease in efficiency. They also lose efficiency rapidly if overheated. Solar panels are already used to power satellites and space rovers. Solar panels in space do not suffer from the intermittency problem caused by day and night or cloud cover. One day, several solar panels may be packed on a single satellite designed specifically for producing electricity at commercial scale. Such a satellite could be used to power future space stations, both land and air based. The main concern for a giant orbiting solar panel is meteor collision. This is a very real possibility and must be countered with astute tracking and movement.

The cost of generating electricity from geothermal power plants is approximately $0.07 per kWh. Similarly to solar panels, the majority of cost to the plant is related to initial installation only. Once capital costs are recovered, the cost per kWh can decrease below $0.05. This cost is stable as geothermal heat is not affected by intermittency. Locations with large amounts of geothermal activity are hotter closer to the surface and are thus ideal places to utilize geothermal energy. Collecting geothermal energy takes little space and occurs underground. This could make it a viable

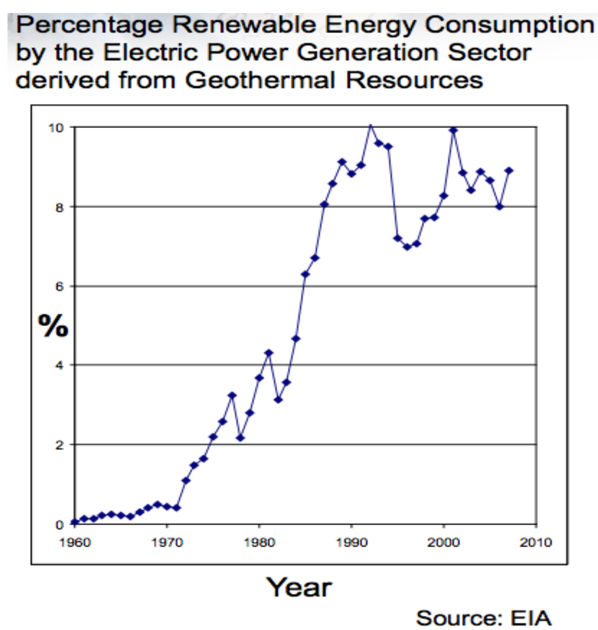


Figure 48: Percentage Renewable Energy Consumption by the Electric Power Generation Sector derived from Geothermal Resources (U.S. Energy Information Administration)

energy source for residents of congested cities. It is also useful in places that rely on their land for agriculture or have less land to use for industrial purposes. Geothermal is also useful in area's that lack native supplies of fossil fuels. Because it is not affected by intermittency, geothermal energy can constantly supplement backbone power sources with electricity that does not fluctuate. Geothermal heating is another possible use of geothermal energy. Unlike electricity generation it is localized to the site of the building that it will be heating or cooling. It functions by using the earth as a source of heat in the winter and as a heat sink in the summer. When used year round the savings of a geothermal heating system pays for itself in 3-5 years. Combustion of biomass such as wood or dung has been providing heat for homes and cooking fires since the dawn of civilization. Individuals who have access to inexpensive lumber frequently use wood burning to heat their homes. Many underdeveloped countries without access to electricity still rely solely on biomass combustion for warmth and cooking heat. Combustion of wood and dung patties causes significantly higher levels of particulate matter emission than oil or coal combustion. The close proximity to the smoke ensures sizable amounts of this matter are inhaled. Pulmonary disease and lung cancer levels in areas that rely solely on biomass combustion are extremely high and the victims simply go untreated. One study examining eight people from rural areas of Turkey found that although all were nonsmokers each had symptoms usually diagnosed as chronic lung disease. Multiple test subjects had developed lung tumors. (Cumhuriyet University) One biomass that combusts cleanly is ethanol which is produced from corn. The advantages and disadvantages of ethanol are described in the "mobile power" section below. Biodiesel is a biofuel made from vegetable oil and animal fats. It can be used in standard diesel engines although it is necessary to change the fuel filter when making the transition to biodiesel as it can react with the regular diesel in the fuel line to form solids. Ethanol and biodiesel will initially aid in alleviating the United States' dependence on foreign oil; providing cleaner burning fuel that can be produced domestically.

"Mobile power" is defined as energy sources that "have the special requirement of transportability." (Chen, An Indispensable Truth: Future Energy I, 2011) These power sources are independent, portable, and required for un-tethered motion. They are used primarily for transportation purposes in technology such as cars, planes, ships, heavy duty vehicles for construction and goods transport. Gasoline and diesel powered internal combustion engines contribute heavily to air pollutants and particulate matter levels. Ethanol and biodiesel are being utilized currently as a fuel additive and replacement respectively. These cleaner combusting biofuels have seen a sharp increase in use over the past decade. This is primarily thanks to the addition of ten percent ethanol to most pump gasoline. These alternative fuels are great temporary solutions to U.S. dependence on foreign oil; however generating power on small scale is simply less efficient than with a power plant. A shift is occurring in personal transport. Electric motors will inevitably phase out all other mobile power sources. The only real inhibitor currently is battery technology. With current battery technology range is limited and recharge is timely and inconvenient. Battery capacity decreases with time and replacement is costly. These cars are expensive however the initial cost of the equipment will quickly be outpaced with savings gained the increased fuel efficiency. The issue is thus one of convenience, and batteries.

Enter the next generation battery. Hydrogen fuel cells are fueled with hydrogen extracted from water molecules at power plants of every sort. This hydrogen is combusted, releasing energy and water. DMFCs, fuel cells using liquid methanol, cost approximately 125 dollars per kilowatt and PEM fuel cells, using gaseous hydrogen, cost approximately sixty-five dollars per kilowatt. This compares to internal combustion engines which cost approximately 30 dollars per kilowatt. This differential is rapidly shrinking as fuel cell technology improves. Hidden costs of using fossil fuel combustion in internal combustion engines such as increased rates of heart and lung disease caused by particulate matter emission are not included in this figure. One concern about hydrogen fuel cells is the need to store flammable hydrogen in a moving vehicle. Collisions are frequent and could prove deadly. The utmost care must be taken in designing hydrogen tanks that will not result in explosion if impacted during a

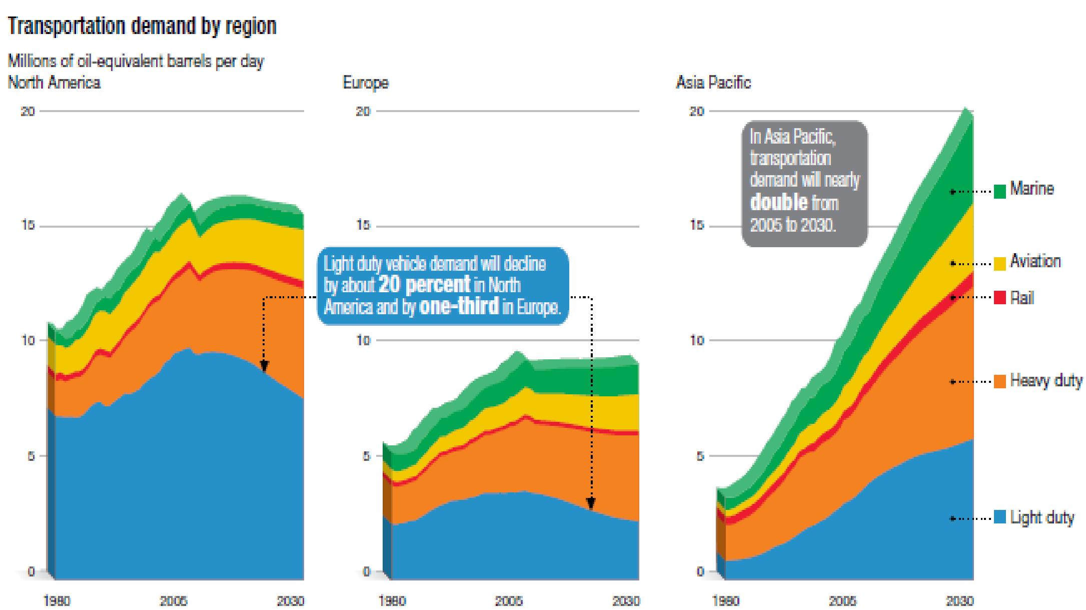


Figure 49: Transportation **demand by region (Exxon Mobil, 2010)**

collision. (King, 2009)

Fuel cells have an advantage over conventional batteries for use in electric cars as they don't store electricity directly but rather generate electricity by galvanic reactions with their fuel source. Batteries must be recharged, a process that takes anywhere between 1 and 8 hours when using household electrical outlets depending on the batteries used and how far the vehicle needs to go. In contrast fuel cells can be "recharged" like a normal car by refilling the tank with the fueling chemical. In theory it wouldn't take any longer to refill your fuel cell powered car then your gasoline powered car. To date there hasn't been any large scale commercialization of fuel cells, and it is uncertain whether enough of the challenges that their presented with can be overcome in the near future. Infrastructure needs to be developed in order for hydrogen tank filling to be convenient for consumers. Continued improvement in fuel cell technology coupled with the sharp rise in personal automobiles sales predicted over the next thirty years Asia Pacific make clean burning hydrogen power ideal for the future.

Energy Taxes for Green Energy

Description of the Problem

Energy is a necessity for many aspects of modern society, but fossil fuel combustion, the major source of electricity worldwide has some hidden costs such as pollution produced by burning fuels and ecosystem damages caused by hydroelectricity. New technology must be developed in order to address the hidden costs some energy sources. The extended use of fossil fuels for energy is a product of their inexpensive upfront cost. This section is an attempt to model an imposition of taxes on various sources of energy based on their carbon emissions and negative effects overall. The funds from such taxes could be used to address the health and environmental issues being posed by these energy sources. Such taxes would ideally minimize the price gap between fossil fuels and renewable energy sources.

Definitions and Notations

$D(t)$ is the total consumption of energy at the time t.

$S(t)$ is the total supply of energy at the time t.

$P(t)$ is the price of 10 trillion BTU energy at the time t.

c(t,e) is the cost of generating 10 trillion BTU energy from e at the time t.

r(e) is the ratio of c(t,e) and P(t).

p(t,e) is the profit to sell 10 trillion BTU energy generated from e at the time t.

d(t,e) is the consumption of energy generated from e at the time t.

α(e,v) is a reference to be decided, called the pollution constant for the area, v, of e.

μ is a reference to be decided, which helps control the money to send back to some companies and industries, called the support constant.

T(t,e) is the tax of 10 trillion BTU energy at the time t for generating energy from e.

Tall(t) is the total tax at the time t.

B(t,e) is the money sent back to the companies and industries who providing renewable energy.

Prediction of the total consumption of energy

We assume the total consumption of energy in some range at the time t, D(t), the price of energy at time t P(t), and the total energy supply at the time t, S(t), all can be separated into two parts: One part is heavily impacted by the market, D(t,1), P(t,1), S(t,1), and the other is relatively stable, D(t,0), P(t,0), S(t,0). A system of equations can be set up approximately:

$$D(t) = D(t,0) + D(t,1)$$

$$P(t) = P(t,0) + P(t,1)$$

$$S(t) = S(t,0) + S(t,1)$$

$$\frac{dD(t)}{dt} = \frac{dD(t,0)}{dt} - a_1 * P(t)$$

$$\frac{dS(t)}{dt} = \frac{dS(t,0)}{dt} + a_2 * P(t)$$

$$\frac{dP(t)}{dt} = \frac{dP(t,0)}{dt} + a_3 * (D(t,1) - S(t,1))$$

A solution to this system of equations can be written as:

$$P(t) = P(t,0) + a_4 * sin(a_5 * t + a_6)$$

$$D(t) = D(t,0) + a_1 * a_4 * \cos{(a_5 * t + a_6)}/a_5$$

$$S(t) = S(t,0) - a_2 * a_4 * \cos{(a_5 * t + a_6)}/a_5$$

In order to determine the consumption D(t), we have to approximate the stable part D(t,0). Since it is almost impossible to know how this changes when the population, technologies, economics and other factors change, we can only choose a reasonable function to approximate it. One thing can be understood is that, in some range, there exists a least upper bound of D(t,0). On the other hand, it can be found that exponential function may be a good approximation of D(t,0) somewhere locally. As a result, the following function F(t), which is called Gompertz function, can be chosen as a good global approximation of D(t,0):

$$F(t) = A\exp(-k_1 * \exp(G * t))$$

Finally, we have:

$D(t) = A\big(P(t)\big)\exp(-k_1 * \exp(G(P(t)) * t)) + k_3 * \cos(k_4 * t + k_5) + k_6,$ where A(P(t)) is the least upper bound and G(P(t)) sets the growth rate, both of which are impacted by P(t) and other factors.

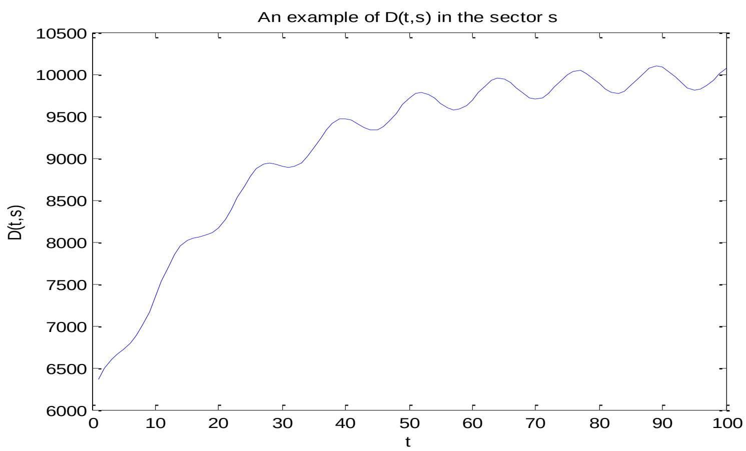


Figure 50: An example of D(t)

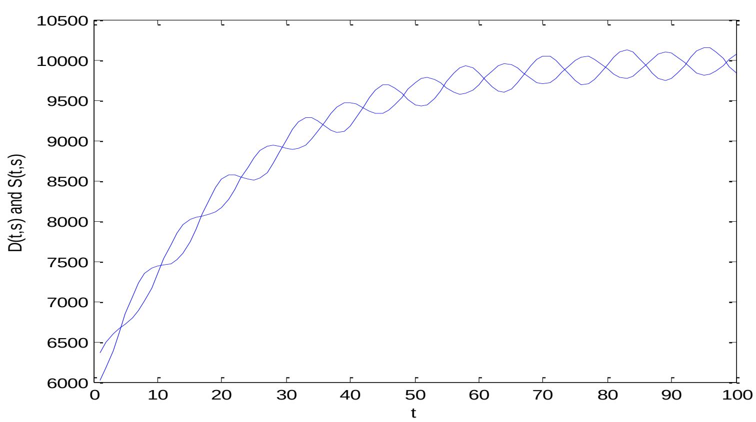


Figure 51: D(t) and S(t)

Price, cost and profit

From the data of Energy Prices by Sector and Source (the U.S. Energy Information Administration), it is shown that the stable part of P(t), which is the nominal value, P(t,0) can be approximated by a linear function:

$$P(t) = P(t,0) + P(t,1) = k_7 * t + k_8 * \sin(k_4 * t + k_5) + k_9$$

The cost of generating energy from energy source e may differ, but at the time t, the average cost can be calculated, which is c(t,e). c(t,e) is almost linearly related to P(t), so:

$$c(t,e) = r(e) * P(t)$$

$$c(t,e) = r(e) * P(t,0) + P(t,1)$$
$$= r(e) * (k_7 * t + k_8 * \sin(k_4 * t + k_5) + k_9)$$

$$p(t,e) = P(t) - c(t,e)$$
$$= \big(1 - r(e)\big) *(k_7 * t + k_8 * \sin(k_4 * t + k_5) + k_9)$$

This is reasonable if p(t,e) usually keeps the real value as a constant.

Coefficients in D(t)

$$D(t) = A\big(P(t)\big)\exp(-k_1 * \exp(G(P(t)) * t)) + k_3 * \cos(k_4 * t + k_5) + k_6$$

As shown in the equation, A(P(t)) is the least upper bound and G(P(t)) sets the growth rate, both of which are impacted by P(t) and other factors. Those factors, which change as time goes by, impact A and G a lot, so the approximation is not really global. However, although A(P(t)) and G(P(t)) are not constants, they can be approximated by some continuous function and then roughly studied. It is known that $\frac{\partial A(t)}{\partial P(t)}$ and $\frac{\partial A(t)}{\partial G(t)}$ are negative. So increasing P(t) is somehow an approach to reducing the side-effects caused by D(t,s).

Taxes

Tax is important for our modeling to adjust the markets of different energy sectors and encourage people to provide and use renewable energy which have few and slight side-effects. However, there are several issues to be thought about:

The taxes in different energy sectors are not the same.

The taxes at different time do not need to be the same.

The taxes for different energy sources are not the same.

The taxes should be in some ranges: they must be large enough in order to powerfully adjust the markets; they can't be too large, since when they are beyond some upper bounds, they can no longer adjust the markets, but make the markets disorder.

The taxes should be efficiently used.

In some sector, such as the transportation sector, where little renewable energy can be used, the taxes should not be large for fuel energy; on the other hand, in some sector, where green energy plays a key role, the taxes for fuel energy should be large.

Specific ideas differ, but those above can be treated as principles. One idea, we suggest, is to set up the function below:

$$\frac{dc(t,e)+T(t,e)}{dt} = (\sum_{i,v}\left(\alpha(e,v) - a(i,v)\right) * d(t,i)) * d(t,e) * (cmax(t) - (c(t,e) + T(t,e)))/D(t)$$

If initial data is provided, the ODE can be solved:

T(t,e)$= cmax(t) - \mathrm{c(t,e)} + \mathrm{k11} - \mathrm{k10} * \exp(-\int \sum_i\left(\alpha(e,v) - \alpha(i,v)\right) * d(t',i)) * d(t',e) / D(t')\, dt')$.

Considering T may not be negative,

T(t,e)$= \max\{0, cmax(t) - \mathrm{c(t,e)} + \mathrm{k11} - \mathrm{k10} * \exp(-\int \sum_i\left(\alpha(e,v) - \alpha(i,v)\right) * d(t',i)) * d(t',e) / D(t')\, dt')\}$

where α(e,v) should be carefully decided. For fuels like coal, which usually cause big problems to our environment and health, α(e,v) usually be large; if, in some area v, pollution is well reduced, α(e,v) can be small; while, on the other hand, for green energy, α(e,v) should be small. α(e,v) is defined to be non-negative. cmax(t) is the maximum of the average costs of generating energy from different kinds of energy sources. The total tax we can get, at the time t, is: $Tall(t+1) = \sum_i \mathrm{T(t,i)} * d(t,i)$

Benefits

After we get the total tax, at the time t, Tall(t), we will use some of them to develop technologies and also send some back to the companies and industries:

$$B(t,e) = \mu * \mathrm{Tall(t)} * ((\sum_{i,v} \alpha(i,v)) - \alpha(e,v)) / \sum_{i,v} \alpha(i,v)$$

Again, the constant μ should be carefully decided for our purpose.

Example

Electric power sector energy consumption in the U.S., 2002 to 2011:

3801.6263, 3806.2218, 3871.3400, 3963.7987, 3942.8442,

4037.6655, 3997.8436, 3807.7111, 3962.8128, 4001.5724

(10 trillion BTU)

The approximating function is

$$D(t) = \begin{cases} 4551\exp(-0.4579\exp(-0.07146(t-1989))) + 29.41\sin(3.575(t-1989) + 4.974 * 10^\wedge(-9)), & t < 2009 \\ 4551\exp\left(-0.4579\exp(-0.07146(t-1989))\right) + 29.41\sin(3.575(t-1989) + 4.974 * 10^{-9}) - 137, & t \geq 2009 \end{cases}$$

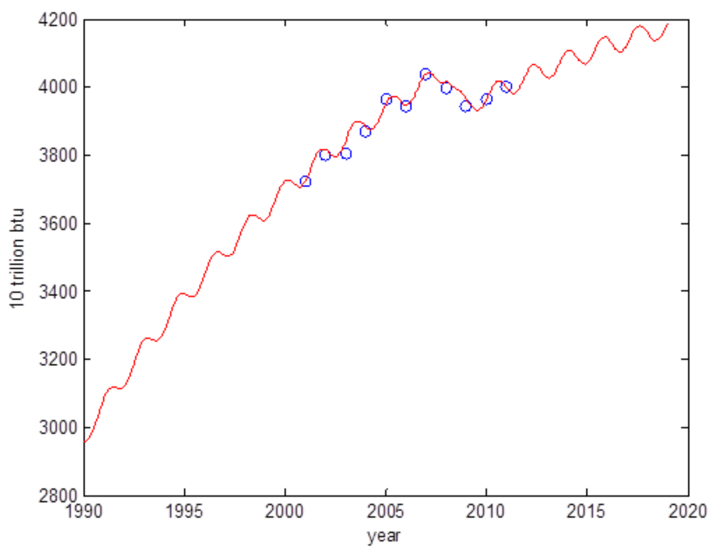


Figure 52: Approximating function of electric power sector energy consumption

Electric power sector energy costs and the average price(million dollar per 10 trillion btu):

c(2009,coal) = 117.228428, c(2009,gas)= 293.071070

c(2009,hydro)= 87.9213211, c(2009,wind)=234.456856

c(2009,nuclear)= 117.228428, c(2009,solar)= 644.756.355

p(2009)= 322.378177

r(e)=p(2009)/c(2009,e), c(t,e)=p(t)/r(e)

Electric power sector energy consumption of coal in the U.S., 2002 to 2011:

1978.2781, 2018.4743, 2030.5035, 2073.7241, 2046.1883

2080.7722, 2051.2955, 1822.5639, 1913.298, 1887.5454

(10 trillion BTU)

The approximating function is

$$d(t, coal) = \begin{cases} 2151\exp(-0.3893\exp(-0.1296(t-1989))) + 20.96\sin(2.766(t-1989)+8.365), & t < 2009 \\ 2151\exp(-0.3893\exp(-0.1296(t-1990))) + 20.96\sin(2.766(t-1990)+8.365) - 197, & t \geq 2009 \end{cases}$$

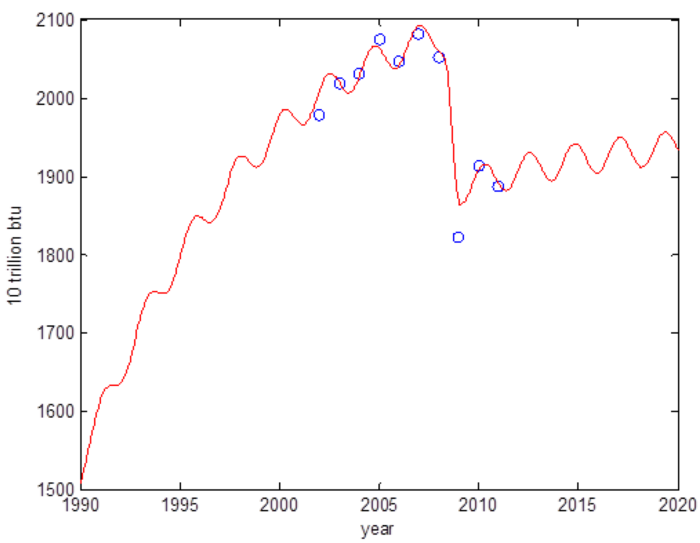


Figure 53: the approximating function of electric power sector energy consumption of coal

Electric power sector energy consumption of gas in the U.S., 2002 to 2011:

576.6795, 524.6249, 559.4924, 601.4544, 637.5123

700.5227, 682.8916, 704.3931, 753.945, 767.5788

(10 trillion BTU)

The approximation function is

$$d(t, gas) = 1138\exp(-2.407\exp(-0.08257(\mathrm{t}-1989))) + 1.23\sin(3.499(\mathrm{t}-1989))$$

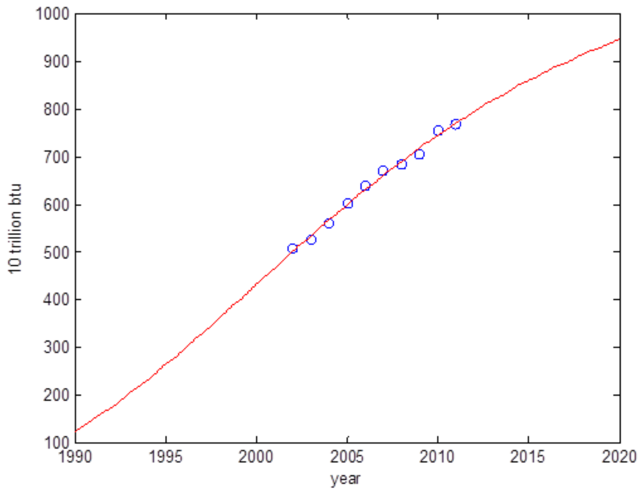


Figure 54: the approximating function of electric power sector energy consumption of gas

In this example, the approach is only applied on gas and coal in the electric power sector with fixed costs and average price.

Electric power sector energy consumption of gas and coal in the U.S., 2002 to 2011:

2555.0, 2543.1, 2590.0, 2675.2, 2683.7,

2781.3, 2734.2, 2527.0, 2667.2, 2655.1

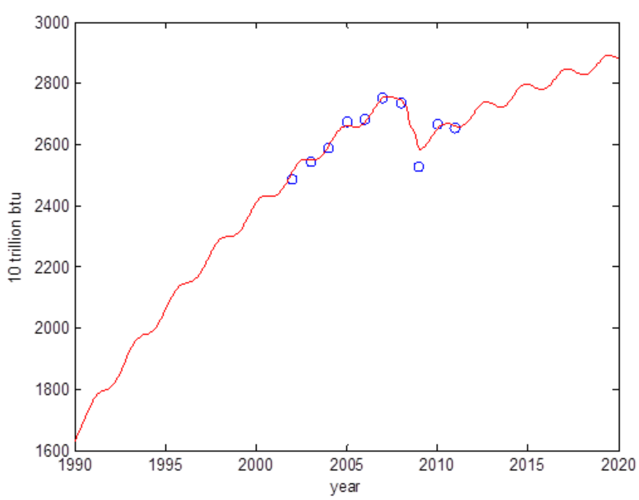


Figure 55: the approximation of electric power sector energy consumption of gas and coal

We set the coefficients $\mu = 0.6$ and $\alpha(coal,\_) = 0.0000014, \alpha(gas,\_) = 0.0000008$.

T(t,coal)= $293.071070 - 117.228428 + 99840 - 100000$*exp(-$\int 0.0000006 * d(t', coal)) *$ $dt', gas/D(t)dt'$)

T(t+1,gas)= 0

Tall(t+1)=T(t,coal)*d(t,coal)

$B(t, coal) = 0.6 * Tall(t) * 0.3635, B(t, gas) = 0.6 * Tall(t) * 0.6365$

T(2009,coal)= 48.5779, T(2009,gas)=0, Tall(2010)=8853.6,
B(2010,coal)=3218.3, B(2010,gas)=5635.3

T(2010,coal)=81.0117, T(2010,gas)=0, Tall(2011)=15500,

B(2011,coal)=5642, B(2011,gas)=9865.7

T(2011,coal)= 113.7259, T(2011,gas)=0, Tall(2012)=21466,

B(2012,coal)=7803, B(2012,gas)=13663

T(2012,coal)=147.2866, T(2012,gas)=0, Tall(2013)=28107,

B(2013,coal)=10217, B(2013,gas)=17890

(U.S. Energy Information Administration)

Conclusion

When the data in some range is known, the consumptions, costs and prices of different kinds of energy resources can be approximated. With this information it is possible to adjust the energy market by setting taxes for different energy sectors to offset the cost disparity between fossil fuels and renewable energy sources. Reducing this cost disparity would give monetary incentive for people to reduce pollution and contribute to sustainability by using renewable energy.

Transportation Within and Between Cities

The prosperity achieved by mankind has fueled exponential population growth in past centuries. Continued developments in communication, food production, medical and transportation technologies support our modern society. Cities have grown to accommodate the social and economic needs of developing society. Modern cities are hubs for both business and social interactions. The convenience of email and portable communication technology has lessened the importance of face-to-face interactions in business. As long distance communication becomes increasingly convenient, cities will shift focus away from business, they will instead be centers of social gatherings, entertainment and education.

Transportation in the city is a large scale ordeal. Subterranean mass transit systems alleviate surface congestion by operating beneath automobile and pedestrian traffic. Monorails and other elevated designs achieve a similar result by operating above ground based travelers. These systems must be expanded and optimized for efficiency in order to meet the larger population and surface area of future cities. The most effective mass transit system for any given city will be determined by local topography and climate. Congestion costs U.S. commuters 4.2 billion hours and 2.8 billion gallons of fuel each year amounting to a total cost of up to $200 billion per year to the American economy. (Ezell, 2010) Congestion increases consumption of energy, air pollution and traveling time. As such people are searching for a better transportation system with more efficient infrastructure.

Mass transit options are the most effective tools to accomplish the goal of reducing the usage in the transportation sector. However, the approach to mass transit requires more constructions and new strategies. Current technology will satisfy the mass transit needs in most cities; however, the public and government must have a desire to achieve serious greenhouse gas reductions from the transportation sector. Generally, an effective mass transit system in a city should provide different kinds of options to the public, which are available and also help to reduce the usage of fossil fuels. Commuter rail is fast, far-reaching, providing a high capacity but having a lower frequency of services. Rapid transit is faster, having more stop stations and a high frequency of services. Light rail has a lower capacity and lower speed than commuter rail or rapid transit, but it has a higher capacity and higher speed than traditional tram systems. These systems must to be well optimized in order to get a high efficiency and also serve the public well.

Figure 56: Light-rail (Relying on Rail Trainsit to Decrease Water Runoff, 2009)

Compared with commuter rail and rapid transit, light rail is more attractive since the system is easier to complete and improve. Light-rail trains powered by catenary lines require miles of electrical wires and poles, breaks, tensioning systems and all the peripheral equipment associated with creating a catenary system, and may cause serious accidents. However light-rail trains powered by a source in the ground rather than in the air are safer, more efficient and more eco-friendly, which may make the future of mass transit exciting. The initial costs to install and maintain a train are fewer, the safety problems are partially solved, because catenary-less systems do not supply power when the light- rail trains are not present and the lines in the ground, which are stable, cannot be easily broken. Moreover, although a light rail system may occupy expensive area in urban centers, it is more feasible than an elevated design or a subterranean for a city to improve its condition of mass transit in a short time.

Information technology, which has helped to make improvements in almost every part of our daily lives, will help to build an intelligent transportation system in the future. Intelligent transport systems vary in technologies applied, but they share similar ideas in wireless communications and computational technologies. By embedding vehicles, roads, traffic lights, message signs, ramp meters and other traffic control devices with microchips and sensors, enabling them to compute and communicate wirelessly, the transportation system will be easily controlled and optimized to maximize the capacity of infrastructure, reduce congestion, the need to build additional highway capacity and reduce relevant pollution. An intelligent transportation system can also provide drivers with travelling time information, such as transit routes, schedules, reduce congestion, and increase travelers' safety. For example, applying real-time traffic data to U.S. traffic signal lights can increase the traffic efficiency significantly, reducing stops by 40 percent, travel time by 25 percent, gas consumption by 10 percent and emissions by 22 percent, congestion by 20 percent or more. For Japan, intelligent transportation systems have helped to reduce, CO_2 emissions by 31 million tons below 2001 levels by 2010. (U.S. Department of Transportation)

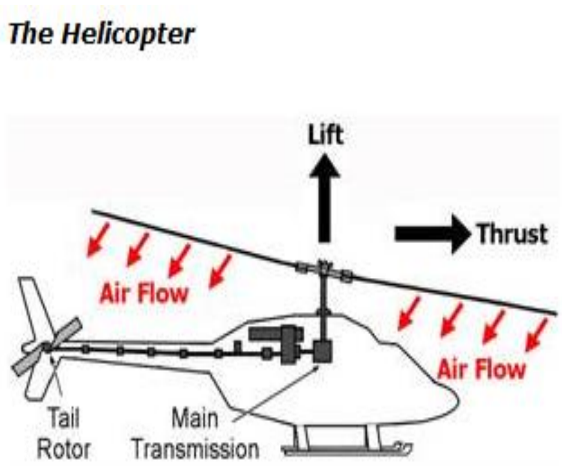


Figure 57 (Groen Brothers Aviation)

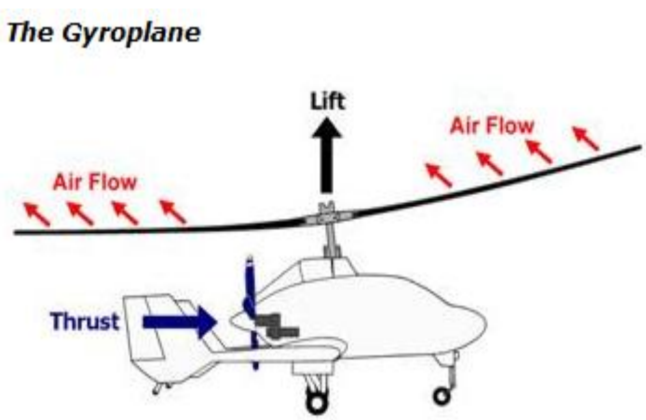


Figure 58 (Groen Brothers Aviation)

Many do not enjoy the noisy congestion of city life and prefer to live outside cities. The practical limitations of automobiles lent themselves to the development of suburbs. Smaller communities on the outskirts of cities, residing in a suburb provides some space and privacy with relatively easy access to one city. Excursions from a rural community are longer and less predictable than in cities. An independent form of transportation, such as a car is ideal for this type of travel. The automobile, used extensively for the transportation of goods and people has changed mankind without doubt. Four wheels and a motor have become so normalized that many immediately assume such automobiles will continue to be the most effective mode of travel. A result of land based transportation is traffic. Every automobile must traverse the same plane of road surface and bottlenecks are a result. Proponents of autogyro technology call for an end of the car mania and a transference to long underutilized technology from the 1920s. (Wise, 2010)

"Gyroplane is an official term designated by the Federal Aviation Administration (FAA) describing an aircraft that gets lift from a freely turning rotary wing, or rotor blades, and which derives its thrust from an engine-driven propeller." (Groen Brothers Aviation)

A rear facing engine and propeller force wind over the tail. The forward movement of the gyroplane causes air to contact the rotor, spinning it and producing lift. This phenomenon is referred to as autorotation. Because horizontal thrust is not generated by the top rotor a tail rotor is not needed as in a helicopter. The unpowered rotor also stabilizes the gyroplane during operation, making this form of flight remarkably user friendly. A pilot's license is not required to operate this type of aircraft; although some pre-flight training is strongly recommended. Research conducted at Eindhoven University of Technology shows that most autogyro crashes can be attributed to inexperienced pilot error. (Pagan) Once a gyroplane is airborne, it cannot stall like an airplane. If the propeller's engine fails the aircraft's momentum will ensure autorotation continues as the gyroplane descends slowly. The gyroplane is still maneuverable if thrust ceases and as such crash landings are relatively controllable. (Groen Brothers Aviation) Unlike helicopters, a simple internal combustion or electric motor will provide enough power for flight. The applied forces associated with gyrocopter flight are relatively low. Simple tube frame designs operate well and provide low initial and maintenance costs. An entire gyroplane kit can be purchased and constructed for under $10,000. (Popular Rotorcraft Association)

Figure 59 (The 7 Group)

Gyroplanes lack the vertical takeoff and hovering ability of helicopters, however the slow speeds associated with takeoff and descent allow short strips to be used for both. Average user built models average fifty to sixty miles per hour, but some travel in excess of one hundred miles per hour. (Popular Rotorcraft Association) Future models may easily achieve cruising speeds in the hundred miles per hour range, providing rapid direct transportation for users. One NASA developed internal combustion powered prototype is boasting roof based takeoff and landing, as well as cruising speeds in excess of four hundred miles per hour, all while accommodating five or more passengers. (Schultz, 1996) Gyroplanes can operate from very low altitudes to twenty-thousand feet above sea level. Current single seat gyroplanes are moderately sized at approximately fourteen feet long, eight feet high and six feet wide. (Popular Rotorcraft Association) Some models have detachable rotors and wings which can then be stored inside the craft. Gyroplanes can travel on land with relative ease. Future models could incorporate improved ground handling capabilities to allow road based transportation between air strips.

Vactrain is a proposed design of high speed transportation, building maglev lines (using magnetic levitation to suspend, guide and propel vehicles from magnets rather than using mechanical methods) in an evacuated tunnel. Because frictional losses are eliminated, a vactrain consumes little power and moves at high speed. Theoretically, vactrain can moves at a speed of 5000 mph, so this design will largely reduce the time for long-distance travels. (Transatlantic Tunnel) Moreover, except for a high speed, vactrain has several advantages when it is compared with airplane, train, automobiles and other modes of transport: it causes little pollution, does not operate with gas or petroleum, produce little noise, can use gravity to assist their acceleration, achieve a high speed by accelerating gradually without affecting the passengers, is available even in some kinds of extreme weather conditions such as extreme rain dust storm. If vactrain can be turned into reality and work efficiently and persistently, it will, definitely, improve the present transportation a lot, but there are also challenges difficulties to overcome in turning it into reality. Firstly, the initial cost of such a long vactrain line may be trillions of dollars. (Alihusain Yusuf Sirohiwala, Ananya Tandon, Raj Vysetty, 2007) Secondly, the huge evacuated tunnel will take up space. Thirdly, the evacuated tunnel may collapse during an earthquake or an accident. (James Powell, Gordon Danby, 2003)

There is a positive correlation between the consumption of energy and the development of transportation: futuristic transportation will be influenced by the reaction of human-beings to the present energy situation, and then it will influence the futuristic energy situation. As a result, developing the present transportation is an important approach to a better energy situation in the future.

Social and Psychological Impacts of Energy Conservation Policy

There are many possible consequences that various energy policies could have, but some of the least explored are the psychological effects they could have on those living with them.

If in order to reduce fuel consumed in traveling working from home for many days a week becomes a reality there are a number of possible consequences. For one it would reduce the amount of informal communication amongst office employees creating an environment that is more socially alienating. The lack of casual “water cooler” talk could reduce general life satisfaction and make it more difficult to deal with stress as the immediate presence of people working with the same problems as you is no longer there. Working from home also means less human energy spent traveling to and from work and the lack of regular exercise could create psychological problems for people as their body produces fewer endorphins. Another possible problem is that people living with stressful home lives would face that stress more frequently as they wouldn’t have the temporary escape of going to an office to work. On the plus side, studies in northern climates have shown that suicide rates increase with exposure to more daylight (Greenland's Constant Summer Sunlight Linked To Summer Suicide Spike, 2009) so people working from home may be less exposed to sunlight and less likely to commit suicide.

Another potential energy policy with psychological consequences is a large-scale change away from individual driving and towards mass transit. In theory some of the consequences would be positive; the increased activity used when commuting via mass transit would be healthy both physically and mentally by reducing insomnia and depression. However, a long commute that requires multiple transfers on crowded public transport could certainly increase stress. There has also been some link between heat and suicide (L. A. Page, S. Hajat, R. S. Kovats) and more time spent in hot crowds could contribute to that effect. Also a decrease in the ability to drive freely could make leisure travel less convenient increasing stress while making it more difficult for some people to relive that stress.

The possibility of rolling blackouts to reduce electricity usage could decrease life satisfaction and increase stress if not handled correctly. Many modern past times depend upon electricity and having to plan on an hour each day when one couldn’t perform them could draw attention to the lack of the activity at that time.

The amount of available energy in the future could also have psychosocial consequences. With very large amounts of available energy individuals could more easily engage in social isolation by relying on electronic entertainment, telecommuting, and even delivery groceries rather than going out into the world where they might have to deal with other people. Conversely, in a low energy future people would be forced to spend more time with others in order to make the most of the available energy resources by sharing energy use and responsibilities.

Efficient Future Housing

The amount of energy available to meet increasing demand will have a number of effects on the world of the future. Even where and how people live will change based on the amount of energy available. In a high-energy future it would be like living in a surplus economy, spending energy with much less caution than the present day. Likewise a low-energy future would act like a recession with people carefully budgeting their energy usage.

In a low-energy future saving energy will necessitate changes in the way people live. In order to use less energy traveling communities would become more localized as people move closer and closer to the places that they visit frequently such as work, shops, and school. This could possibly create mini-communities where neighborhoods or apartments are built with most or all of the daily necessities inside, with people living around general and grocery stores. If this effect becomes more pronounced even within cities blocks could band together to form tightly packed villages with more isolation between them then would normally be found in a city. This sense of community could be increased by using communal appliances to reduce energy usage, things like washing many people's clothes together in a commercial washing machine and carpooling. Another possible effect of low-energy supplies in the future is something that is implemented in many areas already where the power plants can't meet demand, rolling blackouts. In these cases there are planned electricity outages to predetermined areas of the power grid as frequently as is necessary to prevent the power plant from becoming overburdened. Because so much home entertainment in modern times is electronic this could have a significant impact on society as people start storing non-electronic entertainment in preparation for blackouts. This effect would be added to by the possibility of energy rationing, just as limits are placed on the amount and times people can use water in drought stricken areas, there would be limits on the amount of energy a given household could use in a given time. Another effect is that more families would be composed of numerous generations living together as moving becomes more difficult and expensive and by sharing living quarters the economic burden is divided over more people and lessened. If the situation became bad enough governments could end up drastically curbing people's rights in order to ensure that there is enough energy to go around. Limits on the number of children to a family could be placed in order to stabilize future energy demand by not increasing the population. It's even possible that euthanasia programs could be put in place limiting the age someone is allowed to live to in order to further curb the population. In order to save energy people may begin to abandon building new high-rises which would become costly and require more energy to light and heat and instead spend more effort on buildings which take advantage of local geography to save energy, by either having a portion of the building subterranean to save on heating and cooling or even creating large greenhouses in a buildings center to collect and trap solar heat.

In a high-energy future the effects would largely be the opposite of the low-energy state. People would spread out more and with cheaper energy travel more, both for every day errands like shopping and for vacations. The biggest effect that an energy surplus would have, though, is on technology. Larger amounts of energy means that appliances that might be too inefficient to be plausible now could gain widespread use in the future. For instance, multipurpose robots that might be too expensive to use now could be more functional and with the energy surplus designing and building new robots could be made cheaper. In general, many technologies could benefit because the cost of manufacturing prototypes could be brought down by a decrease in the cost of energy. If energy prices drop by enough travel could also increase to such a degree that many people move frequently throughout their lifetimes. In this case houses would be made with the intention of being able to resell it in a very short amount of time. In this way people would possibly spend less time renovating a house to suit their needs as any renovations could actually decrease the resale value. Another possibility is that houses could be made to be more modular with prebuilt parts such that they can easily be modified to suit the new owner's tastes. With a large steady supply of energy people will be given a larger number of choices where convenience can begin to overtake practicality as costs go down. Some people could move from permanent structures like houses to living in flying vehicles like zeppelins that take advantage of the energy supply to enable them to rarely land. If energy availability increases enough the potential overpopulation problem could be remedied as people trade living on earth for houses in satellite colonies performing work for the colony or even telecommuting to earth. In addition the cost to build houses would go down so the current trend of the “Mcmansion” where very large houses are built on small lots could continue to spread to the point where the average middle class citizen is living in a large multistory house in the suburbs.

Overall the effect that the amount of energy will have on housing is a large one. It won’t just affect the kind of homes people have but where they’re located, how many people they hold, and how frequently they’re resold. As energy increases people will become more wasteful spending energy unnecessarily in order to try to make their lives easier or more fun, whereas as energy decreases people will begin to conserve energy as much as they can and even rely more on low energy entertainment methods.

Energy of the Future

Fossil fuels are a non-renewable resource and as such it is inevitable that humanity will eventually deplete the earth's supply. It is crucial that we continue exploring new ways to meet our energy demands. Some of these methods are experimental and still impractical. Rapidly developing countries such as China and India are exploding in population and energy use. As similar situations occur in other nations, fossil fuels will become scarce, increasing the feasibility of alternative fuels. There is no telling which future energy sources will become the most prominent, but it is certain that as time and technology advance more creative ways of capturing transmittable energy will be developed.

Nuclear Fusion: Far from Science Fiction

The atomic forces that bind protons and neutrons are extremely energetic. Releasing this stored energy can be achieved either through fission, splitting the nucleus of an atom with high atomic number, or fusing, combining the nuclei of atoms with low atomic number. (EFDA) Currently all full scale nuclear power plants utilize nuclear fission in order to generate heat energy to convert into electricity. Fission of high mass nuclei is initiated by neutron catapult, which results in the expulsion of neutrons at high enough energy levels to sustain the reaction. While not yet full scale or self-sustaining, experimental nuclear fusions reactors are currently conducting experiments; successfully fusing hydrogen atoms and harnessing the energy released in the form of electricity.

A tokamak is the scientific term for a large doughnut shaped chamber specifically designed to contain the radioactive plasma material used to fuel nuclear fusion reactions. The chamber is a "vacuum vessel" with "vacuum being maintained by external pumps." (Culham Centre for Fusion) Powerful electromagnets surround the chamber and confine the plasma with magnetic fields. The magnets induce a current in the plasma that contains it by repelling the atoms individual magnetic charges. At startup plasma must be heated to operating temperature to initiate fusion. Deuterium contains one proton and one neutron, and tritium one proton and two neutrons. Electric current is used to heat the plasma to extreme temperatures. The atomic motion induced by heating will cause some hydrogen nuclei to collide and fuse, creating helium atoms. The one extraneous neutron in the tritium nucleus is jettisoned from the point of collision with incredible energy. The reaction is written as follows. (Culham Centre for Fusion)

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

The expulsion of just one neutron from the newly formed helium atom releases 17.59 MeV, $1.602*10^{-13}$ joules, of energy. The kinetic energy of the expelled neutrons is transferred to heat as the particle is slowed down by the surrounding plasma and then converted into electricity. (Culham Centre for Fusion) “If we consider the implications of this reaction we can begin to understand why it is called a thermonuclear reaction and why it is so difficult to produce in a controlled manner. The d-t reaction requires that we fuse two positively charged particles. This means that we must provide enough energy to overcome the force of repulsion between these particles before fusion can occur.” (Nuclear Fission and Nuclear Fusion)

The Joint European Torus (Joint European Torus) is an internationally funded tokamak style reactor project that has been successfully fusing deuterium and tritium since 1984. (European Fusion Development Agreement) These experimental fusion reactions are still inefficient. Scientists have not achieved a self-sustaining fusion reaction using the JET or any other hydrogen collider. Fusion requires higher catalyst energy than fission, so sustaining a reaction is more difficult. In a recent test twenty four million watts of input power yielded an output of sixteen million watts. A clear disadvantage of the technology is the high power cost of initiating the reaction. Full-scale fusion power plants would also require a huge vacuum vessel with extensive shielding. (Winters, 1998)

One major hurdle to overcome on the journey to commercial scale fusion reactors is the availability of the radioactive tritium fuel. Tritium has a natural abundance, “the average abundance of this isotope as found in nature on Earth” of $3*10^{-16}$. These may be compared to normal hydrogen’s natural abundance of 99.9845 %. (Hoffman, 2009) Tritium is more abundant on the moon than on Earth. The United States, Russia and China have all stated intentions to develop permanent lunar bases in the coming decades. (Williams, 2007) This initial step will increase the viability of lunar mining and provide a means of commercial scale tritium mining on the moon. Although tritium isn’t very common on Earth it can be produced using another isotope, deuterium, which is somewhat abundant. Deuterium has a natural abundance of 0.0155%. Tritium is produced during the fission of uranium-235, plutonium-239, and uranium-233. Adding to the mineral's rarity is an extremely short half-life, about 12 years as opposed to uranium-233 with a 160,000 year half-life.

In fission, tearing apart uranium and plutonium nuclei leads to the production of many radioactive isotopes, which must be handled properly and stored for long periods of decay. Since fusing hydrogen nuclei results in the formation of helium atoms; an environmental benefit of this reaction type is the reduction of nuclear waste. Some radioactive material is still produced. A percentage of atoms located on the inner wall of the vacuum vessel become radioactive isotopes when they collided with the jettisoned neutrons. (Winters, 1998) Recently beryllium has been found to minimize the amount of radioactivity induced in the shielding by neutron collision. In order to produce enough energy in the plasma to induce a self-sustaining fusion reaction a larger tokamak vacuum vessel will be needed than what is currently in use at the JET.

Enter the Jet's successor, ITER. This fusion reactor construction and research project began in 2006 and is internationally funded. The 30-year timeline includes a decade long construction phase and twenty years of subsequent research. The goal of ITER is to produce a tokamak that can initiate and contain a self-sustaining fusion reaction. Theoretically, ITER will "produce Five Hundred Megawatts of power in a 400 second" self-sustained fusion reaction. If successful, the ITER project would be the first fusion reactor that outputs as much energy as is required for operation. (European Fusion Development Agreement) The research that will be conducted with ITER is crucial to determining the viability of large-scale tokamak style reactors for self-sustained nuclear fusion power plants. The beryllium shielding mentioned earlier is one of the variables that will be tested at ITER.

Tokamaks aren't the only solution to the nuclear fusion problem. Physicist Hendrik Monkhorst has produced a design that theoretically would eliminate the issue of radioactive shielding altogether.

His scheme is based on a well-known process. The reaction of a proton and a boron atom is one of the oldest known fusion reactions, going back to the late 1930s in England, but was studied only for its astrophysical importance, says Monkhorst. When a proton fuses with a boron atom, which has five protons and six neutrons, the nucleus splits into three helium nuclei. With no leftover protons or neutrons, the amount of radiation is greatly reduced. (Winters, 1998)

So what we're talking about here is fusion-powered fission. Boron atoms would be extremely unlikely to fuse under the random velocity and position collisions provided by a tokamak hydrogen smasher. A more elegant particle accelerator will be necessary to accurately line up a neutron for collision with the boron nucleus. Monkhorst's team has conducted experiments, which "validate his claims." They are currently working on gathering funds for further experiments and with luck the eventual construction of the boron fusion fission reactor, which Monkhorst states could fit "in the basement of a large office building." The energy that could be collected by the accelerating helium atoms is less than what is possible with deuterium-tritium reactors but the complete elimination of radioactive contamination makes it an option worth considering. (Winters, 1998)

As technology progresses, utilizing the high-energy bonds that hold nuclei together for generating electricity is becoming an increasing viable option. Research still needs to be conducted before realizing full scale potential. Despite the tremendous progress being made, fusion power plants are not likely to be generating electricity for entire populations in the next few decades. Ultimately it will be a combination of several energy generation and conservation techniques that will power our future planet.

Recycling Human Body Heat

There is currently a large quantity of different methods for generating energy, from coal fired power plants to solar power. And each method is constantly being refined to increase efficiency, decrease cost, and make them better for the environment. However, the future isn't always easy to predict and there are methods of generating electricity, which though highly impractical at the moment could become widespread with future advances in technology.

One such energy source is the human body, or more precisely heat generated by the human body. Humans are constantly producing body heat as part of the metabolic process that gives us energy and in order to keep a comfortable body temperature. Like most heat generated during energy generation it becomes waste heat discharged uselessly into the environment. But it doesn't necessarily have to be useless. One way of making use of human body heat is collecting the excess heat from a place where large quantities of people gather and using it to heat a nearby building during winter. This was done in Stockholm Central Station with the result of reducing heating costs in the adjacent office block by 25% (Hinchey, 2011). This was accomplished by channeling the ventilation to heat water which was then channeled into the adjacent buildings. One of the current problems with this method is that it is only especially useful in places with high population densities and long cold winters. Unlike geothermal heating systems, this doesn't enable any savings on air conditioning in the summer and it cannot completely replace more conventional heating because the amount of heat available rises and falls with the amount of traffic through the station. However if there were a reliable and cost effective way of storing this heat year round it could become an extremely valuable resource for population centers. Take for example New York City's subway system. On an average weekday there are 5000000 riders (Metropolitan Transportation Authority). If one assumes the average trip time is 45 minutes and each rider produces 117 Watts (Ballast, 2010) of heat, then that's the equivalent of 87.75 Watt hours per ride, 438750 kilowatt hours generated on an average day and 160143750 kilowatt hours generated over the entire year. When one takes into account that in 2009 New York City used 53,100 gigawatt hours (ISO) of electricity then that is possibly 30% of the electricity usage saved by stored heat. And if one uses a device like a Stirling engine, which uses external heat to produce mechanical energy, which could then be transformed into electrical energy, it would be possible, in theory, to gain somewhere around 3% of the city's electrical needs from subway heat. At the moment the biggest impediment to this is the cost of renovating that entire infrastructure and the difficulty in gaining a large enough difference in heat between the subway and the heat sink to be useful.

Another means of taking advantage of the heat produced by the human body is through thermoelectric generators, devices which take advantage of temperature differentials to generate electricity. Currently they only work at 5%-10% efficiency and are most commonly used in small devices where more mechanical heat engines like Sterling engines wouldn't be useful. In this case it might be possible to collect small amounts of electrical energy from individuals throughout the day by having them wear some form of heat collection suit. However, that poses the problems of dramatic wear and tear not to mention ventilation allowing someone to breath would also cause heat to be lost. So an alternative method of heat collection from individuals would be to restrict it to when their asleep, however this means collecting less energy over a shorter period of time. Below is a graph showing theoretical heat generated by people for the countries with the top 25 populations as well as the theoretical amount of electricity that could be captured using thermoelectric generators.

Table 13: Table depicts calculations of heat production from humans by population. Assumed an average of 200 W over the course of the day produced by humans, as an underestimate of typical heat production during light activity (Ballast, 2010). Assumed an average of 117 W (Ballast, 2010) during sleep as the typical at rest heat production and an average sleep time of 8 hours. Population data is from 2009-2010 (Wikipedia, 2011).

Pop. Rank	Country	Population	% World Pop.	Yearly GWh of Heat Generated	Theoretical Electricity Generated (GWh)	Yearly GWh of Heat Generated during sleep	Theoretical Electricity Generated (GWh)
-	World	6.98E9	100.00%	12229271	1222927	2384707	238470
1	China	1.34E9	19.21%	2348805	234880	458017	45801
2	India	1.21E9	17.35%	2121711	212171	413733	41373
3	United States	3.13E8	4.48%	548085	54808	106876	10687
4	Indonesia	2.38E8	3.41%	416632	41663	81243	8124
5	Brazil	1.91E8	2.73%	334433	33443	65214	6521
6	Pakistan	1.78E8	2.55%	311778	31177	60796	6079
7	Nigeria	1.62E8	2.33%	284844	28484	55544	5554
8	Russia	1.43E8	2.05%	250557	25055	48858	4885
9	Bangladesh	1.43E8	2.04%	249513	24951	48655	4865
10	Japan	1.28E8	1.83%	223918	22391	43664	4366
11	Mexico	1.12E8	1.61%	196948	19694	38404	3840
12	Philippines	9.40E7	1.35%	164823	16482	32140	3214
13	Vietnam	8.59E7	1.23%	150506	15050	29348	2934
14	Ethiopia	8.21E7	1.18%	143941	14394	28068	2806
15	Germany	8.17E7	1.17%	143287	14328	27941	2794
16	Egypt	8.11E7	1.16%	142203	14220	27729	2772
17	Iran	7.58E7	1.09%	132952	13295	25925	2592
18	Turkey	7.37E7	1.06%	129251	12925	25203	2520
19	Thailand	6.95E7	1%	121880	12188	23766	2376
20	Democratic Republic of the Congo	6.78E7	0.97%	118793	11879	23164	2316.
21	France	6.58E7	0.94%	115398	11539	22502	2250

22	United Kingdom	6.23E7	0.89%	109224	10922	21298	2129
23	Italy	6.07E7	0.87%	106429	10642	20753	2075
24	South Africa	5.06E7	0.73%	88688	8868	17294	1729
25	Myanmar	4.83E7	0.69%	84744	8474	16525	1652

Overall using human body heat, as an energy source is a long way from being feasible for most places. However, it wouldn't be surprising to see energy conscious places taking advantage of the heat that crowded areas produce in order to save on energy bills.

Let's Talk about Energy: Our Energy Future

In addition to this report, we have made this information publically available on the website http:// www.ourenergyfuture.weebly.com/. The current and future use of energy is something that everyone needs to be aware of, as the choices society makes now will have a lasting effect on the cost and availability of energy in the future. We hope that by adding our research and conclusions to the discussion that we will be able to bring attention to the problems and challenges that must be faced; and so that more people will be aware of the issues and contribute to the discussion.

Recommendations for Future IQPs

This is a topic that will probably always be relevant and as such there is a great amount of work that could be done towards examining the future of energy in the world and what we need to do in the present to help ensure the best possible future. Also, as more data becomes available our understanding of what "ideal" futures are possible will shift. As such this is an IQP that could possibly be repeated in 10 or 20 years' time by virtue of the fact that events that unfold in the next decade will likely influence the conclusions we reached in ways that we're unable to predict right now.

Some of the areas that future IQP's could examine more carefully are aspects of future change that aren't directly related to energy. Other IQP's could focus on a different aspect that will change in the future, things like environmental changes, advancements in technology that effect the way people live, and even possible worst case scenarios and what people would have to do in order to adapt. Some of our preliminary research touched on these topics and there is a significant amount of work that could be done examining possible changes to infrastructure and transportation and the consequences of those changes. Also as time passes humanity will face many disasters and challenges and examining what those could be and ways of combatting or even preventing them could provide useful insight.

Another, direction that other IQP's could take would be to examine the impact of previous advances in technology and the availability of energy in the past as a means of predicting likely patterns in the future. By examining major changes in energy and technology since the industrial revolution, they might shed some light on the ways society and technology influences one another. By more exhaustively analyzing past trends it may also be possible to create more accurate models of future change or even identify challenges that could be overcome with preventative planning, things like workforce displacement or major shift in the demand for certain services or industries.

As this IQP primarily dealt with the total combination of energy sources in the future many of the energy sources discussed could be examined individually in greater depth. Especially the newer technologies such as fuel cells that may change rapidly in the future and speculative energy like nuclear fusion. By increasing the amount of depth and limiting the focus to a specific kind or kinds of energy future IQPs could discuss a wider variety of future possibilities, especially those which may be impractical by our current standards but could become much more viable as the technological and economic landscape changes.

Conclusion

Millions of people residing in developed nations depend on access to affordable convenient energy. The globalization of modern society has compounded demand for reliable electricity and mobile power sources. Fossil fuel combustion produces over 80 percent of the United States electricity supply and is used in almost all forms of transportation. Toxins and particulate matter are released during fossil fuel combustion, the negative effects of which are exacerbated by the global scale at which they are being used. These hidden costs of fossil fuel combustion, coupled with their limited supply make it necessary to begin development and utilization of alternative, energy sources. We rely too heavily on fossil fuels to stop using them outright, but it is imperative that we begin to explore unlimited sources of energy immediately. There are two modes of advancement being investigated. Researchers are improving production and use efficiency. Parallel research is resulting in the development of supplementary, passive methods of “green” energy capture. Both technologies must be used in conjunction to extend the lifetime of fossil fuels.

The major challenge for twenty-first century society is and will continue to be the implementation of a global energy production infrastructure that can satisfy total demand, minimize cost, produce as little pollution as possible and extend the lifetime of fossil fuels. Current energy consumption data makes clear that coal is still king. It is the primary source of energy for electricity generation worldwide with the lowest cost per unit power. The culmination of this research is presented as a prediction of the roles each energy type will play in generating future power as well as their overall effect on society.

Particulate matter and other toxins are released in different proportions when combusting different types of fossil fuels. There are methods to capture these pollutants after combustion, but since they cost extra, plants must be persuaded to participate. Regulations are not consistent worldwide so carbon capture is still limited in use. Plans to tax combustion power plants based on their carbon dioxide emissions are being considered. An appropriate method of taxation would be to determine the approximate cost of all the pollutants emitted by a particular combustion power plant. This tax money would be used to fund health care and environmental programs related to fossil fuel combustion. Taxing combustion plants would also help close the price gap between fossil and renewable energy sources.

Research has yielded many promising sources of sustainable, renewable energy. Many of these sources are already being utilized commercially. There are large amounts of energy that can be extracted from solar, wind and hydroelectric energy among others. While these energy sources are more expensive than combustion, they have the advantage of limitless supply. The primary factor driving the development of any particular renewable energy source is cost. Many suffer from high initial cost. However, without investment into renewable energy sources we are destined to deplete our main source of energy quickly and be left unprepared to power our modern society. As hidden costs related to fossil fuel combustion make renewable sources more economically feasible, more research is being funded and more solutions discovered.

Futuristic renewable energy sources such as nuclear fusion reactors and giant orbiting banks of solar panels are still outside the realm of economic feasibility but show promise for future use. It is critical that we utilize alternative energy sources to extend the lifetime of fossil fuels, allowing ample time for the development of permanent renewable energy solutions. The goal is global sustainability, but the first steps in this progression are acceptance of the situation, conservation and supplementation.

Figures

Tables

Bibliography

(n.d.). Retrieved from The 7 Group: 7-gyroplane.com

(n.d.). Retrieved March 5, 2012, from China Three Gorges Project Corporation: http://www.ctg.com.cn/en/

(n.d.). Retrieved December 5, 2011, from European Fusion Development Agreement: http://www.efda.org/

(n.d.). Retrieved February 3, 2012, from Mighty River Power: http://www.mightyriver.co.nz/

Relying on Rail Trainsit to Decrease Water Runoff. (2009, September 23). Retrieved from Wordpress: http://thetransitpass.wordpress.com/2009/09/23/relying-on-rail-trainsit-to-decrease-water-runoff/

U.S. Department of the Interior. (2006, May). Technology White Paper on Ocean Current Energy Potential on the U.S. Outer Continental Shelf Minerals Management Service.

the issues: fossil fuel and energy use. (2006). Retrieved from sustainabletable.org: http://www.sustainabletable.org/issues/energy/index_pf.html

Exxon Mobil Loses Claims to Alaskan Natural Gas Reserves. (2007). *Canadian National Post*.

Greenland's Constant Summer Sunlight Linked To Summer Suicide Spike. (2009, May 7). Retrieved from Science Daily: http://www.sciencedaily.com/releases/2009/05/090507190558.htm

Union of Concerned Scientists. "How Geothermal Energy Works". (2009, December 16). Retrieved from http://www.ucsusa.org/clean_energy/technology_and_impacts/energy_technologies/how-geothermal-energy-works.html

EPA Tackles "Fracking" (Hydraulic Fracturing). (2011 , May 12). Retrieved from the Water Filter Lady's Blog: http://thewaterfilterladysblog.com/2011/05/12/epa-tackles-hydraulic-fracturing/

An Introduction to Tidal Turbines. (2011, July 12). Retrieved March 5, 2012, from http://community.greencupboards.com/2011/07/12/an-introduction-to-tidal-turbines/

The Real Issue With Solar Energy Isn't Its Cost. (2011, November 9). Retrieved from http://seekingalpha.com/article/306468-the-real-issue-with-solar-energy-isn-t-its-cost

Solar Cell. (2012, Feb. 25). (W. Foundation, Producer) Retrieved Feb. 25, 2012, from Wikipedia: http://en.wikipedia.org/wiki/Solar_cell

A. Cadenas, S. Cabezudo. (1998). Biofuels as Sustainable Technologies: Perspectives for Less Developed Countries. *Technological Forecasting and Social Change*, 83-103.

Adey, W. (2009, December 04). Biofuels: algae. *Science*.

Africa News Service. (2011, May 20). *Hope Rises on Commercialization of Ocean Current Marine Energy.*

Alihusain Yusuf Sirohiwala, Ananya Tandon, Raj Vysetty. (2007). *Feasibility and Economic Aspects of Vactrains.*

Al-Shemmeri, T. (2010). *Wind Turbines.* BookBoon.

Alvania, R. (2009, May 20). News from the National Academies, Fuels from Coal and Biomass Could Impact the U.S. Oil Dependence.

Anada, H. R. (1978, May). U.S. Patent #4,197,911, Process for In Situ Coal Gasification.

Antonio Herzog, James Bartis. (2007, May). Coal Gasification: Opportunities and Challenges Senate Hearing.

Ballast, D. K. (2010). *Interior Design Reference Manual* (5 ed.). Belmont, CA: PPI.

Barrows, S. P. *The Law of Population and the Austrian School: How Austrian Economists Interacted with Thomas Robert Malthus.*

BP. (2011). Statistical Reviews of World Energy.

Chen, F. F. (2011). *An Indispensable Truth: Future Energy I.* Springer.

Chen, F. F. (2011). *An Indispensable Truth: Future Energy II.* Springer.

Culham Centre for Fusion. (n.d.). Retrieved November 11, 2011, from http://www.ccfe.ac.uk/

Cumhuriyet University. *"Biomass Lung": Primitive Biomass Combustion and Lung Disease.*

Demirbas, A. (2007). Progress and recent trends in biofuels, Prog Energy Combust Sci 33.

Demirbas, A. (2008, August 8). Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. *Energy Conversion and Management 49*, pp. 2106-2116.

Department of Economic and Social Affairs Population Division. (n.d.). Retrieved from United Nations: http://www.un.org/esa/population/

Duncan, R. C. *World energy Production, population Growth and the Road to the Olduvai Gorge.*

Exxon Mobil. (2010). 2010 The Outlook for Energy: A View to 2030.

Ezell, S. (2010, January). *Intelligent Transportation System.* Retrieved from http://www.itif.org/files/2010-1-27-ITS_Leadership.pdf

G., F. (1998 , June 30). Perspectives on overpopulation. *CMAJ.*

Global Subsidies Initiative. (2008, April 30). *BIOFUELS – AT WHAT COST?*

Grigg, J. *The Health Effects of Fossil Fuel Derived Particles.*

Groen Brothers Aviation. (n.d.). Retrieved from http://www.groenbros.com/products.php

Gunn., S. (2008). Concepts and Practice of Humanitarian Medicine: Man-Conceived Disasters. Springer.

Hallenbeck, W. H. (1994). Radiation Protection. CRC Press.

Hasnan. (2008, April). *Growth Annual Installed capacity of Wind Turbine.* Retrieved from http://winds-energy.blogspot.com/2008/04/annual-installed-capacity-of-wind.html

Hinchey, X. (2011, Jan 9). *Harvesting energy: body heat to warm buildings.* Retrieved Feb 22, 2012, from BBC News: http://www.bbc.co.uk/news/business-12137680

Hoffman, R. (2009). Hydrogen NMR.

Howard K. Koh, Rebecca O. Cadigan. (2008). Social Capital and Health: Disaster Preparedness and Social Capital. Springer.

Huebner, A. L. (2003). The Cost of Fossil Fuels. *The Humanist Journal*.

Hughes, T. (n.d.). *Lesson Number 1. in an Oklahoma Wind Power Tutorial Series.* Retrieved from http://www.seic.okstate.edu/owpi_old/about/library/lesson1_windenergycalc.pdf

International Energy Agency. (2007, January). *IEA Energy Technology Essentials.*

ISO. (n.d.). *Power Trends 2010.* Retrieved from New York ISO: http://www.nyiso.com/public/webdocs/newsroom/power_trends/powertrends2010_FINAL_04012010.pdf

J. Spendelow, J. Marcinkoski. (2011, August). Fuel Cell System Cost -2011.

James Powell, Gordon Danby. (2003). *MAGLEV: The New Mode of Transport for the 21st Century.* Retrieved from 21st Century Science & Technology Magazine: http://www.21stcenturysciencetech.com/articles/Summer03/maglev_3.pdf

Joint European Torus. (n.d.). Retrieved October 23, 2011, from http://www.efda.org/

Josey, J. (2008). *Conservation Update: Natural Energy Laboratory of Hawaii Authority Returns to Its Energy Roots.* Retrieved from http://www1.eere.energy.gov/wip/update/m/2008-01_nelha_roots.html

Kapoulitsas, G. M. (1985). On the generation of tides. *Eur. J. Phys. 6 (1985) 201-207*.

King, B. W. (2009, Mar 2). *How much coal is out there?* Retrieved from http://energybulletin.net/node/48240

Knier, G. (n.d.). *"How Do Photovoltaics Work?".* Retrieved Feb 25, 2012, from http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/

Kolson, S. *Malthus at mid-century: neo-Malthusianism as bio-political governance in the post-WWII United States.*

L. A. Page, S. Hajat, R. S. Kovats. (n.d.). *Relationship between daily suicide counts and temperature in England and Wales.* Retrieved from http://bjp.rcpsych.org/content/191/2/106.full

Levine, S. (2009). New Business: “XTO: Exxon Buys a Green Headache”.

Lipfert, F. *Assessment of Mercury Health Risks to Adults from Coal Combustion, Biomedical and Environmental Assessment Group.*

Lunar Energy Tidal Power. (n.d.). Retrieved from RENEWABLE ENERGY UK: http://www.reuk.co.uk/Lunar-Energy-Tidal-Power.htm

MacKay, D. J. (2007). *Sustainable Energy - without the hot air.*

Mann, N. (2011, March 8). Hydraulic Fracturing: Making the Headlines in 2011.

Marples, D. R. (1996). Chernobyl: The Decade of Despair. *Bulletin of the Atomic Scientists*, 10.

Mauderly, J. *Health Effects of Subchronic Inhalation of Simulated Downwind Coal Combustion Emissions.* Lovelace Biomedical and Environmental Research Institute.

McKelvey, S. (n.d.). *Malthusian Growth Model.* Retrieved February 12, 2012, from http://www.stolaf.edu/people/mckelvey/envision.dir/malthus.html

McKenna, P. (2009, May 21). New Scientist, Ignore the spin: Coal gasification is a stupid idea.

McMillan, J. M., & Lickley, M. J. *The Potential of Tidal Power from the Bay of Fundy.*

Metropolitan Transportation Authority. (n.d.). *Subway and Bus Ridership.* Retrieved Feb. 24, 2012, from http://www.mta.info/nyct/facts/ridership/index.htm

Meyers, Jeremy P. (2011, August 7). Getting Back Into Gear: Fuel Cell Development After the Hype. *The Electrochemical Society Interface*, pp. 36-39.

Morgan, J. *Comparing Energy Costs of Nuclear, Coal, Gas, Wind and Solar, Nuclear Fissionary.*

Mouawad, J. (2009). Estimate Places Natural Gas Reserves 35% Higher. *The New York Times*.

Mufson, S. (2009). Washington Post: “Exxon Mobil to Buy Natural Gas Specialist” .

National Cancer Institute. (n.d.). Retrieved September 13, 2011, from National Institutes of Health: http://www.cancer.gov/

National Environmental Respiratory Center.

National Petroleum Council Unconventional Gas Subgroup of the Technology Task Group of the NPC Committee on Global Oil and Gas. (2007, July 18). Unconventional Gas.

National Renewable Energy Laboratory. *Geothermal Electricity Production.*

Nuclear Fission and Nuclear Fusion. (n.d.). Retrieved from http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch23/fission.php

Offshore Wind Energy.

Pagan, B. *Gyroplane accidents 1985-2005: epidemiological analysis and pilot factors in 223 events.*

Pimentel, D. *Ethical Issues of Global Corporatization: Agriculture and beyond .*

Pimentel, D., Cooperstein, S., & kaye, B. *Ecology of Increasing Diseases: Population growth and Environmental degradation .*

Popular Rotorcraft Association. (n.d.). Retrieved from http://www.pra.org/default.aspx?p=gyroplanes&i=16

Reijnders, L. (2006). Conditions for the sustainability of biomass based fuel use, Energy Policy 34.

Renewable Energy Research Laboratory. (n.d.). *Wind Power: Capacity Factor, Intermittency, and what happens when the wind doesn't blow?* Retrieved from University of Massachusetts at Amherst: http://www.umass.edu/windenergy/publications/published/communityWindFactSheets/RERL_Fact_Sheet_2a_Capacity_Factor.pdf

Renewable Energy World Network Editors. (2010, December 28). *The Big List: 2010's Biggest Renewable Energy Projects.*

Rowe, M. (2010, August). Safety in Numbers? *Geographical*.

Schultz, J. (1996). GYROPLANE IS IDEA THAT NASA THINKS WILL FLY. *The Virginian-Pilot*.

Sea Solar Power. (n.d.). Retrieved from PESWiki: http://peswiki.com/index.php/Directory:Sea_Solar_Power

Shemyakin, E. I. (2009, 12 1). Changes in the earth's magnetic field: Causes and possible consequences. *Herald of the Russian Academy of Sciences (1019-3316), 79(6)*, p. 558.

Skoloff, B. (2008). Ocean Currents Hold Promise as Energy Source.

Tae Sup Yun, Jong-Sub Lee, Seung-Cheol Lee, Young Jin Kim, Hyung-Koo Yoon. (2011). Geotechnical Issues Related to Renewable Energy. *KSCE Journal of Civil Engineering 2011 15(4)*.

Than, K. (2005, October 17). *Scientists: Natural Disasters Becoming More Common.* Retrieved from http://www.livescience.com/414-scientists-natural-disasters-common.html

The American Cancer Society. (2011). *Cancer Facts and Figures 2011.*

The Cooperative Institute for Marine and Atmospheric Studies.

The European Wind Energy Association.

The European Wind Energy Association. (2011, March). *Wind Directions.*

Transatlantic Tunnel. (n.d.). Retrieved from Discovery: http://dsc.discovery.com/convergence/engineering/transatlantictunnel/interactive/interactive.html

Tushar K. Ghosh, Mark A. Prelas. (2011). Energy Resources and Systems: Volume 2: Renewable Resources. Springer.

Tushar K. Ghosh, Mark A. Prelas. (2011). *Energy Resources and Systems Volume 2: Renewable Resources.* Springer.

U.S. Department of Energy.

U.S. Department of Energy. (2009, June 8). Carbon Capture and Storage from Industrial Sources.

U.S. Department of Energy. (2009, April). Modern Shale Gas Development in the United States: A Primer.

U.S. Department of Energy. (2010, November 30). Current State of the U.S. Ethanol Industry.

U.S. Department of Energy. *Fuel Cell Basics.*

U.S. Department of Energy. *Fuel Cell Challenges.*

U.S. Department of Energy. *Fuel Cell Types.*

U.S. Department of Energy. *Fuel Cells Technology Program: Comparison of Fuel Cells Technology.*

U.S. Department of Transportation.

U.S. Energy Information Administration.

U.S. Energy Information Administration. (2010). Retrieved from Electric Power Annual 2009.

U.S. Energy Information Administration. (2011). Annual Energy Review 2010.

U.S. Geological Survey. (2008). *Assessment of Moderate and High Temperature Geothermal Resources of the United States.*

United Nations Framework Convention on Climate Change.

Wald, M. L. (2007). Science Panel Disputes Estimates of U.S. Coal Supply. *The New York Times*.

Wave Power. (n.d.). Retrieved from University of Strathclyde Glasgow: http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/wave%20power.htm

Wikipedia. (2011, Nov. 18). *List of Countries by Population*. Retrieved Feb. 22, 2010, from Wikipedia: http://en.wikipedia.org/wiki/List_of_countries_by_population

Williams, M. (2007). Mining the Moon. *Technology Review*.

Windy Nation. *Tip Speed Ratio: How to Calculate and Apply TSR to Blade Selection.*

Winters, J. (1998, May 1). *Physics Watch: Fusion's Future?* Retrieved from http://discovermagazine.com/1998/may/physicswatchfusi1449

Wise, J. (2010, March 1). *The Gyroplane Dilemma.* Retrieved from Popular Mechanics: http://www.popularmechanics.co.za/article/the-gyroplane-dilemma-2010-03-01

Wright, G. (2007, October 31). Democracy, GDP and natural disasters. *Geotimes 52(10)*, p. 36.

Wu, M. (2007). Analysis of the Efficiency of the U.S. Ethanol Industry.

Zaragoza, K. (2007). Reducing Fossil Fuel Emissions. *Innovation Journal*.

Zarella, G. J. (2011, August 13). Will We Learn? Or, Repeat History?