Overview

The Current State of Electricity

The United States consumes 3,741,485,000 MW hours of electricity per year, or 13,650 kilowatt-hours (kWh) per capita per year. One kilowatt hour is equal to 3.6 x 106 joules.[1] For perspective, one kWh is enough energy to light a standard 40-watt light bulb for an entire day, or to run a personal computer for about two hours.[2] That energy must come from somewhere. This website is designed to help you understand current energy sources and options for alternative resources in the future.

48% of the electricity currently produced in the United States is produced by burning coal.[3] The heat that is released from the combustion of coal is used to boil water and create steam. The steam is then driven through turbines, which turn generators to create electricity.

Nuclear fission is the second most prevalent electricity source, accounting for 21% of the US electricity production in 2010.[3] Nuclear fission uses the decay of radioactive elements (primarily uranium) to create heat, which is then used to boil water to create steam and turn generators, similar to coal electricity plants.

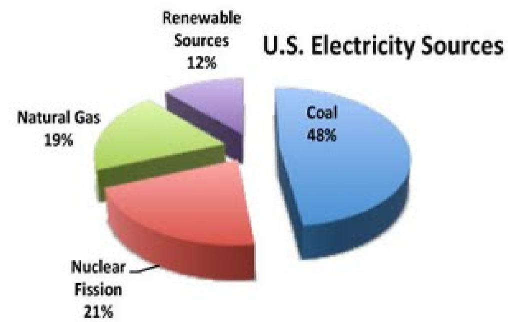

Figure 1. United States electricity generation by source. (EIA, original graphic.)

The burning of natural gas accounts for 19% of the electricity produced in the U.S. Only the remaining 12% of the energy we use is produced from renewable sources (Figure 1).

Why Study Electricity Fuels?

We do not have an unlimited supply of coal, uranium, or natural gas, and all of those methods for producing electricity can cause significant environmental damage. How can we provide electricity for a growing market without devastating environmental impacts? Our group members have provided several alternatives to current electricity production methods, and we are investigating the feasibility of implementing them on a nationwide scale. Our alternative processes are: carbon sequestration from coal-fired power plants, solar energy, wind energy, and wave energy.

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Coal Energy - Carbon Sequestration

Should senate bill 699: Department of Energy Carbon Capture and Sequestration Program Amendments Act of 2011, be passed to create demonstration programs for the commercial application of carbon sequestration?

The U.S. senate is currently considering several bills that would push large consumers of fossil fuels to adopt carbon sequestration technologies. Congress is considering a carbon tax (H.R. 3242: Save Our Climate Act of 2011) and is also

considering allocating funds for carbon sequestration demonstrations (S. 699: Department of Energy Carbon Capture and Sequestration Program Amendments Act of 2011). Research has shown that carbon dioxide can increase the global mean temperature and that the burning of fossil fuels has likely raised the carbon dioxide levels in the atmosphere from 280 parts per million (ppm) to 390 ppm (IPCC 2007). The idea of carbon sequestration has gained popularity in recent years because it provides an opportunity for us to maintain current energy use patterns and reduce the effect these patterns have on the climate.

Senate bill 699 proposes that the federal government will pay for a demonstration program for the commercial application of integrated systems for the capture, injection, storage, and monitoring of carbon dioxide from fossil fuel power plants. The bill also proposes the Department of Energy would take over the sequestration site for long term stewardship, and that those in charge of the demonstration will not be held liable for certain mistakes should they occur. It is estimated that if passed the bill will cost taxpayers $329 million by 2021.

There are significant pressures on congress to pass laws to reduce the impact of global climate change due to the burning of fossil fuels. The primary reason this bill is being considered is to reduce the impact of burning coal on the effects of climate change. The primary opposition to this bill is due to the high price of carbon sequestration. There is also a part of the scientific community that does not believe that carbon sequestration is a good idea because the carbon dioxide could escape.

Subpages (1): How It Works

Solar Energy: Photovoltaics

Is the failed solar panel manufacturer Solyndra a "litmus test" for U. S. DOE loan guarantees, or should we continue to use tax dollars to guarantee renewable energy ventures?

Green energy and new jobs are an enticing combination for new companies to offer in a United States plagued by unemployment, pollution, and the knowledge of a globally dwindling fossil fuel supply. George W. Bush's 2005 Energy Policy Act established a federal loan program to fund innovative energy technologies, and in 2006 the solar panel manufacturing company Solyndra was a final contender in the exhaustive vetting process to determine which companies would receive federal funding. With Obama's inauguration and stimulus package in 2009, Solyndra's $535 million loan guarantee was pushed through with what many republican representatives claim was improper haste.[3] Two years later on September fifth, Solyndra closed its factory doors, bankrupt.[3]

High production costs, the end of a silicon shortage that hindered competitors, and heavily subsidized solar cell factories in China meant Solyndra was shooting at a "moving target" and failing to acheive the market volume that could drive their costs down.[4] In light of Solyndra's failure, other solar panel manufacturers worry about future funding. Amidst accusations of crony capitalism and improper haste circulate whispers that solar power is a doomed industry.[2] On the other hand, the rapidly falling price of solar modules and the little-mentioned DOE loan successes tell a more encouraging story.[1,2]

These web pages present the technology of photovoltaics from various perspectives, from thermodynamics to market dynamics, in order to inform our readers and aid the policymaking that will determine our electricity future.

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[1]Krugman, Paul. "Here Comes the Sun." *The New York Times*: The Opinion Pages. November 6 2011. Accessed November 8 2011. http://www.nytimes.com/2011/11/07/opinion/krugman-here-comes-solar-energy.html?_r=2

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Image: http://politics.blogs.foxnews.com/sites/politics.blogs.foxnews.com/files/Solyndra%20headquarters.JPG

Comments

Alexandra Rempel - Nov 8, 2011 2:08 PM

Your question is still pretty broad; do you think you can answer this convincingly for the whole U.S.? If not, what would be a more manageable piece of it? (Ideally one that involves some current struggle that will be enlightening to investigate!) Your first paragraph zooms through a number of ideas very quickly and then lands on Solyndra. Would the issue of federal funding for solar technologies be one option? (Paul Krugman has new things to say about that! RG today and NYT a few days ago.)

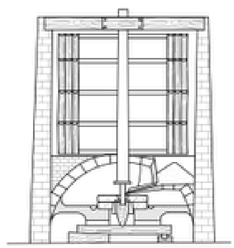
Wind Energy

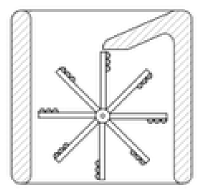
Overarching Question:

Should the U.S. government shift its focus from large wind systems to small wind systems?

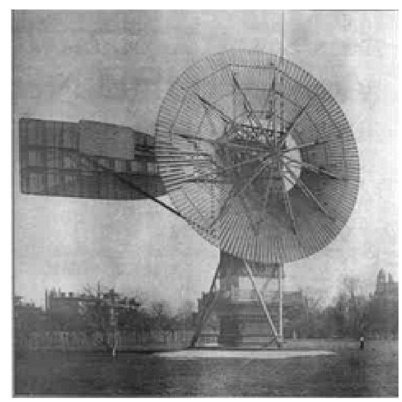
History

The first practical mechanical use of wind power came about during the 6th to 9th centuries in Persia. The windmills created were used to grind grain or pump water. They were made with vertical sails of bundles of reeds or wood, which were attatched to a vertical axle, and needed heavy shielding to block the wind from slowing the other side of the windmill (image below).[1]





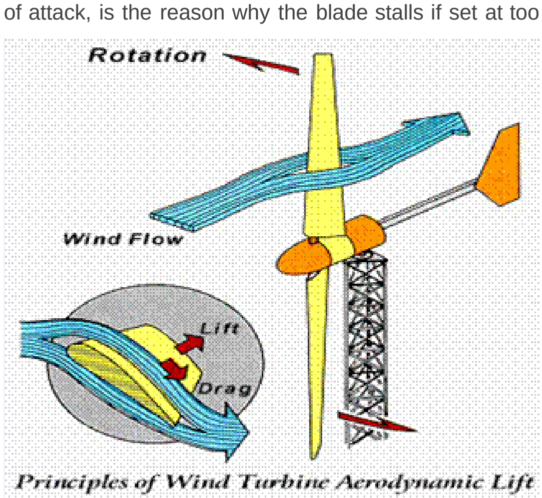
The first European windmills appeared in the thirteenth century and used horizontal axles instead of vertical axles. This eliminated the need for shields and made the machines more efficient. There is some debate about whether the horizontal windmill was an independent invention or whether Europeans improved the Persian windmill. In any case, these windmills had four blades mounted on a central post, and were called "postmills." They used wooded gear elements to transfer the horizontal motion of the shaft into vertical motion to turn a grindstone. Later, the "tower mill" was created; this consisted of a windmill attached to a tower where there were separate floors for grinding and storing grain. The blades on a tower mill had to be manually oriented toward the wind.[1]



In 1888, the first windmill used to generate electricity was created by Charles F. Brush (image on right). He used the old postmill design, but with 144 blades and a large tail to turn the windmill in the direction of the wind. He also included a gear box and a direct current generator that sent power to 408 batteries in his basement. The windmill produced 12 kW at its peak.[2]

Modern Wind Turbines

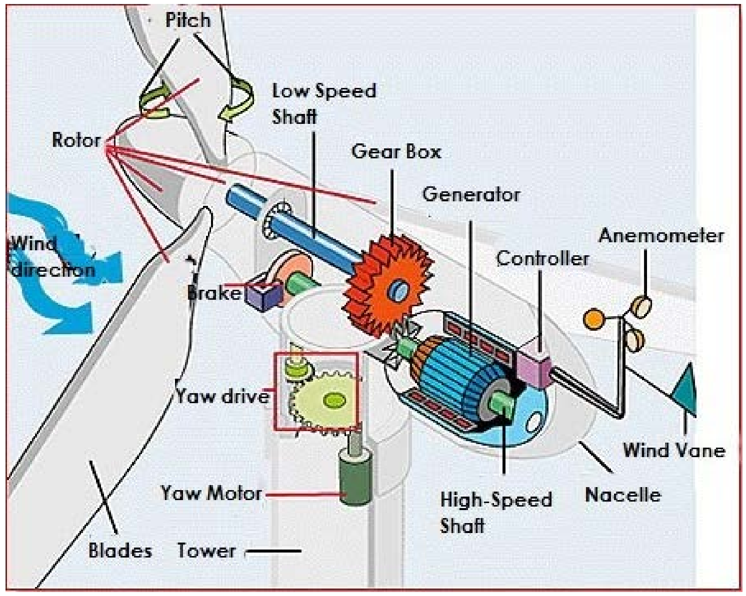
Like airplane wings, a wind turbine propeller is designed to use the wind to "lift" it up--or in this case, around a shaft. As the wind hits the blade, the curved side creates low pressure while high pressure blows over the other side. The result is a "lift force" perpendicular to the direction of the wind. As the blade is turned at a greater angle to the wind, this lift force increases; however, if turned too far, the blade will "stall" and lift force decreases. The position at which the blade creates the most lift is called the "optimum angle of attack." "Drag," which is a force parallel to wind flow and increases with angle of attack, is the reason why the blade stalls if set at too steep of an angle.[3]



A modern wind turbine is traditionally mounted on a tower, facing the direction of the wind. The wind blows through two or three propeller blades and spins them around a rotor at 30 - 60 rotations per minute (rpm). The rotor is connected to the main shaft which turns a generator, converting the wind's power into electricity. The gearbox in the generator converts the 30 - 60 rpm to 1000 - 1800 rpm (the speed necessary for generators to produce electricity).[4] The electricity created by the generator is then sent through transmission lines to the utility grid. In large wind turbines, the voltage generated is usually 690 V three-phase alternating current (AC). The current is sent through a transformer (either next to the turbine or inside the turbine) to raise the voltage between

10,000 and 30,000 volts, depending on the grid requirements.[5]

In general, large turbines begin to produce power at wind speed of 9mph and achieve rated power at 29 mph. They stop power production at 56 mph. A typical turbine from the United States is rated to produce 1.5MW to 2 MW of power.[6]



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[1]TelosNet Web Development and Darrel Dodge (2001). "Part 1 - Early History Through 1875." Illustrated History of Wind Power Development. Accessed 8 November 2011. http://www.telosnet.com/wind/early.html

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Images:

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Lift/drag: http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/wind.htm
Diagram of windmill: http://www.ucsusa.org/clean_energy/technology_and_impacts/energy_technologies/how-wind-energy-works.html

Subpages (5): Concerns Conclusion Small Wind Turbine Efficiency Wind Formation and Thermodynamics

Wave Energy

Should the US Government implement an expedited permitting process for Wave energy?

There are many natural phenomena that can be harnessed to produce energy. However, there are few forces of nature that carry as much energy as the oceans. Because water is about 840 times more dense than air, its energy is much more concentrated and forceful than Wind or Solar energy and can therefore produce considerably more Kilowatt hours per square foot than either a wind turbine or a solar panel. (Murray) It would take less than 0.2% of the ocean's wave power to provide the amount of energy that is currently needed to power the world (about 18,000 Terawatt hours per year, and 3,780 Terrawatt hours per year in the US). (Drollette, 2) There is enough energy in waves to provide about 2 trillion watts of power. (DeFreitas, 1) However, most of that energy is too far out at sea to harness. "Economically recoverable" wave energy is believed to be 140 to 750 Terawatt hours per year globally, but as technology improves, that number could go way up. (Murray) Wave energy would not account for all of the world's energy, but it would contribute significantly.

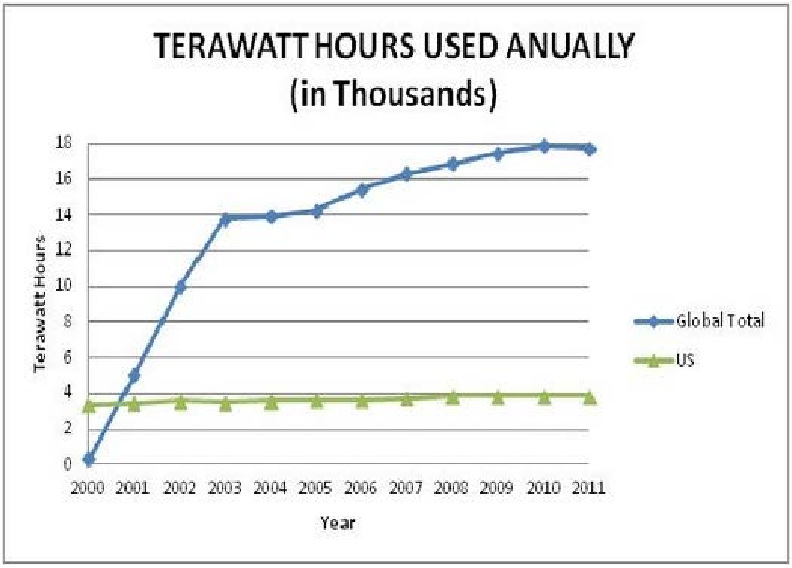

Figure 1: Total global energy consumption over the past decade

The best places in the world to collect wave energy are the coasts of Australia, southern Africa, Northern Canada, Scotland, and the the Pacific Northwest of the US. These areas are known for their rough seas and ample large waves.

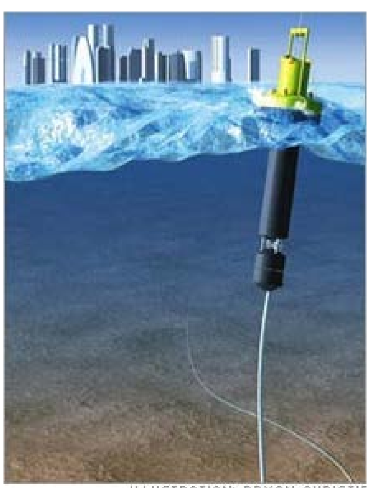

Figure 2: PB 150 or point absorber

A design known as PB 150 (shown in figures 2 and 3) was first deployed off the coast of Scotland in April this year and it quickly became a success. This model produces on average 150 Kilowatts of power, and it has inspired the Oregon Coast project. Ten of the same design buoys will be deployed off the Oregon coast near Reedsport soon.

These buoys have very little if any environmental impact. There are no turbines or netting or any other parts that may be hazardous to animals. They are floating on the surface so they barely affect the ocean floor. They are not an eyesore because they are far enough off shore (1-3 miles) and low enough in the water (~20 feet out of the water) that they cannot even be seen from shore. There is no risk of fishermen running into them either because they are substantial in size from up close and the surrounding zones are well marked off. For further details on environmental impact, see Negatives.

The most important thing to note about wave energy is that it is environmentally friendly. wave power does not cause CO2 emmissions, it does not pollute the atmosphere, and it will last forever. Using energy is no longer a bad thing. When energy is clean and green, we do not have to worry about how much energy we use, because it is having no negative effect on our planet.

Figure 3: PB 150 out of water

Video Courtesy of Ocean Power Technologies

This video shows how Ocean Power Technologies and their associates installed the first PB 150 buoy (shown in Figure 3) off the coast of Scotland in July 2011. Since then, that test buoy has exceded expectations and is producing more energy than they had hoped. This is currently one of the three buoys of this model in operation in the world. One of the others is off the coast of New Jersey, and the third is powering a Navy base in Hawaii. All were projects of Ocean Power Technologies, the same company that is now contructing a wave farm of ten such buoys off the coast of Reedsport, Oregon.

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Subpages (7): Conclusion How it Works Locations Other Wave Energy Models Politics The Oregon Coast Project Thermodynamics

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Dec 16, 2011 8:56 AM	Maria Chianello edited Coal: The Status Quo
Dec 16, 2011 8:53 AM	Maria Chianello attached peatcoal.gif to Coal: The Status Quo
Dec 16, 2011 8:48 AM	Maria Chianello edited Problems
Dec 16, 2011 8:44 AM	Maria Chianello edited Concerns
Dec 16, 2011 8:43 AM	Maria Chianello attached grid.jpg to Concerns
Dec 11, 2011 10:11 PM	Maria Chianello deleted a comment from Wind Energy
Dec 11, 2011 10:11 PM	Maria Chianello deleted a comment from Wind Energy
Dec 11, 2011 10:11 PM	Maria Chianello deleted a comment from Thermodynamics
Dec 11, 2011 10:11 PM	Maria Chianello deleted a comment from Coal: The Status Quo
Dec 11, 2011 10:10 PM	Maria Chianello deleted a comment from Electricity Fuels: A History of Limited Resources
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Dec 11, 2011 10:10 PM	Maria Chianello deleted a comment from Overview
Dec 11, 2011 10:10 PM	Maria Chianello deleted a comment from Overview
Dec 11, 2011 8:39 PM	haas@uoregon.edu deleted a comment from Wave Energy
Dec 9, 2011 4:35 PM	haas@uoregon.edu edited Wave Energy
Dec 9, 2011 4:28 PM	haas@uoregon.edu edited Politics
Dec 9, 2011 4:18 PM	haas@uoregon.edu deleted Cost
Dec 9, 2011 4:12 PM	haas@uoregon.edu edited Politics
Dec 9, 2011 3:52 PM	haas@uoregon.edu edited Conclusion
Dec 9, 2011 3:47 PM	haas@uoregon.edu edited Politics
Dec 9, 2011 3:35 PM	taylor wilson edited Solyndra's Rise and Fall
Dec 9, 2011 3:28 PM	haas@uoregon.edu attached IMGP0003.JPG to Conclusion
Dec 9, 2011 3:28 PM	taylor wilson edited Reasons to Fund Solar
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The Team

Adam Schreiner-McGraw - Coal and Clean Coal Technologies

Maria Chianello - Wind Energy

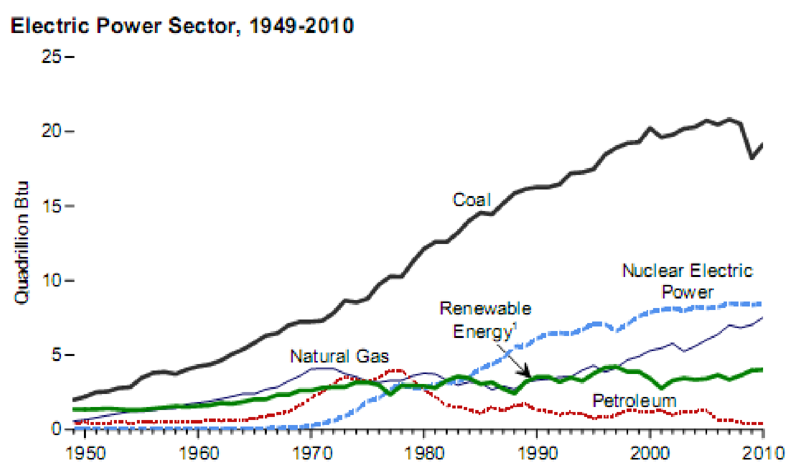
Taylor Wilson - Solar Electricity

Tyler Haas - Wave Energy

Electricity Fuels: A History of Limited Resources

It seems that human beings are merely newborns when comparing the length of their existence to that of planet Earth. Newborns must eat, grow, develop, and most importantly, learn. Looking at the history of electricity fuels, we can certainly say that humans have eaten, grown, and developed. Now, it's time for them to learn.

Humans must learn that many of Earth's resources are finite, especially ones that they use the most: coal and oil. What the Earth has taken millions of years to form, humanity is consuming in a few thousand; simple logic says that humans will use all of the coal and oil on the Earth before Earth can form more of these substances.



That is not to say that humans were wrong to use fossil fuels for energy, in the beginning. These fuels were abundant and cheap to purchase, and allowed humanity's technology, industry, science, and population to grow at a rate that could not have occurred otherwise. One could say that the use of coal and oil, and the technological advancements that accompanied it, gave humans the capacity to learn what they know today about finite resources and new technologies for renewable energy. It is time for human beings to recognize what they have learned and move to the next step of implementing change.

Studying the history of electricity fuels can provide a way for us to reflect on what we've learned and how we should proceed to change. This history begins with the discovery of coal, and its instrumental role in creating the Industrial Revolution.

Image

Electric power sector since 1950: http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf, p38

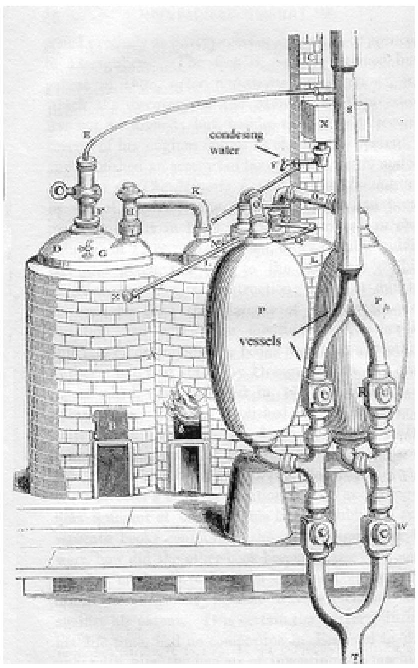
Subpages (3): Coal and the Industrial Revolution Environmental Concerns and Renewables Nuclear Power

Electricity Fuels: A History of Limited Resources >

Coal and the Industrial Revolution

The Industrial Revolution and Invention of Electricity

In the 1600s coal was first used only for heating the poorest residential homes in England, due to the odor and filth that accompanied it. However, when it became clear that wood was running low, coal became the most popular heating method
for all of England and several mines were constructed. Coal mining was not very efficient because the miners did not have a



way to pump groundwater out of the holes they dug, and this not only resulted in slower coal mining but many miners' deaths.

In 1698 Thomas Savery patented a device called the "Miner's Friend" which was a mechanical pump for the water in the mines (image on left). The pump was powered by the burning of coal; this was the first time that burning coal was used to create mechanical work. From there, steam engines were created and were able to make the process of generating power from coal much more efficient. The current method for turning coal into electricity is very similar in principle to that of a steam engine.

The Grid

Throughout the early 18th century, electricity was extensively studied and the link between electricity and magnetism was discovered. Michael Faraday created the first electric motor in 1821, and Georg Ohm mathematically defined the electrical circuit in 1827, which allowed engineers to create the electrical grid.

The electrical grid has steadily been evolving since we began to harness electrical power in the late 19th century. Currently, the electric grid is a large interconnected network that incorporates electrical production facilities, transport mechanisms, and consumption facilities (our homes). Electricity is produced in a power plant and immediately transformed to very high voltages (typically > 110kV) for transport (less energy is lost when it is transported at high voltages). Electricity is transported through conducting aluminum alloy wires for long distance transport. When the electricity reaches its destination, it is passed through another transformer and brought back down to a low enough voltage for appliances and home use (120V).

Images
Miner's Friend: http://www.egr.msu.edu/~lira/supp/steam/savery.htm

Electricity Fuel Resources

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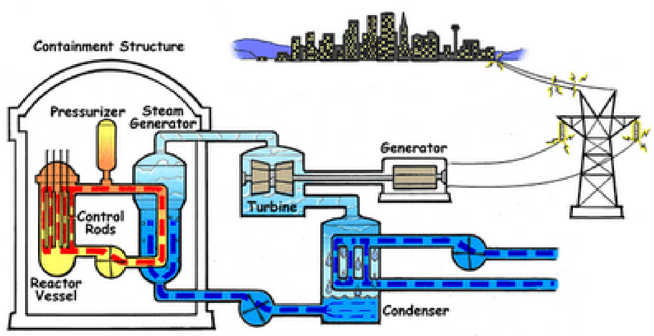
Nuclear Power

Beyond Coal: Nuclear Power

The next major innovation in electricity generation did not occur until 1934, when physicist Enrico Fermi bombarded uranium with neutrons and split the uranium atoms, creating elements much lighter than uranium-- a process called "nuclear fission". Working with other scientists, Fermi and his associate Leo Szilard designed the first uranium chain reactor in 1941, and in 1942 successfully created a self-sustaining nuclear reaction. While this technology was used to create the first atomic bomb, it was also used for the generation of electricity. The U.S. government created the Atomic Energy Commission (AEC) in 1946 and in 1957 built the first nuclear power plant in Shippingport, Pennsylvania. The plants worked much like coal plants, using the heat produced during nuclear fission to heat water and generate steam, which drove a turbine and produced electricity. By 1991 the US had twice as many nuclear power plants in operation as any other country, accounting for 22% of the electricity produced in the U.S.



While nuclear power did not produce CO_2 pollution like coal, it had its own problems. On March 28, 1979, the Three Mile Island nuclear plant experienced the worst commercial reactor accident in U.S. history. On April 26, 1986, human error causes two explosions at the Chernobyl power plant in the Soviet Union, contaminating the air, land, and water, and exposing workers to large amounts of radiation. On March 11, 2011, the Fukushima nuclear power plant in Japan experienced an earthquake that resulted in equipment malfunction, explosions, meltdowns, and exposure to radiation. In 1974 the U.S. abolished the AEC because of poor regulation programs, and created the Nuclear Regulatory Commission to oversee the safety of nuclear power plants, which it still does today. In the late 1970s the worldwide anti-nuclear movement increased awareness of the problems associated with nuclear energy. There is much debate over whether or not nuclear energy is the safest and most efficient way to generate electricity.[1]

Sources

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Electricity Fuels: A History of Limited Resources >

Environmental Concerns and Renewables

Electricity and the Environment in the Mid-20th Century

Electricity from nuclear power has its drawbacks, but it does have the advantage of zero carbon emissions. Pollution has been an issue in industry and electricity generation since the Industrial Revolution, but events in the mid-20th century made the hazards of pollution immediately apparent. In 1948, a heavy cloud of air pollution formed over Donora, an industrial town in Pennsylvania. In the span of five days the cloud of toxins killed 20 people and sickened 6,000 of the town's 14,000 residents. In 1952, another "killer fog" descended on London, killing over 3,000 people and obscuring visibility so that vehicles required a guide walking with a lantern in order to drive. Acid rain, caused by sulfur dioxide and nitrogen oxides from power plants and traffic, eroded property, caused human health problems and dissolved foliage in European forests.[1] These pollution disasters alerted the public to the need to regulate industrial pollutant emissions.

Clean Air Act

The Clean Air Act (CAA) is one regulatory law in the United States. The original 1963 version provided funding to research and start to clean up air pollution. It was amended in 1970 to be much tougher, with specific emissions reductions required across the country. The Environmental Protection Agency (EPA) was created at the same time, as a governing body in charge of enforcing, updating, and creating new pollution-prevention laws. The CAA was further amended in 1977 and 1990, primarily to set new timeline goals, as many states failed to reduce their pollution emissions by the original deadlines. The 1990 version also requires "maximum achievable control technology" standards for major pollutant sources, such as power plants. A major source is classified as a stationary source or group of stationary sources that emit or have the potential to emit 10 tons per year or more of an individual pollutant, or 25 tons per year or more of a group of pollutants. A market-based cap-and-trade approach encourages industries to develop technologies in order to better meet emissions requirements.[2]

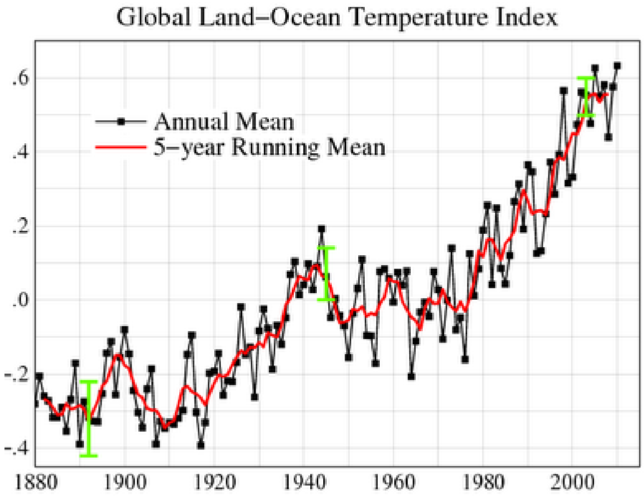
The full impact of CAA regulations will take many years to become apparent, but monitoring systems are in place, within individual communities and on a national scale. The EPA Air Trends website (http://www.epa.gov/airtrends/) allows the reader to check air trends by pollutant, location, and a number of other indexes.

Clean Water Act

Air is not the only medium affected by pollution. The Clean Water Act was originally enacted in 1948 under the name Federal Water Pollution Control Act to try to control water pollution. It was amended in 1972, and it received its current name when it was amended again in 1977. The Clean Water Act serves a similar purpose to the CAA, requiring permits for pollutant discharges into various types of water bodies and providing avenues for monitoring and enforcement through the EPA.[3]

Global Warming and the Kyoto Protocol

Global warming is a highly controversial topic in the United States. The basic concept refers to the rising of the average temperature of the Earth's atmosphere and oceans (image below), melting polar ice, causing droughts, etc. Many believe that global warming is caused by the emission of greenhouse gasses (like CO_2) produced by human activities, electricity generation included. (For a fun and basic explanation of how global warming works, see NPR's video series here.)



The Kyoto Protocol, enacted by the United Nations, is one way that world leaders are trying to fight global warming. It was adopted in December of 1997, and states that the countries who sign it (37 as of today) will commit to a reduction of four different greenhouse gasses (CO_2, methane, nitrous oxide, and sulphur hexafluoride). The U.S. has not yet signed this protocol.

The Beginning of Renewables: Hydropower

Although original models were designed in the late 1700's, it was not until 1878 that the first hydroelectric dam was created. However, because the first few were so successful, by 1889 there were over 200 hydroelectric dams in America alone. The speed and force of a river provided the necessary power to rival coal. Major dams have been built over the last 130 years such as the Hoover Dam, the Bonneville Dam, the Grand Coulee dam, the Itaipu Dam, and the Three Gorges Dam (image below). The Three Gorges Dam is currently the largest producing dam in the world, with an output of 22,500 megawatts of power.

Three Gorges Dam in China

Other Renewables

In the late twentieth and early twenty-first centuries, scientists began to realize that fossil fuels not only caused pollution, but that they are finite.[1] When Earth's reserves of oil and coal are exhausted, humans must have alternative energy sources already in place. Hydroelectricity was a successful first forray into renewable energy. Further innovations in wind, wave, solar, and other renewable energies, as well as cleaner coal and nuclear alternatives, can be combined with policy changes and reduced consumption to ensure the availability of electricty for generations to come.[2]

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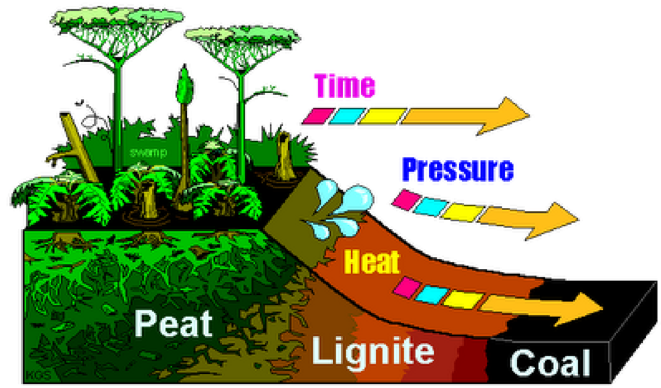
Coal: The Status Quo

Formation of Coal

Coal is made of peat, or layers of partially decomposed plant matter, that has been compressed for thousands of years. The peat must remain in a cool, wet, low-oxygen environment during its transformation into coal; otherwise, it will decompose
completely. An example: the peat involved in forming Ohio's coal seams compressed for 11,000 of years in an environment similar to that of the Amazon River delta.[1]



The length of time needed for coal to form is one reason why, at our current consumption rate, we are in danger of running out of coal. Another reason is that most of the coal on Earth was made during the Palezoic Era, when conditions for coal-generation were at an optimum. During the Silurian and Devonian Periods (440-360 million years ago), green plants appeared for the first time on Earth. Because of the high levels of CO_2 in Earth's atmosphere, plants grew quickly and proliferated rapidly. In the Carboniferous Period (360-290 million years ago), the large numbers of plants and trees created extremely dense forests with little sunlight perforation. Large amounts of plant matter fell to the forest floor and were compressed quickly--and with no sunlight to warm the air, they only partially decomposed, turning into peat. Several thousand years later, the compressed peat layers from this era became the coal that gave rise to the Industrial Revolution.

Coal is the most abundant and widely-distributed fossil fuel, with global reserves totaling about 990 billion tons, or enough to supply 150 years of energy at current consumption rates.[2] Forty-two percent of the world's electricity supply comes from coal, with some countries relying on it for as much as 93% (Figure 1).

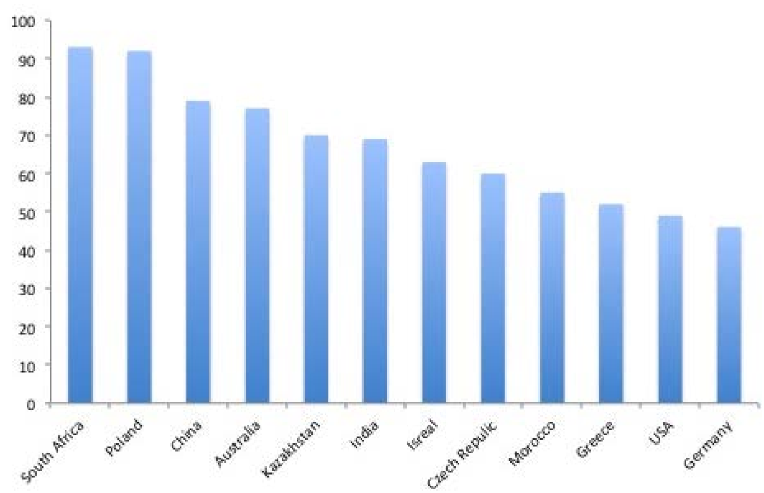


Figure 1. Percent national energy obtained from coal, by country. Data from IEA 20101. 1Original graphic.

How Electricity is Generated from Coal

The majority of the global electricity supply is generated using what is called the "vapor power cycle" (Figure 2). In this cycle a fluid (usually water) is heated by energy transfer from a high-temperature source. In many cases this source is a pulverized coal-fired boiler, but it can also be geothermal, solar, nuclear, gas turbine exhaust, or waste heat from other processes. As the temperature of the working fluid rises, it vaporizes into steam. Restriction of steam exit causes an increase in pressure in the steam generator. When the vapor reaches suitable pressure and temperature, it is released into a turbine compartment through a regulator valve. The steam expands upon entering the turbine. The pressure and kinetic energy of the steam turns the turbine blades, which turn the attached shaft and coupled electrical alternator. This step generates the electricity that is sent out to the consumer grid and partitioned to drive processes within the power station.

The low-pressure steam that is exhausted from the turbine is cooled in a non-contact heat exchanger using sea water, cold river water, or cooling towers. The steam exhaust can also be used for space heating. Many turbines reduce steam to sub-atmospheric pressures at this point. Finally, high-pressure pumps raise the re-condensed liquid to sufficient pressure to make it flow back into the boiler to continue the cycle.

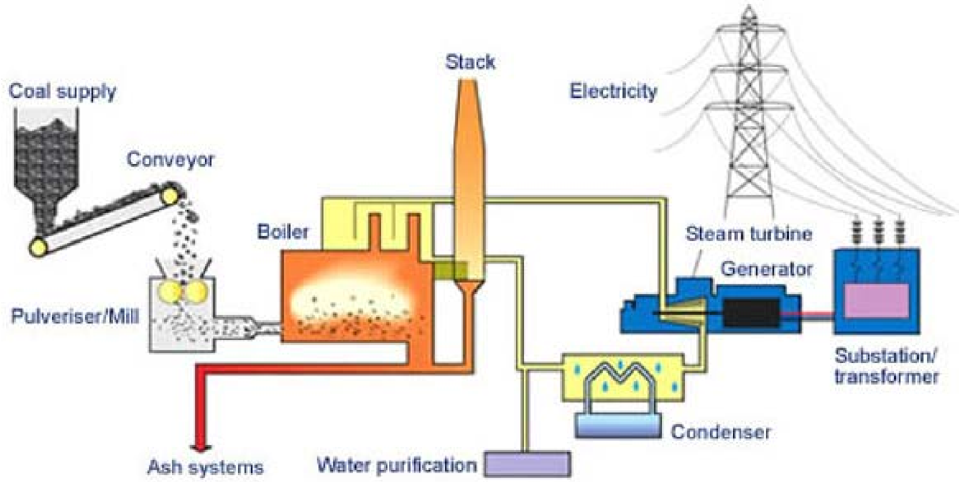


Figure 2. Vapor power cycle using pulverized coal. Coal is pulverized to increase its reactive surface area. The pulverized coal is ignited, and the resulting combustion reaction releases energy as heat, which is used to heat the working fluid (water). As the fluid temperature rises, steam pressure increases in the fixed-volume compartment, until it is sufficient to drive the steam turbine and generate electricity. Exhaust steam is cooled and pressurized in the condenser and returned to the cycle. Image from “Coal and Electricity,” World Coal Association.

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Images
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Subpages (2): Influence of Coal Industry Thermodynamics

Coal: The Status Quo >

Thermodynamics

Heat is produced from coal by a combination of combustion, pressure, and chemical breakdown. A fire needs oxygen, fuel, and flame to burn; in a normal combustor, the coal (fuel) is simply given a flame and uses whatever surrounding oxygen it has to burn. A new type of process for coal plants, called “gassification,” uses controlled minimal oxygen to create a small, hot flame for the coal.[1] This process avoids the larger flames of traditional combustion which consume matter quickly but create less heat.

The heat generated during the combustion of coal is transferred to the water, vaporizing it. The water molecules move faster and build up pressure (because their volume is restricted) until the random kinetic energy is organized into a “cue stick” by the release of pressure through the regulator valve. When energy escapes as heat because of imperfect insulation, it causes reduced efficiency.

In a traditional combustion system, work is done when the random kinetic energy of the steam molecules is transferred to the turbines and “organized” into electricity. In a gassification system, additional work is done to maintain the pressure in the gassifier, for a flame can burn hotter under higher pressure. Work is also done during the operation of other machinery at the plant as well as during the mining and transportation of coal and the building of the plant. In analyzing the total effects (on the environment or otherwise) of a coal-fired power plant, all instances of work should be considered.

The process of combustion is spontaneous and is accompanied by an increase in entropy. As the heat from this process boils the water, the steam (gas: high entropy) generated from the water (liquid: low entropy) drives the turbine and shows an increase in the disorder of high-energy water molecules—as well as another increase in entropy. However, the process of converting the turbine’s movement into electricity is an organized, non-spontaneous process. This process requires work and causes a decrease in entropy.

According to the Coal Industry Advisory Board, the worldwide efficiency for coal-fired power plants averaged 35.1% in 2007.[2] Efficiency varies among energy plants because of differences in procedures as well as the quality of the fuel (measured by how much ash, sulphur, or moisture the coal contains). Efficiency is also affected by “off-design conditions;” plants operating at part-load instead of full-load capacity are less efficient. Legal regulations and emissions controls may add to efficiency loss as well. For example, if a plant has to work at less than optimal capacity to control pollution, it may be operating at a lower efficiency.

Consistent with the laws of thermodynamics, there is a significant portion of energy lost as heat during the burning of coal. In a typical 500 MW (megawatt) coal-fired boiler, electrical output is 39% of the “heat input,” or coal (Figure 3). Thus the remaining 62% is lost as heat through turbine-generator mechanical processes and the production of steam and “hot flue gasses.” The hot gasses, which contain CO_2, account for the majority of the energy lost during the conversion process. For this reason scientists have determined that CO_2 emissions from fossil fuels are closely related to efficiency. A typical power plant produces about 900kg of CO_2 per MWh (megawatt hour).

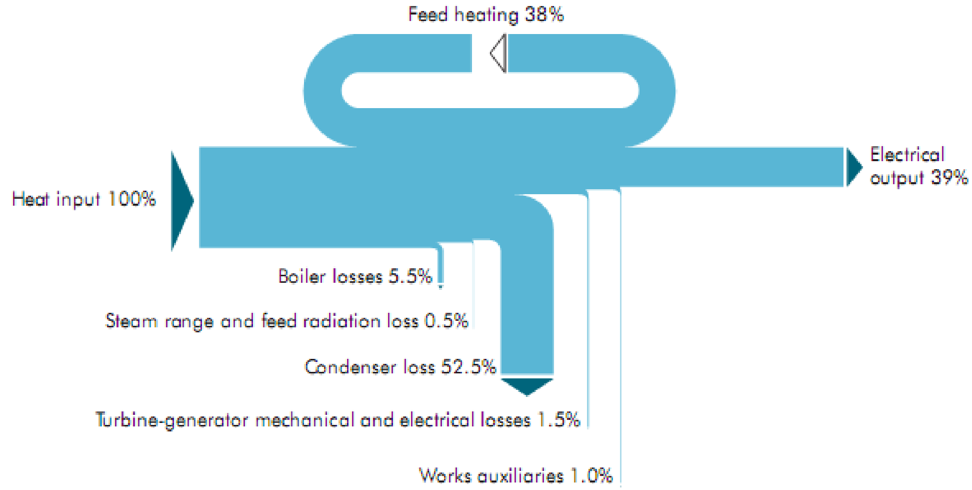

Figure 3: Example energy flows in a typical 500 MW subcritical pulverised coal-fired boiler.[2]

Power is the rate at which work is performed or energy is converted and is represented by the unit watt (W), which is one joule per second. In the case of power plants, "power" means the rate at which electricity is produced. A typical coal-fired power plant can produce 500-1000 MW. The power generated is proportional to the speed of the generator, which is directly related to the rate at which the coal burns. Electric power can be defined by the equation:

$P(t) = I(t) * V(t)$

where P(t) stands for instantaneous power measured in watts, I(t) stands for electric current measured in amperes, and V(t) stands for the potential difference measured in volts.

Power is the most important concern for coal-fired power plants, because the electricity generated at power plants is not stored in batteries--it is almost instantaneously consumed. This means that at peak electricity usage times, power plants must run at full capacity to supply the amount of electricity needed; during non-peak hours they can slow down the rate at which they are burning coal. As mentioned above, a coal-fired power plant that is not working at capacity is less efficient.

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Influence of Coal Industry

Money = Power

If we are going to change our current electricity fuel patterns, there are large obstacles to overcome; primarily the political power of the coal industry. Coal generates much more money from electricity production than any other form of electricity fuel: coal generated $96.5 billion of revenue in 2010 while wind generated $3.7 billion and solar generated $85 million. Because the executives in the coal industry have so much money, they can hire lobbyists and donate to politicians in order to get legislation that they want passed. The coal industry currently employs 174,000 people, which is a substantial amount, but is not drastically greater than the amount of people employed by renewable energy technologies. For example, the wind industry employs 50,000 people. However, the amount of money in the coal industry in proportion to the amount of people in the coal industry is much higher than in any other electricity fuel industry, and this money equals more power and influence.

For example, representative McKinley (R-WV) proposed a bill to Congress that restricts the EPA from labeling fly ash from coal plants as hazardous material, even though it contains toxic heavy metals such as arsenic. After he proposed that bill he received $233,000 in campaign donations from the coal industry.

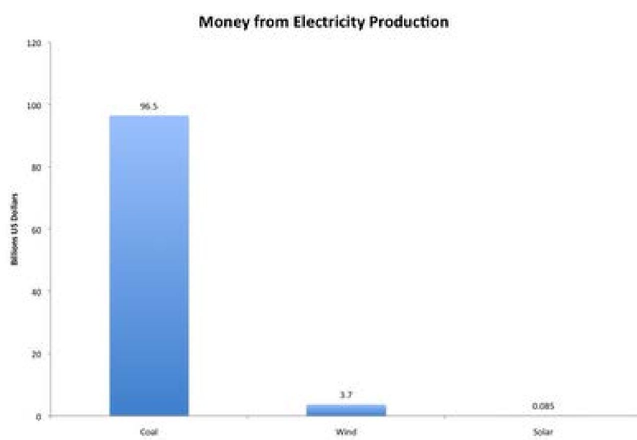

Figure 1: Comparison of revenues generated from coal, wind, and solar electricity production in 2010. Original graphic. Statistics source: IBISWorld.com.

Electricity Fuel Resources

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Coal Energy - Carbon Sequestration >

How It Works

There are three steps to successfully sequester carbon dioxide: 1) the carbon dioxide has to be captured, 2) it must be transported to the sequestration site, 3) it must be sequestered for long term storage. These three tasks have been the subject of a lot of research recently in order to improve their efficiency and feasibility for large scale introduction. The primary inhibiting factor of carbon sequestration is cost, which is primarily due to the high cost of separating the carbon dioxide from the other gasses released when coal is burned.

Carbon Capture

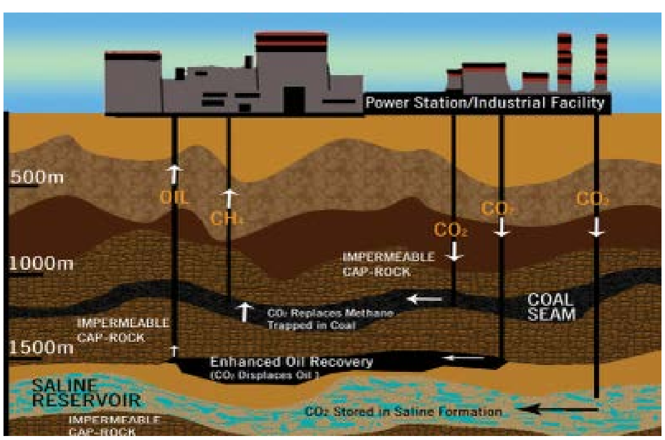
Carbon dioxide can be separated from the rest of the gasses released when burning coal using several methods. The most common is to use a series of chemical reactions to isolate the carbon dioxide. This is expensive because the most commonly used chemical reactions to isolate the carbon dioxide must occur at high temperatures in order to work quickly enough to be used on industrial scales. How it works is a chemical called monoethanolamine is dissolved in water and then the gasses emitted from the power plant are passed through this solution. The monoethanolamine bonds with the carbon dioxide and it is easy to then take the aqueous solution of monoethanolamine and carbon dioxide out of the coal plant. The carbon dioxide can then be forced away from the monoethanolamine by heating the solution. Then the carbon dioxide can be shipped to wherever it is to be sequestered and the monoethanolamine can be reused to capture more carbon dioxide.

Carbon Transport

This step is very simple, the carbon dioxide can be transported through pipelines to where it is going to be sequestered. These pipelines have been in existence for a while because carbon dioxide is already commercially used (primarily in beverages). They are simply pipes that the carbon dioxide can flow through.

Injection/Storage

While the first step of the process of carbon sequestration (capturing carbon) is the most expensive, the injection and storage of carbon dioxide is the most controversial. This step is controversial primarily because we do not know if the carbon dioxide will stay underground. Carbon dioxide is poisonous and if it escapes in a plume it could kill animals or people in the path of the plume. Or, if the carbon dioxide slowly leaks out we will put a lot of money and effort into putting it underground for no good. Pilot tests in Norway have shown that geologic formations have the ability to sequester carbon dioxide. A company called Statoil has been capturing and sequestering carbon dioxide in a natural gas field (Sleipner West) since 1996 and all monitoring efforts have shown that no carbon dioxide is escaping.



The injection process consists primarily of compressing the carbon dioxide into a supercritical state, meaning that it is under enough pressure that the phase boundary between liquid and gas ceases to exist. Then the carbon dioxide can be injected into several different geologic formations that are possible for sequestration. The primary formations are deep saline reservoirs, coal seams or exhausted oil or gas fields.

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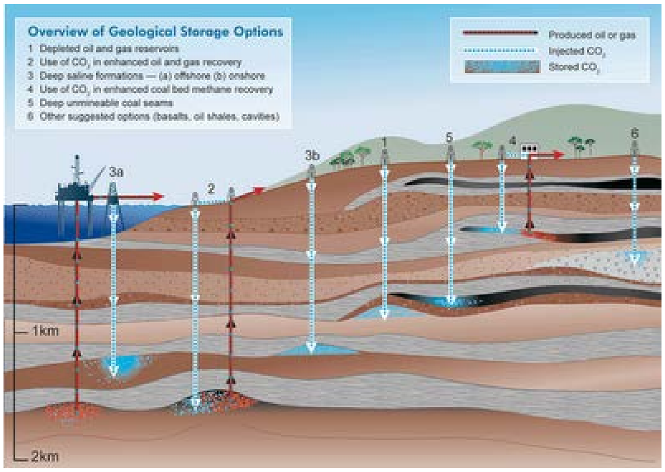
Storage Reservoirs

Oil and Gas Traps

Geologic oil and gas traps consist of a permeable, porous rock (e.g. sandstone) that fluids can flow through that is capped



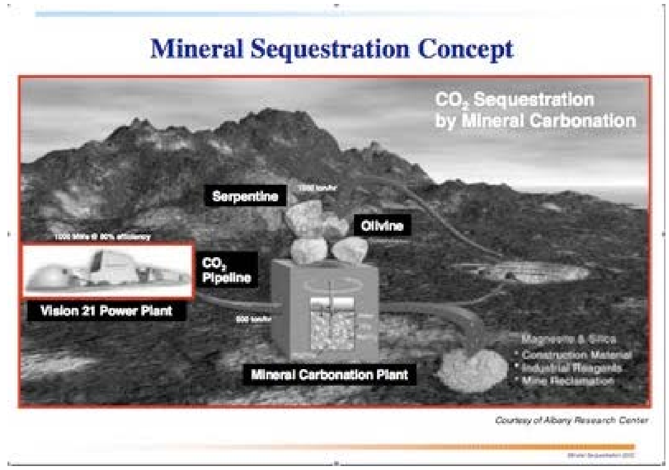
in top by an impermeable rock (e.g. shale). Because oil and natural gas are less dense than water they will rise to the top of the rock due to buoyancy forces and be trapped there. Oil and gas traps are being considered for CO2 sequestration because we know that they can trap fluids over geologic time scales because they trapped the oil and gas there, natural gas traps are the most promising because they have shown the ability to hold gas, not just a liquid[1]. The idea is to pump CO2 into the well in a supercritical state, which means that the CO2 is under enough pressure that it no longer behaves like a gas. It can effuse through solids like a gas, but it can dissolve substances like a liquid. The CO2 is denser than oil so it sinks below the oil in the reservoir and adds pore pressure to the system[2], which allows more oil or gas to be pumped out. After the CO2 is put into the well it must be capped, and the standard product for capping wells is concrete.

Sequestration in Deep Saline Aquifers

Carbon dioxide sequestration in deep saline aquifers is very similar to sequestration in depleted oil and gas reservoirs, but instead of pumping the CO2 into reservoirs it is pumped into saline aquifers. A deep saline aquifer is a rock that has sufficient pore space and permeability to allow groundwater flow, and is deep enough underground that the water has been there long enough to dissolve salts[3]. It is estimated that the global sedimentary basins are capable of holding 320 Gt of CO2[4]. Carbon dioxide sequestration in saline aquifers in sedimentary basins can be achieved by four main mechanisms: (a) CO2 dissolution in the formation water called solubility trapping, (b) geochemical reactions with the aquifer fluids and rocks known as mineral trapping, (c) structural trapping, where the CO2 rises to the top of geological structures below an impermeable top seal and is stored there due to capillary pressure and (d) hydrodynamic trapping where the aquifer does not allow the CO2 plume to seep out of the targeted reservoir zone (in the condition where the density of the CO2 is very close to that of water) hence increasing its residence time[5]. The water in deep saline aquifers contains mostly sodium chloride at concentrations of about 250,000 mg/L[6]. It is believed that the only way the concentrations could get that high is if the water was initially seawater that was trapped in the formation as the sea retreated[7], this indicates that the water has been there on the order of millions of years because sea level changes of that magnitude occur very slowly. It is believed that water in these deep saline aquifers is trapped and therefore would be able to trap CO2 there as well[8]. The CO2 in supercritical state that is injected into the aquifer has a density of 660 kg/m3, which is less than the saline solution so it would rise to the top of the aquifer due to buoyant forces and be trapped by the impermeable caprock[9].

Mineral Sequestration

Mineral sequestration of CO2 is a technique where CO2 is reacted with minerals containing certain elements that will form stable carbonates. The elements that CO2 reacts with are calcium (Ca) and magnesium (Mg), which are found in many silicate rocks[10]. They can also be found in industrial waste products such as cement kiln dust[11] and fly ash from coal burning plants[12]. Because Ca and Mg are such common elements in the earth there have been a variety of mineral sequestration ideas proposed. The basic principle is that carbonates are in lower energy states than CO2 so they are thermodynamically stable. Out of the naturally occurring minerals, olivine [(Fe,Mg)SiO4] and serpentine [Mg3Si2O5(OH)4][13] are the ones that ha ve the highest potential to react with CO2 and form carbonates. The rocks that contain these minerals are called ultramafic rocks and are formed through volcanic processes. There are similar reactions for Ca based minerals to form calcium carbonates. Mineral sequestration in rocks occurs naturally (weathering of ultramafic rocks), but is a slow process. The sequestration reactions can be sped up by increasing the surface area of the rocks (grinding them into a powder) and adding catalysts such as HCl[14]. In order for this to occur the ultramafic rocks need to be mined which uses energy, research is being done to see if these reactions can be sped up underground, but there have not been any significant developments[15].



Mineral sequestration of CO2 using waste products from industrial processes is also being investigated. The two primary waste products are cement kiln dust[16] and fly ash from coal-fired power plants[17]. Cement kiln dust contains Ca and fly ash can contain both Ca and Mg so they would be able to complete the carbonation reactions. These sequestration options involve mixing CO2 with a brine solution and the waste product to make the reaction occur[18]. This is being looked into because we would not need to mine the reactants and it would help us make use of industrial waste that otherwise is collected in landfills[19].

Sequestration in Unminable Coal Seams

Carbon sequestration in coal seams that are too deep to be mined is another sequestration technique that is being examined. The mechanism for CO2 trapping in coal seams is primarily absorption through micropores in the coal matrix[20]. The wetting properties of coal are such that CO2 is preferentially adsorbed to it. It is a similar situation to if you drop water on wood and the wood absorbs it. Theoretically the CO2 should stay absorbed in the coal as long as the pressure on the system remains above the desorption pressure[21]. The CO2 would be pumped into the coal through fractures in the coal called cleats then absorbed by the coal. As the coal absorbs the CO2 it pushes methane that is already trapped in the coal out which can be harvested in a process called enhanced coal-bed methane recovery[22].

Soil Organic Carbon Sequestration

Another technique to sequester CO2 is to use plants and biomass to do it for us. The basic principle is to increase the amount of soil organic matter through different agricultural practices such as using mulch instead of tilling. This would allow for roots and organic matter to accumulate and get buried[23]. Organic matter contains large amounts of carbon, some of which is taken from the atmosphere[24]. The goal of increasing the soil organic carbon is to encapsulate the carbon within stable micro-aggregates and protect it from microbial processes[25]. Many soils in the world have had the soil organic carbon depleted by modern farming practices and by other natural factors such as erosion and oxidation[26]. It is believed that soil carbon degradation affects 1216 million hectacres (Mha) worldwide[27] and that soil has to potential to hold much more carbon than it currently is.

Deep Ocean Sequestration

The final technique I examined was sequestration of CO2 in the ocean. The ocean is the largest sink available to store CO2. There are two options regarding ocean storage being considered, dissolution and deep-sea injection in the form of clathrate hydrate[28]. Dissolution involves pumping CO2 into the ocean in a droplet plume, which will dissolve in the water and form carbonic acid[29]. Deep-sea injection entails injecting the CO2 in the deep ocean below the thermocline, 1500 m or deeper, and it will form clathrate hydrate which is an ice-like substance where water molecules surround a CO2 molecule[30]. The ocean is currently removing 6 Gt of CO2 from the atmosphere a year; this would simply be accelerating this process.

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[27] Oldeman, 1994
[28] Voormeij and Simandl, 2002
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Electricity Fuel Resources

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Scientific Concerns

The scientific community is unsure if implementing carbon sequestration on a large scale is a good idea. This is the reason why Senate Bill 699 is proposing demonstration plants for carbon sequestration, not large scale implementation. The primary concern with the idea of carbon sequestration is our ability to successfully sequester carbon dioxide. There are many different techniques to sequester carbon, you can find more under Storage Reservoirs. None of these reservoirs are perfect for sequestration of carbon dioxide and they each present different problems. Some of the reservoirs do not appear to be capable of long-term carbon sequestration, while others may not be feasible or not have large enough storage capacities. This page outlines some scientific problems with sequestration that will need to be addressed if it is to be implemented on a large scale. I focus only on the sequestration methods that could be encompassed by senate bill 699.

Depleted Oil and Gas Fields

Sequestration in depleted oil and gas traps is the most common and well researched way to sequester carbon. This is because this method appears to have the most promise, and there can be economic benefits from carbon sequestration in oil and gas fields. There are two concerns with sequestration of carbon in oil and gas fields, the first concern is that the carbon dioxide would escape the trap and our sequestration efforts would be futile, and the second concern is that enhanced oil recovery (EOR) methods would cause further environmental damage. It appears that sequestration in depleted oil and gas fields can be successful over long time periods. The Norwegian oil company Statoil has been sequestering carbon in a deep saline aquifer since 1996 and all of their monitoring efforts show that the carbon has not been escaping[1] Deep saline aquifers have very similar geologic properties as oil or gas fields, they are simply trapping a different fluid (water instead of oil or gas) so evidence from the Statoil project can be applied to future projects in oil or gas fields.

The second concern with sequestration in depleted oil and gas fields can be viewed as both a concern and a benefit. Currently, we cannot extract all of the oil out of oil fields. When you pump carbon dioxide into depleted oil and gas wells it adds more pressure to the well and makes it easier to extract more oil or gas.This can provide financial incentive for oil and gas companies to sequester carbon, but then the extra oil or gas that is removed from the well can be burned and create more carbon dioxide.

Deep Saline Aquifers

The primary concerns with sequestration in deep saline aquifers is that carbon will be able to escape the aquifer. These fears are probably unwarranted considering that the saline water has been trapped in the aquifer for millions of years[2]. The Statoil project also shows that long-term sequestration can be achieved in saline aquifers.

Mineral Sequestration

The primary concern with mineral sequestration is feasibility. Although the reactions between carbon dioxide and the minerals are very exothermic and favored by the resulting energy states, they occur very slowly in nature[3]. The reactions do not occur quickly enough for large-scale sequestration. Mineral sequestration in fly ash or cement kiln dust is a promising because it is easy to accomplish and will provide long term sequestration[4], the problem here is that there is not enough fly ash or kiln dust to sequester large amounts of carbon. Using industrial waste such as fly ash or kiln dust for carbon sequestration can be a very good solution if it is combined with other techniques.

Sequestration in Coal Seams

Theoretically, carbon sequestration in unminable coal seams is a safe option. As long as the pressure on the coal seams remains above the desorption pressure for the carbon dioxide it will remain sequestered. The pressure on the system will remain because for a coal seam to be unminable it must be very deep underground where pressures are above the desorption pressure[5]. One concern with sequestration in coal seams is that when the carbon dioxide adsorbs to the coal is displaces methane that is already in the coal[6]. The methane can be harvested and burned which gives economic incentive, but it also reduces the effect of sequestration. If the methane is not harvested and burned it can escape into the atmosphere where it is a much more potent greenhouse gas.

[1] Chadwick, 2006.

[2] Introducing Groundwater, Michael Price.

[3] Voormeij and Simandl, 2002

[4] Soong et al., 2005.

[5] Shukla et al. 2010

[6] Shukla et al. 2010

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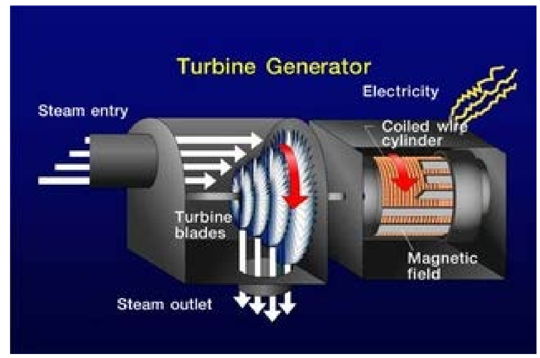
Thermodynamics

The burning of fossil fuels, primarily coal, to produce electricity causes a combustion reaction where oxygen (O_2) combines with carbon in the fuels to produce carbon dioxide (CO_2) and release energy in the form of heat, which is used to boil water and turn it into steam (Eqn (1)). (The example reaction shows the combustion of pure carbon, or coal in its purest state, but most coal contains hydrogen, oxygen and other elements)

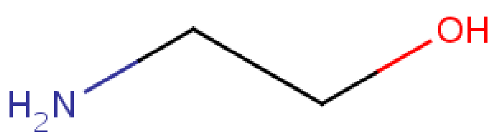
$$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g) + \text{energy} \qquad \text{Eqn. (1)}$$



The steam is allowed to pass into a turbine where it expands increasing its entropy and turning the generator. The generator spins magnets that are encased with stationary coiled wires, which produces electricity by induction. Scientists

have discovered that the CO_2 is increasing in the atmosphere at an exponential rate[1] and that CO_2 is a greenhouse gas that leads to global warming[2]. Because of this, scientists are considering new ways to reduce CO_2 in the atmosphere. One of those ways is carbon sequestration, which involves three processes: capture of CO_2 from emission sources, transport, and injection deep underground.

Monoethanolamine:



The first step in carbon sequestration is to capture the gaseous CO2 from the atmosphere. This is primarily being attempted at point sources for CO2 emission, i.e. the power plants that are burning coal. One way to capture the CO2 is to use chemical solvents to capture it after combustion. A common solvent that is used to do this is an aqueous monoethanolamine (C2H7NO)[3] solution, but more efficient solutions are being developed. The CO2 bonds with monoethanolamine because it creates a product that is more thermodynamically stable due to a reduction in Gibb's free energy. This process is not particularly efficient, however; the reaction has an activation energy that requires it to take place in steam, and the monoethanolamine must then be forced to release the CO2 so that it can be sequestered, which uses more energy. The process of making the monoethanolamine release the CO2 is a non-spontaneous process so it must be driven by doing work on it. It is estimated that this form of carbon capture will decrease a coal-fired power plant's efficiency by approximately 30%[4].

The next step in the process is to put the CO2 that has been captured into a vapor-liquid supercritical state. A supercritical state is a state where phase boundaries cease to exist and can be achieved by putting the compound under the right pressure and temperature combination. For CO2 that combination is at least 31° C and 72.9 atm of pressure. In order for CO2 to reach its supercritical state significant amounts of work must be done on it. This work requires energy that is produced from the burning of coal, and because the energy is taken to reduce CO2 emissions this reduces the efficiency of the coal-fired power plant.

Thermodynamically the rest of the CO2 sequestration process is not as interesting, CO2 is kept in a supercritical state when it is pumped into the ground and once it is underground it remains in the supercritical state because it is pumped deep enough that pressures and temperatures are high. It takes work to pump the CO2 into the ground, but the amount of work needed is relatively small and the energy costs are low. As sequestration becomes less thermodynamically interesting it becomes more geologically interesting and issues of CO2 escaping sequestration, or bonding with rocks and minerals become more important.

Carbon capture and storage is an energy intensive process, primarily because the energy cost of capturing the carbon is high. Injection and storage costs are quite low, the IPCC estimates that it will cost $0.5-8.0 per tonne of carbon for injection, which is relatively low. The capture of carbon, however, increases the energy demands on the coal-fired power plant by 30%. If more efficient methods of capturing carbon can be developed the energy cost of carbon sequestration could be greatly reduced.

[1] Scripps CO_2 Program (2011) CO_2 Concentration at Mauna Loa Observatory, Hawaii, accessed 10/10/11. http://scrippsco2.ucsd.edu/

[2] IPCC 2007 report

[3] Jared Ciferno et al. **Capturing Carbon from Existing Coal-fired Power Plants**. American Institute of Chemical Engineers (2009).

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Politics

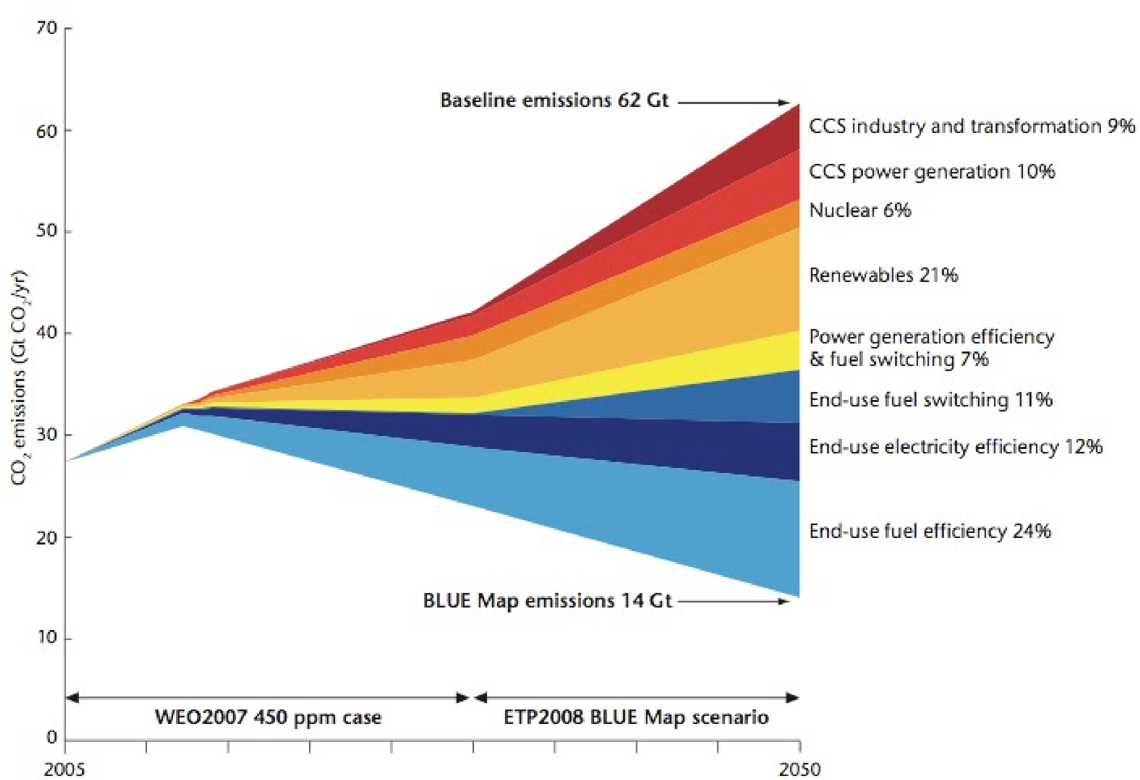
Senate bill 699 proposes that the federal government will pay for a demonstration program for the commercial application of integrated systems for the capture, injection, storage, and monitoring of carbon dioxide from fossil fuel power plants. The bill also proposes the Department of Energy would take over the sequestration site for long term stewardship, and that those in charge of the demonstratio

n will not be held liable for certain mistakes should they occur. It is estimated that if passed, the bill will cost taxpayers $329 million by 2021[1]. This bill is a relatively small part of the larger carbon sequestration picture. This bill proposes the development of one demonstration program, the International Energy Agency (IEA) claims that the Unites States needs to increase spending on CCS demonstration projects to $3.5-4 billion annually[2]. So an important question to answer when considering senate bill 699, is are we willing to invest enough in CCS to make it commercially viable? If we are not, passing senate bill 699 would be a waste.

The IEA proposed a

50% reduction of greenhouse gas (GHG) emissions by the year 2050 and created the BLUE map scenario to address strategies to accomplish this goal[3]. Carbon capture and storage is the only technology available to mitigate GHG emissions from fossil fuel fired power plants. So unless we want to abandon fossil fuel use CCS must be implemented in order to meet GHG emission reduction goals. In the BLUE map scenario CCS is responsible for ~20% of the total GHG emission reductions. If CCS technologies were not available, the overall cost of reducing carbon emissions by 50% by 2050 would increase by 70% based on information from The Stern Review[4] on the economics of climate change.

Figure 1: CCS delivers one-fifth of the lowest-cost GHG reduction solution in 2050



Based on this information from the IEA it seems that investing in carbon sequestration technologies, though expensive, will be worth it considering that it will save 70% of the money we would spend to reduce the GHG emissions without CCS. This is assuming, however, that the United States aims to reduce our GHG emissions by 50%. This is an important goal for the people of the United States to have because the effects of climate change will be felt here and will be expensive to mitigate.

In order for CCS to be implemented on a large scale, international cooperation will be important. The developed world now has the charge of researching and developing CCS technology, but once it is developed it must spread quickly to the rest of the world. This will require international collaboration for both the development of CCS technologies, and the implementation of the technology throughout the world. According to the IEA, this will require investments from the currently developing countries of the world of an average of $1.5-2.5 billion per country, per year[5]. One way this money could be provided is if CCS is approved as a Clean Development Mechanism under the Kyoto Protocol.

If carbon sequestration technologies are going to be implemented there will need to be flexible, adaptive regulation to protect public health and our investment in CCS. If sequestration techniques are not properly regulated public health could be affected by the use of certain chemicals, or infiltration of carbon into groundwater. Also, if there is not proper regulation carbon dioxide could be haphazardly sequestered and escape, making our investment in the technology useless. There will also have to be regulations and rules about long-term stewardship of sequestration sites, which must be monitored and protected from drilling.

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[1] Congressional Budget Office Cost Estimate, Senate Bill 699.

[2] International Energy Agency. Technology Roadmap: Carbon Capture and Storage. 2009.

[3] International Energy Agency. Technology Roadmap: Carbon Capture and Storage. 2009.

[4] Nordhaus, William D., The "Stern Review" on the Economics of Climate Change (December 2006). NBER Working Paper Series, Vol. w12741, pp. -, 2006. Available at SSRN: http://ssrn.com/abstract=948654

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Conclusions

The continued use of coal as our primary electricity fuel is not sustainable because we are burning coal at much higher rates than it is being produced. Coal production goes so slowly that we can essentially say that more coal is not being formed. Because of this, the current coal reserves are all that we have to use and they are estimated to last for ~200 years[1]. Carbon sequestration therefore cannot be a long-term solution to our current energy and climate problems, but it can provide a 100-200 year window for us to continue using coal, while developing other methods to generate electricity.

A related concern is that carbon sequestration will not be implemented commercially until 20-40 years from now (the IEA roadmap has CCS being fully implemented in 40 years). So if we choose to invest in CCS now rather than abandoning coal and using other methods for electricity production we will continue to emit carbon dioxide into the atmosphere for another 20-40 years. But, if we chose to abandon coal and use other methods to generate electricity it would probably take a similar length of time to build the infrastructure needed to switch. Carbon sequestration is not a short-term solution nor is it a long-term solution due to the limited amount of coal, but it is a valuable asset in our search for clean energy.

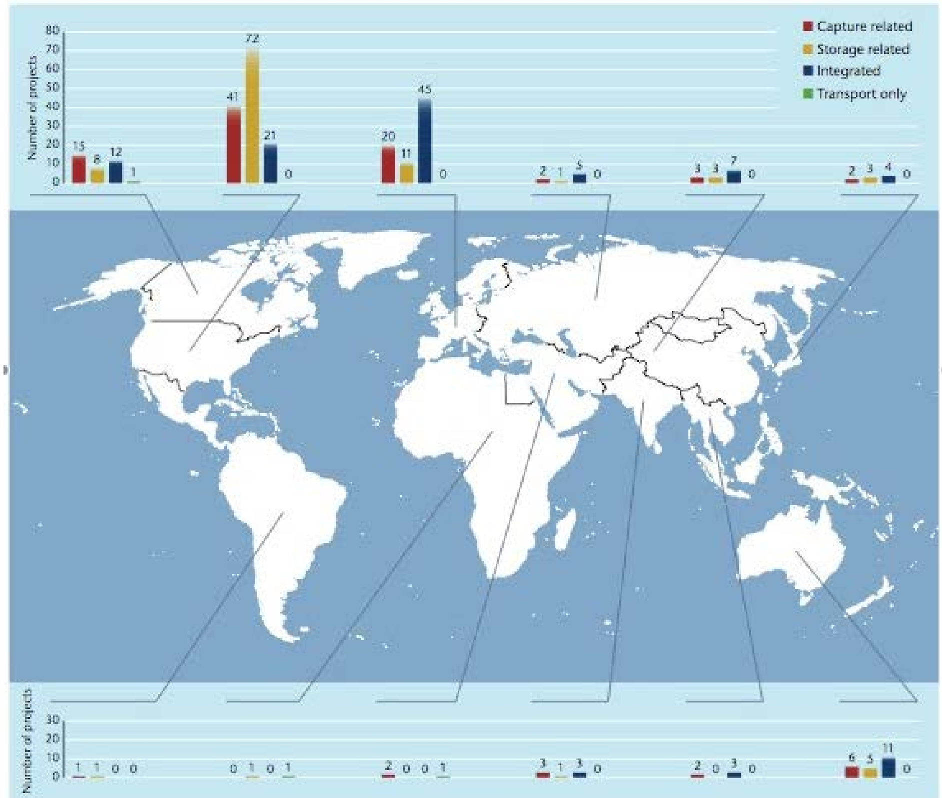
Passing senate bill 699 can be viewed as a pledge to invest in carbon sequestration, but it is a very small amount of the money that needs to be invested in order for CCS to be commercially viable. Many other small bills would need to be passed in the coming years to continue the investment otherwise the money spent now would be wasted. The political climate can undergo large shifts in relatively short periods of time, and the taking into account the current political climate of partisanship and unwillingness to work together I think that if we are going to invest in CCS we need a bill that will guarantee a long-term investment. Because of this I believe that senate bill 699 should not be passed. But, that does not mean we should not invest in CCS technologies.

Should we invest in CCS?

Senate bill 699 should not be passed, but then where does that leave us with regards to carbon sequestration? Carbon sequestration remains the most cost effective way to reduce our emissions by 50% by 2050[2]. Because of that it is worth making an investment of $3.5-4 billion a year as the IEA recommends. That may seem like a large amount of money, but considering that the proposed defense budget for 2012 is $671 billion it is not really a large amount of our national budget. Carbon sequestration must be a part of the solution for our climate crisis, as the IEA recommends CCS can account for ~20% of our GHG reductions, the other 80% reduction will require an investment in some or all of the other technologies covered on this website.

While it is clear that the individual stages of capture, injection, and storage are technically viable, the problem is integrating all of these processes and scaling them up so they can sequester carbon on an industrial scale. There are currently 5 fully integrated CCS projects operating in the world right now. The figure below is a snapshot of the currently planned CCS projects in the world.

Figure 3: Planned and operational large-scale (>1 $MtCO_2$/year) CCS projects



The primary facilities that need to implement CCS technologies are coal-fired power plants, but there are many other industries that can adopt CCS in order to reduce emissions more effectively. Carbon capture and storage needs to be adapted by gas-fired power plants, biomass power plants, and emission intensive industrial sectors such as cement, iron and steel, and paper. Carbon sequestration technologies are going to have to vary depending on the industry using them, and where the facility is geographically located. There will have to be localized solutions to this global problem.

Congress should pass legislation that will finance the implementation of carbon sequestration demonstration projects costing up to $4 billion a year. I propose that the coal industry should be required to pay a significant share of that money. The implementation of a carbon tax would make this possible. According to IBISworld, a market research website, the coal industry recorded profits of $25.1 billion in 2011. Profits are high enough that they would be able to pay for all of the demonstration projects and still have $21 billion in profits.

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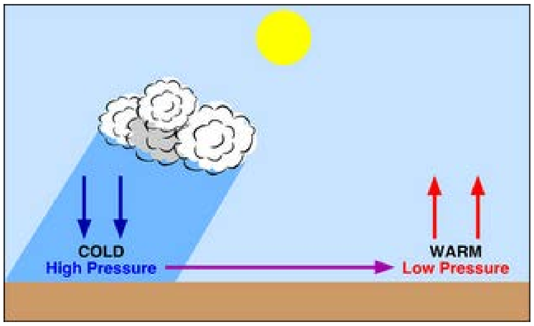
[1] United States Energy Information Agency, 2010 Annual Coal Report.

[2] International Energy Agency. Technology Roadmap: Carbon Capture and Storage. 2009.

Wind Energy >

Wind Formation and Thermodynamics

Wind is a form of solar energy, caused by the sun heating the atmosphere unevenly in conjunction with the varied topography of Earth's surface and Earth's rotation (image below).[1] The sun's process of generating energy by nuclear fission of hydrogen into helium is a spontaneous process, and an increase in entropy always accompanies such spontaneous events. Thus, the wind is also spontaneous, and the spinning of a wind turbine's blades causes an increase in entropy. However, this increase in entropy is used to propel a non-spontaneous process: the generator's work in converting the wind's power to electricity.



The generator does work by converting mechanical energy into electrical energy. Work is also done during the cooling of the generator. If a fan is used, work is done as the machine pushes air molecules toward the generator. If a water-cooling process is used, work is done as cold water or other cooling fluid is pumped into the system.[2]

Sources

[1]US Department of Energy (2011). "How Wind Turbines Work." Energy Efficiency and Renewable Energy: Wind Program. Updated 23 September 2011. Accessed 11 October 2011. http://www1.eere.energy.gov/wind/wind_how.html

[2]Danish Wind Industry Association (2011). "Generators." The Guided Tour. Accessed 11 October 2011. http://wiki.windpower.org/index.php/Generators

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High/low pressure: http://www.physicalgeography.net/fundamentals/7n.html

Wind Energy >

Turbine Efficiency

Because of the variability of wind gusts, as well as technological imperfections, the best turbines operate at only 35% of capacity averaged over one year.[1] The capacity is equal to the amount of power produced divided by the turbine's potential power output. Since a typical turbine is able to supply 2 MW of power, but currently only works at 35% capacity, the turbine actually produces 700kW of power. A watt is defined as one joule per second, therefore a turbine that is able to produce 2,000,000 joules per second of power is typically only producing 700,000 joules of power per second.

Albert Betz, a German physicist, discovered in 1919 that a wind turbine can extract a maximum of 59.3% of the wind's energy. If a turbine were to extract 100% of the available energy in the wind, it would use up all of the wind and stop the turbine; to keep the turbine moving there must be excess wind to blow over the blades.[2] Technological advances in blade design and generator efficiency may have the potential to extract the full 59.3% of energy from the wind, but this is not currently the case; turbines currently capture between 20 and 40 percent of the energy in the wind.[3] A precise measurement of wind turbine ouptut is called "specific yeild", which measures the annual energy output per square mile of area swept by the turbine blades. Therefore, increases in blade length can increase the energy extracted from the wind.[3]

Total power in the wind is calculated by:

$P = 1/2(pAu^3)$

Where P is total power (Watts), p is air density (kg/m^3), A is rotor swept area (m^2), and u is wind speed (m/s).[4]

The amount of energy that a turbine can extract from the wind depends on the length of the turbine blades as well as several factors. Increasing the height of the turbine increases wind speed, as seen in the chart below. Temperature and altitude affect air density, and as air density increases so does the turbine output; therefore, a turbine on a high plateau with colder temperatures will produce more power than a turbine at sea level in a warmer climate.[3]

Classes of Wind Power Density at Heights of 10m and 50m

	10 m (33 ft)		50 m (164 ft)	
Wind Class	Wind Power Density (W/m^2)	Speed m/s (mph)	Wind Power Density (W/m^2)	Speed m/s (mph)
1	0	0	0	0
	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1,000	9.4 (21.0)	2,000	11.9 (26.6)

Sources

[1]NYSERDA. "Wind Energy Toolkit." NYS Energy Research & Development Authority. Updated March 3 2011. Accessed 11 October 2011. http://www.nyserda.ny.gov/~/media/Files/EERP/Renewables/wind-energy-toolkit.ashx?sc_database=web, p 11

[2]Danish Wind Industry Association (2011). "Betz' Law." The Guided Tour. Accessed 11 October 2011. http://wiki.windpower.org/index.php/Betz%27_law

[3]Union of Concerned Scientists (2011). "How Wind Energy Works." Clean Energy. Accessed 11 October 2011. http://www.ucsusa.org/clean_energy/technology_and_impacts/energy_technologies/how-wind-energy-works.html

[4]Schram, Todd J. (1998). "Energy Production Potential of Wind Resources in Texas." University of Texas. Accessed 6 December 2011. http://www.crwr.utexas.edu/gis/gishydro99/class/schram/project.html

Images

Chart of wind power density: http://www.ucsusa.org/clean_energy/technology_and_impacts/energy_technologies/how-wind-energy-works.html

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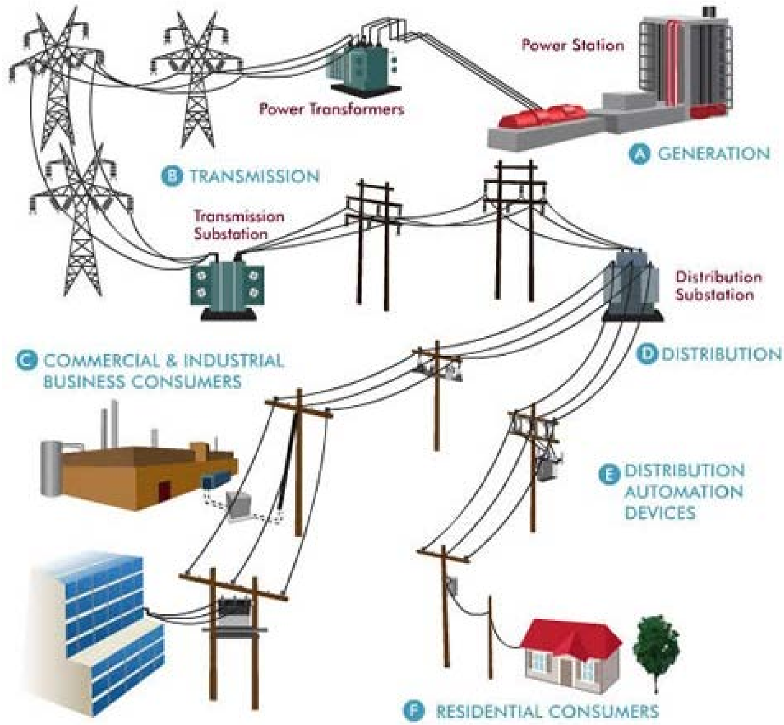
Concerns

Transmission

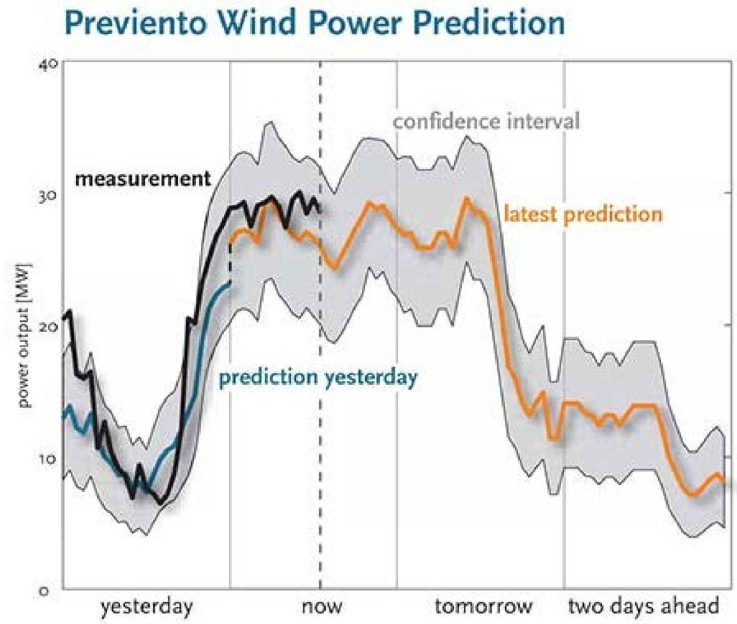
One problem with wind turbine efficiency is the amount of energy lost during transmission to the grid. The U.S. Energy Information Administration (EIA) estimates that 7% of the electricity in each transmission is lost in the transforming process and the distance traveled to the grid.[1] This is a problem with all electricity, not just the electricity created by wind power. Allowing the electricity to travel shorter distances (like community energy projects) or directly to the source of use (residential energy projects) can greatly reduce these losses.



Wind Intermittency

One of the biggest issues with wind energy is the variability of wind gusts. Most wind turbines are programmed to run idle, without grid connections, when wind speed is too low for electricity generation. When wind speeds increase to an efficient electricity production level, the turbine must be manually connected to the grid. The intermittency of wind complicates the process of turning the connection on and off, and because of this critics of wind energy argue that wind power is not sustainable on its own; it must have coal or nuclear powered back-up plants for when wind is not blowing hard enough or steady enough to generate electricity. Recently, the Duke of Edinburgh went so far as to call wind farms "absolutely useless" and accused wind energy supporters of believing in a "fairy tale" because of this issue.[2]

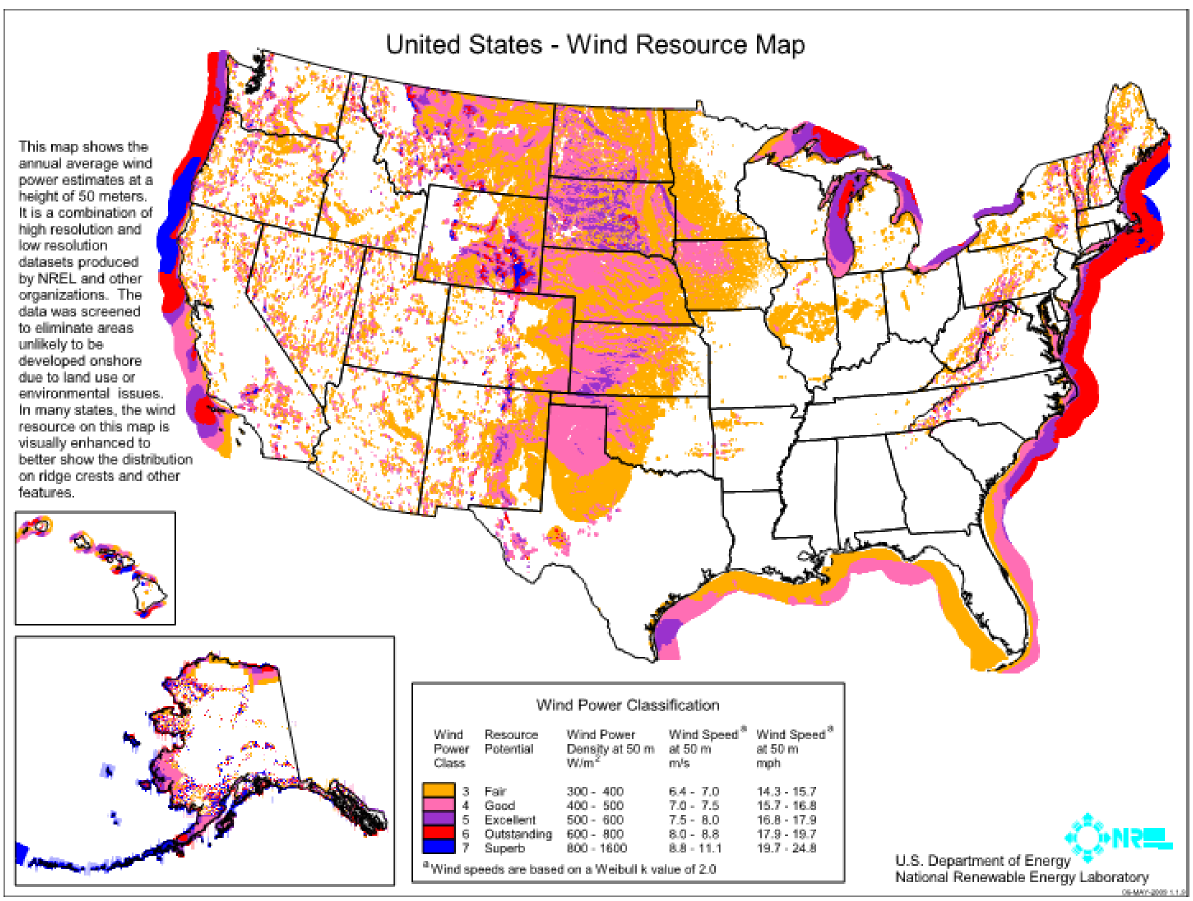
However, meteorologists and other wind experts are improving technologies to forecast wind speeds up to four days, and more, in advance. (diagram on right).[3] Engineers are also finding better ways to store energy, such as "pump storage" schemes which use excess energy from wind power to pump water into reservoirs which is used to generate electricity during periods of high demand or short supply.[2]



Some proponents of wind power argue that "the wind is always blowing somewhere";[4] the more wind farms that exist, the lower the risk of electricity shortages. Also, because of demand for electricity can change suddenly when people changing their electricity usage with the weather or other events, grid operators already know how to store the energy, sell it to another grid, or turn plants off. Intermittency of demand occurs with any type of power plant, and grid operators are trained in how to store supply to match demand.

Wind Distribution

Unfortunately, the best areas for large wind farms (according to wind levels) are not close to the highest population centers. As seen on the map below, the best areas are in the Midwest: Wyoming, North Dakota, Montana, etc. If the U.S. was solely dependent on wind power from large farms, it would have to transmit electricity from the center of the country out to the West and East coasts (where the majority of U.S. electricity is used). One way to combat this issue could be institution of offshore wind turbines; as seen below on the map, coastal waters have the highest wind speeds. Another way could be to have smaller wind farms (discussed more here).



Landscape and Wildlife

Critics of wind energy argue that wind farms destroy landscapes, because turbines need to be in open areas and maintenance crews need to build access roads to these areas. In Vermont's Lowell Mountains, workers are clear-cutting healthy forests and using dynamite to cut paths for a 21 wind turbine project. The turbines could supply up to 25% of the state's power, but protesters argue that erecting them is causing too much damage to "environmentally sensitive landscapes."[5]

Critics also argue that wind farms disturb wildlife habitats. For example, there is a debate surrounding the Antelope Ridge Wind Farm, a proposed 300-megawatt project for Union, Oregon. The project would include the installation of 150-164 turbines, creation 250 temporary jobs, and creation 20 permanent jobs. However, the public continues to protest the project because of the possible risk to elk and deer habitats as well as the undesirable aesthetics of the turbines.[6]

Wind energy associations agree that landscapes and wildlife should not be disturbed; best way to combat these problems is to use areas of land that do not currently have trees or known wildlife habitats. For example, wind turbines should not be placed in areas where there are endangered species of birds, because birds occasionally fly into turbines. However, the amount of birds killed by wind turbines needs to be put in perspective: birds killed by turbines account for less than 0.003% of all human-caused bird deaths according to the American Wind Energy Association, and house cats and glass windows cause 10,000 times more bird deaths than wind turbines.[7]

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Small Wind

For the purposes of this study, the term "small wind" will include both residential wind turbines and community wind projects.

Residential Wind

The U.S. government currently defines "small wind" as projects that are rated to produce less than or equal to 100kW of electricity. These projects are also known as residential wind turbines, which are usually set up to generate electricity for a single house or other building. They are rapidly growing in popularity; 7,811 residential wind turbines were sold in the U.S. in 2009 compared to the 2,100 units sold in 2001.[1] This growth has not only been in the U.S.; in 2010, Britain reported a 65% growth in the small-turbine industry.[2] The growth in small wind has been helped by government incentives in both the US and Britain.[3] Current U.S. federal policy provides a 30% tax credit for individuals who choose to install small wind systems. There are other tax incentives and grants which vary from state to state.

Categories and Capabilities

There are two categories of residential wind systems:[4]

1. *"Autonomous" electrical systems* ("stand-alone", "grid-isolated", or "off-grid"). These systems are not connected to the grid and are solely responsible for control of voltage and frequency. Their electricity is sent directly to the source of use.
2. *"Distributed generation"* ("grid-connected" or "on-grid" generation). These systems have small generators connected to a larger public distribution network, or grid, where an operator is responsible for overall control.

Community Wind

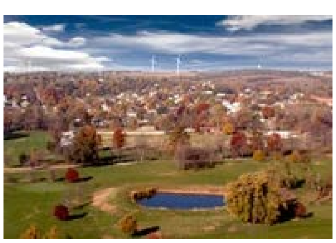
Community wind projects have similar benefits to residential projects, and for the purposes of this study are considered part of the "small wind" category. Community wind involves using a small number of larger turbines to produce power for a neighborhood or small community. They can be owned and operated by public institutions or the community itself. While this type of project is beneficial, the U.S. government does not currently provide a definition for "community wind" and does not offer subsidies for projects that are over 100kW (most community projects are rated above 100kW).

There have been several successful community wind projects worldwide, including:

Tocco da Casauria, Italy

This small, poor town of 2,700 residents installed 4 turbines which produce 30% more power than its residents use, making it completely energy independent.[5] As electricity is very expensive in this region, energy independence has saved the town a lot of money (more than $200,000 in 2009), which is being used to fix up schools, municipal buildings, and more.[6]

Rock Port, Missouri, USA



In 2008, Rock Port, Missouri became the first community in the U.S. to be 100% wind powered. The community has four wind turbines located on agricultural lands, which produce 16 million kW hours of electricity each year. As the community's 1,300 residents only require 13 million kW hours per year, the four turbines produce 18% more electricity than the community needs. The extra electricity is sold back to the grid.[7]

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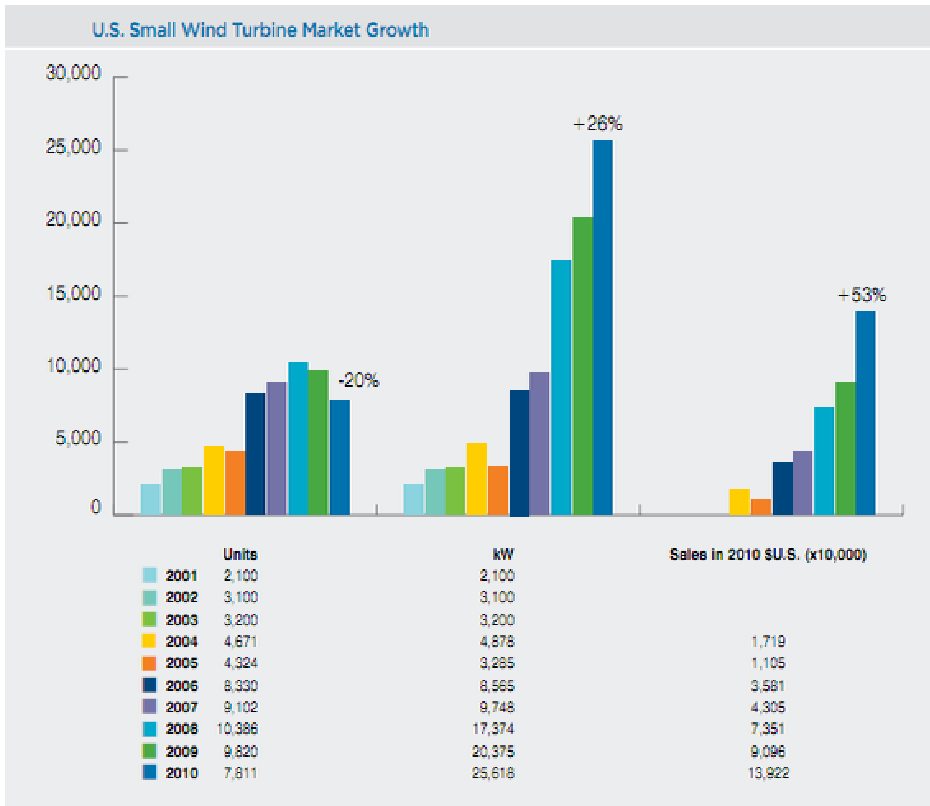
Conclusion

Should the U.S. government shift focus from large wind to small wind?

Based on statistics from the American Wind Energy Association, it seems that residential wind turbine sales have been increasing rapidly. This raises the argument that if demand increases, it may be incentive enough for companies to develop small wind technology. However, simply looking at sales in 2001 and 2010 is misleading; below is a graph of sales every year from 2001 to 2010:[1]



According to this graph, units sold in the U.S. have actually been decreasing since 2008 when they peaked at 10,386. Minor technological improvements and more consistent usage have accounted for the rise in kW from year to year, but less and less people have been purchasing small wind systems every year since 2008; if demand is decreasing, companies have no incentive to provide more advanced products. Tax credits may be enough for the die-hard wind fans to invest in a small wind turbine, but clearly these credits are not enough for demand to grow each year.

Real progress cannot be made unless the U.S. government acknowledges small wind as superior to large wind. We've seen that small wind, including both residential and community projects, has the potential to solve the shortcomings of large wind. The U.S. government should change its focus from large wind to small wind so that the proper improvements and incentives are made and communities and individuals can make the transition to small wind systems.

Community Self-Sufficiency

Changing focus from large to small wind would mean more than just recongizing the benefits of small wind turbines; it would mean recognizing the benefits of community self-sufficiency, to have every community responsible for its own power generation and consumption. This has more far-reaching effects than simply putting power generation on a more manageable scale; for example, it makes communities and individuals energy independent, creates jobs, and helps reduce consumption overall.

Shifting focus to small wind would also mean recongizing that each community has its own set of resources, and that wind energy is not ideal for every community. Some communities, such as those in southern areas of the United States, do not have much potential for using wind power (see map on Concerns page). However, they may have solar power potential, or hydropower, or biomass, or other types of renewable energy using the resources in their natural habitats.

Wind energy will never be the single solution for all electricity generation in the United States, but neither will solar, wave, nor any other type of renewable system; it is a "fairy tale" to think so, as the Duke of Edinburgh put it. However, a combination of renewable sources, based on community resources, will offer the perfect avenue for transition into small scale renewables. With wind power, this transition must begin with a federal recognition of small wind systems as superior to large.

Current Legislation in Progress

- *S. 1491: PURPA PLUS Act*: Bill to amend the Public Utility Regulatory Policies Act of 1978 to expand the electric rate-setting authority of States. This would give states more regulatory flexibility to institute and incentivize renewable energy programs, including small wind turbines. It would also remove cost caps on qualifying facilities that do not have more than 2 MW of capacity so that States can set their own rates for these facilities.[2]
- *H.R. 1861: Infrastructure Jobs and Energy Independence Act*: Among many other things, this bill would extend the federal tax credit for small wind projects from 2016 to 2019.[3]
- *S. 1741: Community Wind Act*: Bill to amend the Internal Revenue Code of 1986 to provide an investment tax credit for community wind projects having generation capacity of not more than 20 MW.[4]

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Solar Energy: Photovoltaics >

Technology Overview

Fossil fuels constitute 85% of conventional energy production worldwide.[7] The combustion of any fossil fuel releases carbon dioxide, nitrogen and sulfuric oxides, and other greenhouse gasses into the atmosphoree, which are implicated in global climate change.[7] Meanwhile, one alternative to fossil fuels bathes us in unharnessed energy every day: our sun. The technology that captures sunlight and converts it into useable energy is known as photovoltaics. The root words of “photo” and “voltaic” mean “light” and “electricity,” respectively.[6] A photovoltaic (PV) system is a collection of conductive cells that convert photon energy into harnessed electricity. The material used in PV cells exhibit a property called the photoelectric effect. When certain wavelengths of light strike the atoms of a photoelectric material, electrons are excited from their resting states and liberated to create an electric current through the material.[5]

How PV Electricity is Generated

Photovoltaic cells use similar technology to that of semiconductors used in the microelectrics industry.[5] A semiconductor is a material with conductive properties intermediate between a conductor, which readily transports charge, and an insulator, which resists the flow of charge. Electric charge "flows" in the form of mobile positively or negatively charged ions, or in the form of electrons, which are negatively charged elementary particles. One example of a conductor is the copper or aluminum transmission lines that carry electric current from power plants to our homes. That current is a flow of electrons through the wire. Examples of insulators include materials such as glass, teflon, and some rubber-like polymers. These materials are often used to support or protect electrical conductors because they do not transmit current themselves.[2]

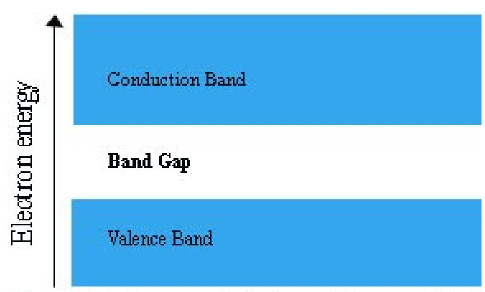

Figure 1. Electron energy level schematic for a generalized atom. No relative scale is implied.

The conductive properties of different materials are determined by the amount of energy that is required to excite and liberate electrons. The electrons of an atom exist in probability densities concentrated at distinct energy levels. The outermost stable energy level is called the valence band. Sufficiently excited electrons are liberated from the valence band into the conduction band (Figure 1), in which they are free to flow through the material to create a current. Between those two bands there is a "band gap" in which no electron states exist. The width of the band gap is measured in electron volts (eV). In order for a photon to induce a photoelectric response from a material, it must be of high enough energy (short enough wavelength) to excite electrons in the valence band beyond the band gap and into the conduction band. Conductors have a very small or nonexistent band gap, insulators have a very large band gap, and semiconductors have a small but non-zero band gap. Accordingly, a semiconductor is not as conductive as a conductor, but does not resist electric flow as strongly as an insulator.

Semiconductors are most commonly made of silicon, but can also be manufactured from germanium, aluminum arsenide, arsenide phosphides, and tellurides, among other elemental combinations. The electrical properties of the chosen material can be altered by "doping," adding trace quantities of charged elements. One surface of the semiconductor is doped with a positively charged element such as boron, to form a positive or P-

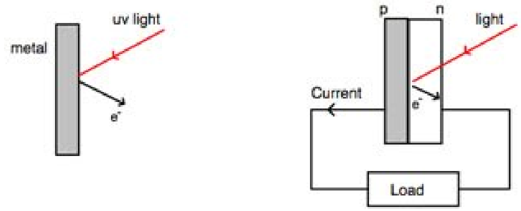

Figure 2. Comparison of photoelectric effect (left) with the photovoltaic effect (right). The spatial asymmetry of contacts with different electrical properties, such as the P- and N-type surfaces, drive the excited electrons through the external circuit (Nelson 2003).

type surface. The other surface of the material is doped with a negatively charged element such as phosphorus, to form a negative or N-type surface. The P and N sides are connected by a conductive wire. The "P-N junction" between the two surfaces acts as an insulator. When electrons in the N-type side are excited into the conduction band, they are attracted to the positive charge on the P-type side, and to the electronegative "charge holes" left behind by other excited electrons. Because of the insulating P-N junction the electrons must flow unidirectionally through the wire to reach the P-type side, creating a direct current through the wire (Figure 2).[10]

Cells of these photovoltaic semiconducting diodes are mounted in a supporting structure to form a photovoltaic module, which is designed to provide a standard voltage, commonly 12 volts.[5,10] The current provided by a module can vary with with operating conditions. Often modules are arranged in parallel arrays to increase production (Figure 3). The careful arrangement of PV cells is essentia to optimal performance. The angle of incident light at a given latitude, season, and time of day determines the effectiveness of photon absorbtion, as does the material and the material's crystalline state.[10] The benefits and limitations of different materials and crystal states are discussed in greater detail on the PV efficiency page.

Although silicon is commonly known as one of the most abundant elements on earth, semiconductor- and solar-grade silicon are not the same as beach sand. Photovoltaic cells require a slightly lower crystal quality than do microelectronics, so PV cells are frequently made from microelectronic industrial surplus.[8] With recent booms in PV production in Germany, Japan, and China, this surplus has been unable to keep up with demand, causing a shortage of solar-grade silicon that had driven up solar cell prices by 2006.[8,11]

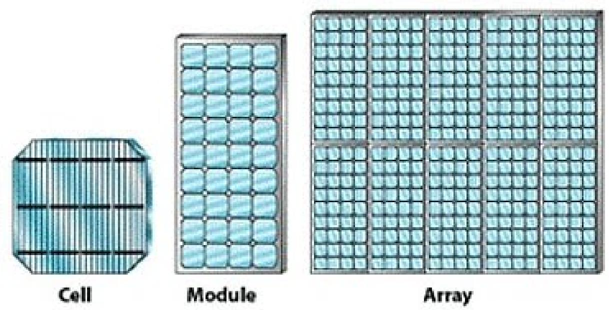

Figure 3. Individual PV cells are usually connected in modules where cells are attached to a frame, interconnected, and protected from the environment. To increase the total voltage, current, or both, PV modules are connected into arrays (Gyorki 2009).

Solyndra's PV panels did not require silicon, but the end of the silicon shortage drove down production costs for Solyndra's competetors, making Solyndra's business model suddenly too expensive to be competitive.[11] To learn more about how Solyndra's PV design is unique, see Solyndra's Rise and Fall.

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Thermodynamics

Physics and thermodynamics define energy in terms of many different components, including work, power, efficiency, and heat. Our page about the thermodynamics of electricity from coal explains how these components operate in standard electricity production. Here are some definitions and explanations of how they operate in photovoltaics. See the PV efficiency and economy page to learn more about what makes solar photovoltaics an economical energy source.

Work

Work is defined as a force applied over a distance.[3] Work is done when organized energy is transferred from one object to another. In a PV system, light energy drives the excitement of electrons in the photoelectric effect. Work is done by photon energy when excited electrons are driven through the P-N junction in an organized fashion by the spatial asymmetry of the P-and N-type surfaces, creating a useable direct current.[10]

Power

Power is defined as the rate at which energy is transformed, or the rate at which work is done.[3] The unit of work is the Joule (J), so power is measured in Joules per second, commonly known as the watt (W). The power produced by a PV system depends on the number and arrangement of PV cells, the materials used, and operating conditions. One PV cell produces a small standard voltage. Voltage is measure of electrical potential. Potential energy is a capactity for doing work. Like charges repel each other, so the work required to bring charges into proximity is the electrical potential energy. The electrical potential energy per unit charge is the voltage. The voltage describes the "pressure" of charge that can be generated in a device or system.[5] Current is a measure of the quantity of electrons that produce that pressure, and is measured in Amperes (amps). The resulting power available to consumers is calculated by multiplying voltage by current.

Heat

When an object gives off heat, the molecules of the object are transferring excess kinetic energy to molecules in its surroundings. This energy transfer continues until the system reaches a dynamic equilibrium, in which energy continues to pass back and forth but the net change in kinetic energy, and therefore in temperature, is zero. This is the same phenomenon as a cooling cup of coffee. The water and organic compounds are high-energy and fast-moving while the liquid is hot. They may have enough energy to change phase and escape as a vapor (steam). This excess energy is transferred down the energy gradient to the lower-energy, lower-temperature surroundings, until your coffee reaches ambient temperature.

Energy dispersed as ambient heat cannot be used to do work, so any energy dispersed as heat in an electricity-generating process is essentially wasted. Very little energy is lost as heat in the photovoltaic energy conversion process, unlike electricity generation from fossil fuel combustion. Because excitement by kinetic energy can confound the energies of specific wavelengths of photons that drive the photoelectric effect, high temperatures actually reduce the efficiency of PV cells. Photovoltaic are maximally efficient at 25 degrees Celcius.[9]

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Efficiency and Economy

Energy Out vs. Energy In

PV materials, like other semiconductors, are optimally excited by different wavelengths of electromagnetic energy. A given material cannot use photons with energies that fall in its “band gap,” or the energy range in which no electron states exist for that material. The ideal wavelength falls within the “valence band,” at an energy level to excite just the valence electrons of the PV material. More conductive materials have smaller or nonexistent band gaps. (See the technology overview page for more information on band gaps.) A combination of materials with different band gaps will be able to capture a broader range of wavelengths and generate electricity with higher efficiency.

The percentage of power converted from absorbed sunlight to electric power is defined as "solar cell energy conversion efficiency," and is given by the equation

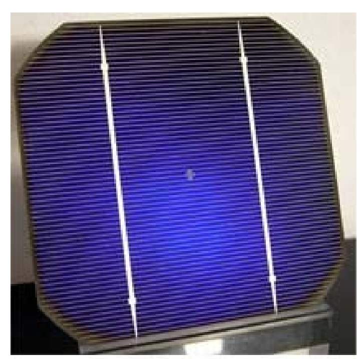
$$\eta = P_m/EA_c$$

Where η = energy conversion efficiency (%), P_m = maximum power point (W), E = input light irradiance (W/m^2), and A_c = Solar cell surface area (m^2).[1] Input light irradiance, E, is the amount of solar light power divided by the surface area of the PV cell. The maximum power point, Pm, is the power output at maximum input light irradiance. This maximum occurs at the "solar noon," not necessarily 12:00 pm but rather the mid-time between sunrise and sunset.[1]

Current solar cells have a theoretical maximum efficiency of 31%, due to the conductive properties of silicon.[5] Current commercially available PV cells acheive a conversion efficiency of 7%--17% by current DOE estimates. The operating standard is 12%, on average.[4] This seemingly low percent conversion efficiency is due to the limited wavelengths of photons with energy greater than the band gap of the PV cell, suboptimal environmental conditions, and suboptimal installation.[1] Development of more efficient cells will lead to more affordable solar power and eventual grid parity. New materials arranged in new ways continually improve the efficiency of PV, and experimental cells have exceeded 40% efficiency.[5] This may not seem very impressive, but one must keep in mind that the sun's energy is neither finite nor damaging to capture, unlike the polluting combustion of finite fossil fuels.

Materials Comparison

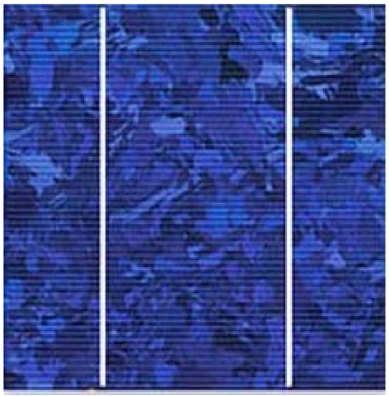
The efficiency of a solar array also depends on the kinds of materials used. The four most common PV materials are mono-crystalline silicon, polycrystalline silicon, amorphous or thin film silicon.[1] Mono-crystalline silicon is made by drawing single crystals out of molten silicon. The intensive process makes mono-crystalline cells more expensive and energetically costly to make. Dutch researcher Alsema estimates the energy required to produce mono-crystalline silicon PV cells (frameless) to be 600 kWh/m^2.[4] The single crystal reduces interference from grain boundaries (boundaries between individual crystals), which can reduce efficiency. This makes mono-crystalline silicon more efficient at capturing solar energy than polycrystalline silicon.[1] At the average 12% operating efficiency, a mono-crystalline system would pay off the energy investment for its production in about four years.[4]



Mono-crystalline silicon PV cell

Poly-crystalline silicon, also termed polysilicon, is less efficient than mono-crystalline silicon, because of grain boundaries and imperfections inherent in its coarser manufacture process. Polysilicon can be made from raw silicon that is derived from refined sand.[2] The raw silicon is baked in bell-shaped ovens containing silane gas, which condenses over a period of days to form rods of over 99% pure silicon. Diamond-edged saws are used to slice the rods into wafers suitable for solar cell manufacture.[2] Alsema estimates the embodied

2

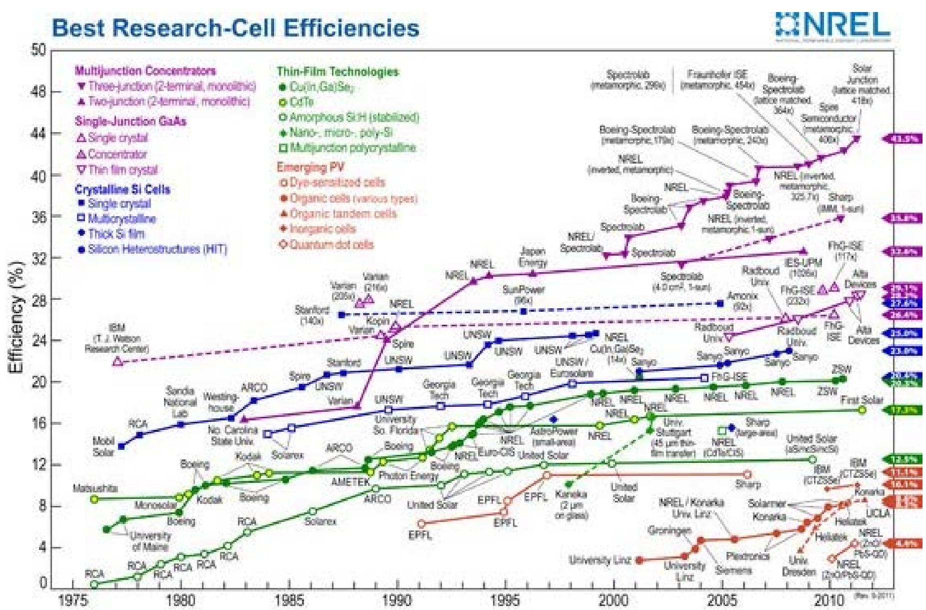


Polysilicon PV cell

energy of polysilicon cells to be 420 kWh/m . A poly-crystalline system could payback that energy investment in less than four years, especially as PV technology becomes more efficient and less expensive every year.[4] Despite its reduced efficiency due to crystal imperfections, polysilicon is one of the most widely-used PV material due to its economical production costs. In fact, polysilicon has become a little too economical: European subsidies drove up demand and therefore prices beginning in 2004, but increased production that came online in 2008 and the end of many subsidies led to a price crash in 2011.[2,3] Read more about the effects of the silicon glut under Solyndra's Rise and Fall.

Amorphous or thin-film silicon is the least theoretically efficient of the solar silicon states, made by depositing a thin layer of silicon onto a backing material. It is, however, the least energy-intensive to make, and therefore the least expensive silicon PV material. Alsema's estimate is 120 kWh/m^2 embodied energy. That energy can be paid back in about three years, at a standard operating efficiency of 6%.[4] Crystalline PV materials require particular angles of incident light to achieve maximum efficiency. Thin-film solar panels can capture even diffuse light, as on a cloudy day. Thus depending on local conditions, a thin-film roof panel might be just as efficient as a more-expensive crystalline system, although thin-film silicon is less efficient than crystalline silicon under ideal conditions.

The following graph from the National Renewable Energy Laboratory is a representation of efficiency developments in various PV materials, from 1975 through 2010:



See http://www.nrel.gov/ncpv/images/efficiency_chart.jpg for an enlargeable version.

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[4]"PV FAQs." *US DoE.* National Renewable Energy Laboratory.December 2004. Accessed 8 December 2011. http://www.nrel.gov/docs/fy05osti/37322.pdf

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images:

http://www.m0ukd.com/Solar_Panels/monocrystalline.jpg

http://4.bp.blogspot.com/_OM4A3aUcWIc/SdR3_RiIl4I/AAAAAAAAAFs/_NI1VShzjAE/s320/multicrystalline+pv+solar+cell.jpg

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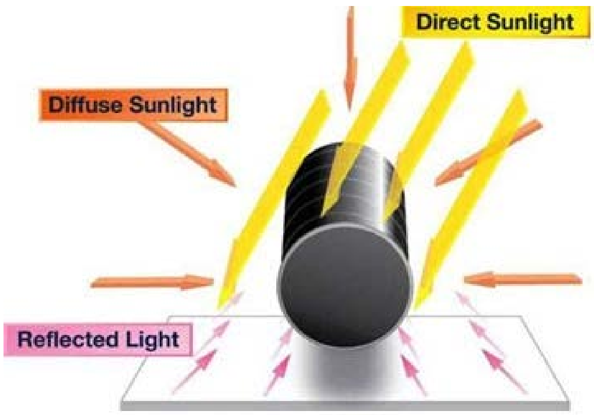
Solyndra's Rise and Fall

The company Solyndra began its short life in 2005 under the name Gronet Technologies, after its founder, Chris Gronet. Eight months later Gronet change the name to "Solyndra," a word that suggests not only the intended source of energy ("sol"), but also the company's technological design. Gronet had noticed that conventional solar panels had to be placed at careful angles to the sun and had to be spaced several feet apart on a rooftop in order to avoid shading. It occurred to him that a cylindrical design would eliminate both problems and use available space more efficiently.[1] The Solyndra team developed a cyllindrical solar module that can absorb sunlight from any angle without tracking devices, made of one glass tube nested inside another. Wrapped around the inner tube were 150 solar cells made from copper, indium, gallium and diselenide, rather than silicon.[1]



Solyndra's cylindrical design

The lightweight modules offered immediately apparent advantages. Installation was easy, and the cylinders did not require ballast to keep them in place because they did not catch any wind. Not using silicon was also an advantage. Increased European subsidies on renewable energy in 2004 lead to a boom in solar construction in Germany, Spain, and Japan.[2,3] Prices peaked at $400 /kg at the height of the Spanish polysilicon market. Higher production costs for competitors meant Solyndra had a good chance of success once production could be automated and expanded to a commercial scale.[1] To fund the construction the required fabrication plants, in 2006 the company applied for a federal loan guarantee through a DoE loan guarantee program that was instated with President G.W. Bush's 2005 Energy Policy Act. With President Obama's stimulus package in 2009, Solyndra was celebrated as the first company to receive a DoE loan guarantee with a $535 million inaugural loan.[5] Even that much funding did not cover so much as half the projected construction costs, however, and Solyndra expected to continue to lose money "for the forseeable future."[1] The company sought further loans from the government and from private investors, but it quickly became apparent that Solyndra was in trouble.

New polysilicon production capacity had come online in 2008, driving prices down. Lack of consumer confidence then led to the end of many subsidies in Europe, further reducing demand.[4] By Februrary 2011, the price had crashed to $52 /kg, and it has fluctuated in the $50-$100/kg range since then.[4] "Overall the industry anticipates further price declines," Martin Simonek, a New Energy Finance Analyst, told *Bloomberg.* "Producers are preparing for a painful consolidation that could see several players exit the solar industry."[4]

Low polysilicon prices were a boon to Solyndra's competitors. Heavy subsidies on mass solar manufacture in China further undercut the American company's prospects. Solyndra's small scale meant they produced solar power at a cost of $4 per watt, whereas competitors were producing at $1.25 per watt.[1] The federal government issued a warning that it would not disburse any more of the DoE loan unless Solyndra could line up additional financing. Private investors Argonaut Ventures and Madrone Partners agreed to provide an additional $75 million, with the possibility of another $75 million in the future, on the condition that the DoE loan be restructured so the private investors were guaranteed to have their $75 million returned first in the event of a failure.[1] By September 2011, Solyndra joined the ranks exiting the solar industry, defaulting on a final total of $528 million in taxpayer dollars.[1]

It is unlikely the federal government will ever get back the money it loaned to Solyndra. Does Solyndra's failure mean the government should cease funding solar ventures? The pages Anti-Solar Arguments and Reasons to Fund Solar examine some of the arguments on each side of this question.

Timeline

from Baker (2011):

2005

May: Company founded by Chris Gronet. Department of Energy loan program created.

2006

December: Solyndra submits pre-application for DOE loan.

2007

Company leases first factory, Fab1, in Fremont.

October: DOE invites Solyndra and 15 other companies to submit full applications.

2008

July: First commercial shipments of Solyndra's solar panels.

2009

March: DOE gives company conditional loan guarantee for $535 million.

September: Loan guarantee finalized, Fab2 construction begins.

December: Company files papers for initial public stock offering.

2010

March: PricewaterhouseCoopers auditors question company's financial outlook.

May: President Obama visits factory.

June: Solyndra cancels IPO.

November: Company closes original factory, Fab1, and lays off 40 full-time employees.

2011

January: Commercial production begins at Fab2.

February: DOE agrees to restructure loan, and private investors provide another $75 million.

June-July: Company tries to raise more funding, from outside investors as well as ongoing investors.

July: Solyndra CEO Brian Harrison tells members of Congress that company is "in no danger of failing."

August: Company and DOE negotiate over a second loan restructuring. DOE and investors discuss bridge financing. Investors purchase $3 million of Solyndra's inventory on Aug. 29. DOE tells the company on Aug. 30 that the restructuring and bridge financing wouldn't happen. Company closes factory on Aug. 31.

September: Company files for bankruptcy. FBI raids Solyndra office.

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Conclusion

We must continue to fund innovative energy ventures, including solar, if we hope to sustain our electricity-dependent society beyond the exhaustion of fossil fuel resources. We must pay attention to the success stories, like First Solar, and not wallow in despair over one company's misfortune. We must remind naysayers that bad politics does not equal bad technology, and that individual greed must not outweigh the pursuit of solutions to an energy crisis that is already quite personal to many global citizens. With enough government financial support at key points for developing business, we could see more successes like SolarCity, solar manufacturers joining the free market on strong footing without further need for government loans. The sun lavishes our planet with nearly infinite energy every day. Taxpayer investment now can speed the spread of PV as one reliable, affordable way to capture and use that energy before we have no other choice.

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How it Works

Figure 1:

Michael Faraday (1791-1867) **Figure 2: Faraday Flashlight**

In the 1830s, scientist Michael Faraday discovered that when a magnet passes through a coil of wires, it creates an electrical charge that can be stored in a capacitor or generator if the ends of the wire on either side of the coil are hooked up to that generator. This principle has been put into practice in both the Faraday (shake) flashlight (Figure 2) and the "point absorbers" or wave power buoys (Figure 3) that are shown below.

Faraday's motor is the main model for most modern motors today. There are two directions that energy can go. the first is like the flashlight and the wave power buoys producing energy by creating this magnetic field. The other way involves putting electricity through the coil, creating an electromagnet which then can propel an object that is connected to a magnet.

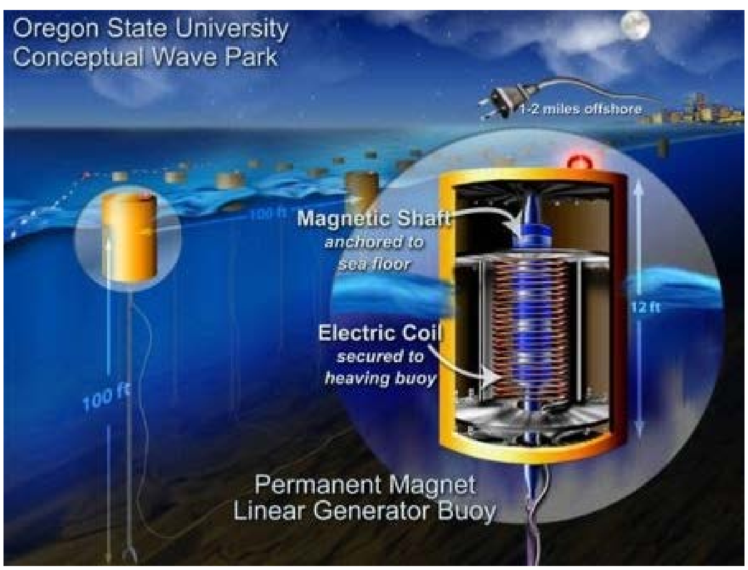
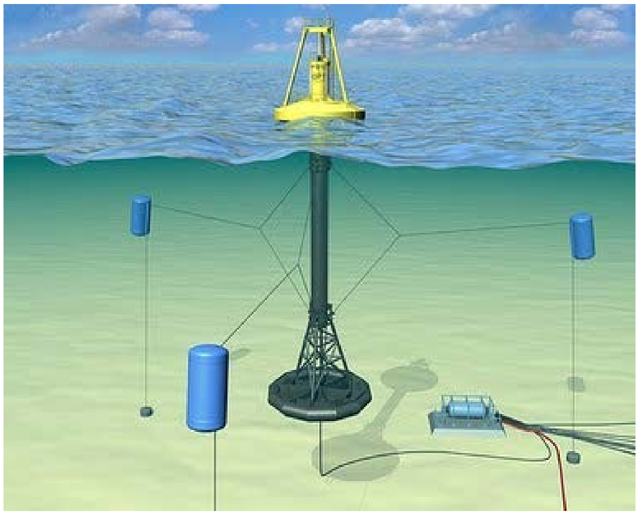


Figure 3: Internal mechanics of a PB 150 Buoy

The projects that are already underway vary considerably in size, output, and design. However, the basic design uses the same principles as the Faraday flashlight (Figure 2) that is powered by shaking it. The concept involves a coil of wires wound around the inside of a buoy. The more coils there are, the stronger the magnetic field. This means more power will be produced, but also that the buoy must be even bigger to hold this massive coil of metal at the water's surface. The buoy can be made of plastic or metal and has a hollow space filled with air, keeping it afloat. The coil is open in the center like a donut and there is a long shaft of magnet that is grounded on the ocean floor.

There are three ways of anchoring the buoy that have been used thus far. The first is to attach the base of the shaft to the ocean floor, such that the shaft will stay still as the vertical motion of the waves carry the coil up and down as it floats (as seen in figure 3). The second (and more practical to account for giant waves



or storms) is to have a second floating air chamber at the bottom of the buoy and allow for it to have just enough buoyancy to float in the water column and also be anchored to the sea floor by a chain such that it cannot move up or down, but is flexibility horizontally so that waves and weather cannot break it. This way, while the lower part of the buoy remains steady in the water column, the floating coil at the surface can still bob up and down with the waves. The third method is the most practical, because it accounts for tidal fluctuations as well as any

Figure 4: Underwater buoy system of the PB 150

other significant changes in the depth of the water. As shown in figure 4, the PB 150 buoy is anchored by three separate anchors that are also attached to buoys such that as the tide rises, the 90 degree angle of the anchor lines increases, drawing the blue buoys in toward the central buoy. This system allows for the buoy to move freely in any direction and yet still remain anchored.

Negatives

There are three significant downsides to wave energy. The first is transporting the acquired power first to land, and then dispersing it to wherever it needs to go. The process is expected to have a net energy loss of about 7%. Ideally, a trench could be dug along the ocean floor, and a power line could be laid down and buried in it. It would be relatively sound, but not easily accessible, especially for maintenance, which would probably be necessary because salt water can be highly corrosive. Once it gets to land, it must be dispersed via electrical lines just as electricity from coal power plants is done. However, this does exclude most inland areas and another power source would probably be more sensible to them. Fortunately though, sixty percent of the world's population currently lives within forty miles of an ocean, and that number is expected to go up to 75 percent by 2025. Forty miles is an easily accessible distance for power lines.

The second impediment is cost. Clearly it is no easy thing to construct a 114 foot buoy that weighs up to 50 tons, install it in one of the most dangerous and turbulent marine environments in the world, and then build the infrastructure and electrical lines to get that energy to where it needs to be. A lot of work must invested initially, but once the installation is complete, the system requires almost no energy or work input. It simply taps into some of the vast energy available in the ocean. Most of the funding thus far for these projects has been provided by grants from the government, energy boards, and other foundations, as well as private corporation such as Lockheed Martin. The cost of these projects has so far been anywhere from $650 to 20 million dollars each. The average thus far has been around 6-7 million though. These numbers are expected to go down however as this technology advances. There would also be a cost associated with maintenance, but as there are no precedents yet of how the buoy will fare, it is hard to estimate the need for maintenance. All we can say at this point is that maintenance and upkeep costs will be very minimal in comparison to initial costs. Similarly, the price estimates at which electricity can be sold has varied significantly. I have seen estimates anywhere of 2.5 cents per kilowatt hour, 4.5, 10, and 32. The truth is it is not known yet. Below is a table of energy costs from different fuel sources:

Energy Source	Gas	Coal	Nuclear	Wind	Geothermal	Hydropower	Solar	Tide	OTEC	Wave
Cents/kW-h	3.9-4.4	4.8-5.5	11.1-14.5	4-6	4.5-30	5.1-11.3	15-30	2-5	6-25	2.5-32

(Akau)

The third is an environmental concern. These buoys would be installed in areas where the water is most turbulent, in order to maximize the forces acting upon the buoy. These areas typically contain a unique ecosystem that thrives in that wild habitat. Because the buoys are absorbing energy, they are taking some of the energy out of the waves, thus decreasing the turbulence in the water and affecting the ecosystem. However, considering the massive power available in the oceans, 150 kilowatts is only a tiny fraction and barely noticeable. However, these buoys might also be creating stationary foundations on which ocean animals and plants may grow, affecting the ecosystem. (Langhamer)
An MMS file from 2006 lists some environmental concerns, most of which have turned out to be insignificant over the past few years of studying habitats around a buoy. (Murray) The list is as follows:

- Visual appearance
- surface and submerged noise
- Reduction in wave height
- Changes in sediment patterns
- effects on marine habitat (creation of a new habitat as mentioned above, as well as disruption of the original habitat during contruction and while digging the trench and laying the power line in it)
- Releases of toxins from hydraulic fluids into the water
- Ecosystem disturbances from mooring equipment and electrical cable placement
- Social impacts, such as infringing upon fishing, shipping, and recreation

There is also the issue that with any metal object in a corrosive environment such as these rough parts of the ocean, upkeep is difficult and finding material and technology strong enough to resist the corrosive nature of salt water and pounding surf is even more so. Rust can negatively impact the

environment as well as the functionality of the buoy.

Langhamer, Olivia, Dan Wilhelmsson, and Jens Engström. “Artificial reef effect and fouling impacts on offshore wave power foundations and buoys – a pilot study.” Estuarine, Coastal and Shelf Science 82.3 (2009) : 426-432.

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Thermodynamics

Work

Work goes is done initially in the form of construction, manual labor, installation, and setting up the wiring. work is also done on the electricity because it must be transported a long way, often 1-2 miles from the buoy to the coast, before it is even distributed into the grid. Work is force times distance, and it takes a great deal of force to transport, construct, and install a 50 ton buoy, 114 feet in length. However, once installed, all the work will be done by the waves acting upon the buoy and that work will be converted into power.

Power

The PB 150 is capable of converting the power of the waves into electricity. It can absorb power from waves 5 to 23 feet in height, and the bigger the better. As it pumps up and down, the magnet on the shaft sends electrons in one direction along the wires encircling the inner side of the buoy. These electrons are forced along the wire and down to the ocean floor where they are transported to land as electricity, and then dispersed via power lines.

Efficiency

The PB 150 Buoy produces anywhere from 45 kilowatts on a calm day at low tide to 400 kilowatts in a storm. These numbers average out to about 150 kilowatts. Therefore, we can call 400 kilowatts capacity for the PB 150 buoy and 150 the average, so we can calculate efficiency by dividing 150 by 400. This gives us 37.5% efficiency, or as the Ocean Power Technology website indicates, anywhere between 30% to 50% efficiency. Once the energy is generated as electricity, it travels through a powerline along the ocean floor all the way to shore, and then it is distrubuted into the grid. the power lines used in all of this are standard power lines, used everywhere in the US, and as such have a similar loss of energy to resistance. This is estimated to be between a 6% and 7% energy loss, depending on the voltage.

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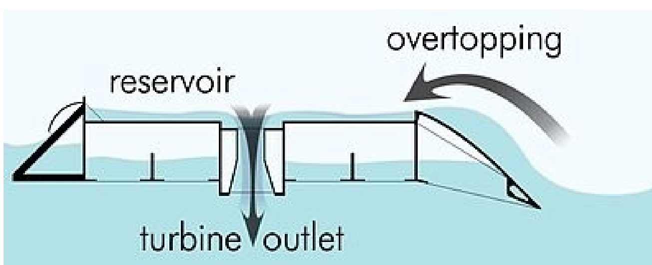
Other Wave Energy Models

Pelamis:

The Pelamis is a long floating buoy, about 142 meters in length and 3.5 meters in diameter. The motion of the waves drives hydraulic pumps which at full capacity can produce up to 750 kilowatts of electricity.

The particular model shown in the video to the left is one of three pelamis' aligned next to each other and located off the coast of Portugal. Combined they produce about 2.25 Megawatts of energy, and it is all supplied to the grid in Portugal.



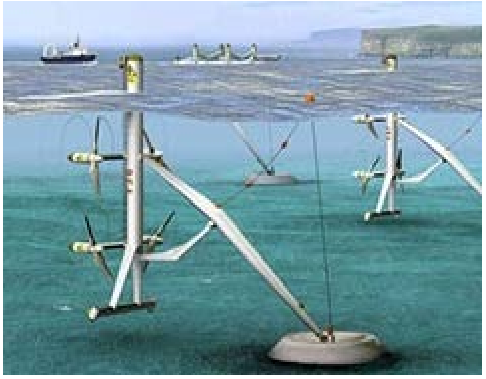
Wave dragon

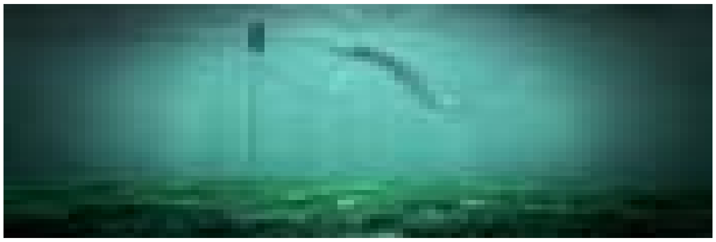
The wave dragon (to the left) is an over-topping device. Waves are carried up the ramp and water is deposited in the reservoir in the middle. After that it is just gravity that drains the water out of the reservoir through a hole in the middle and the flow of water runs a turbine. There are already two 30 meter long wave dragons in place off the coast of Denmark, and a 150 meter long unit with an output of 7 megawatts off the coast of Wales.

OCS (Oscillating-column system)

This system uses the concept of forcing air in and out of a balloon. The concrete structure shown to the left has a maleable and loose, but sturdy material on its far side. As huge waves pound the shore, the air is pushed out of the hollow concrete chamber, and forced through the green tunnel, turning a turbine and creating energy. Energy is also created as the air is pulled back into the chamber by the receding waves.

Wave energy is not hard to capture and there are countless other solutions, some better than others. Scientists, visionaries, and engineers have been developing countless potential alternatives, but we have yet to see which ones prevail. Below are some creative examples that may very well be the models of the future.





Morris, Craig. Energy Switch. Gabriola Island, Canada: New Society Publishers, 2006. 149-154. Print.

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The Oregon Coast Project

Ocean Power Technologies (OPT) has been building a wave farm off the coast of Reedsport, Oregon over the past several years. They applied for their permit in 2006, and it took several years to finally acquire one. OPT has installed several test buoys off the coasts of Scotland, Hawaii, and New Jersey, so they know that these PB 150s work. However, at this point, there are no wave farms large enough to feed into the US grid. While these buoys will not be the first wave power buoys in US waters, they will be the first created on a commercial scale.

The initial construction of this project began when OPT signed a contract with Oregon Iron Works in December 2009, hiring them to build the giant buoys. (Sickinger) Each buoy is about 114 feet long and weighing up to 50 tons. This is no small task, especially to construct 10 of them. The hardest part is the magnet. (Sickinger)

OPT has partnered with Lockheed Martin, a defense contractor who can offer assistance in manufacturing, design, and system integration into the grid. (Danko)

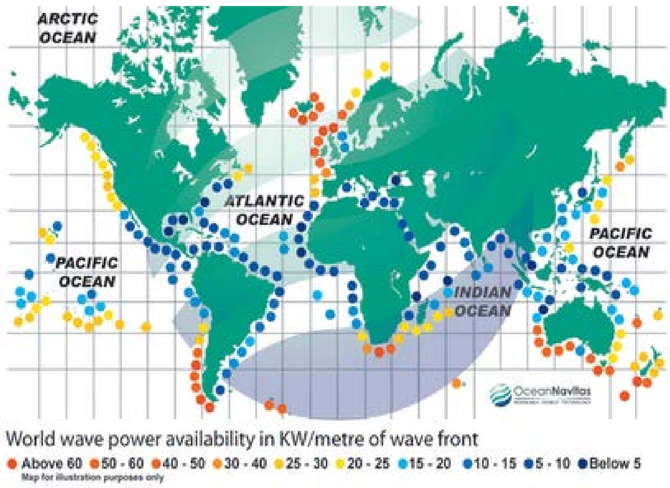
The first buoy was scheduled to go into operation a year ago, followed by the other nine by the end of 2012. While the first buoy is a little behind schedule and is still being tested in a controled environment, there is still hope that the farm could be fully operational by december 2012. (Danko)

The final product will provide jobs for about 150 Oregonians, mainly in the upkeep of the 10 buoys. (Sickinger) Combined, this wave farm is predicted to produce a total of 1.5 to 2.5 megawatts of power, enough to power 1500-2500 homes. (Danko)

Sickinger, Ted. "Oregon Iron Works will build first buoy for wave farm off Reedsport." Oregonlive.com . The Oregonian, 04 Dec 2009. Web. 16 Nov 2011. http://www.oregonlive.com/business/index.ssf/2009/12/oregonians_build_wave_energy_b.html.

Danko, Pete. "Oregon Wave Energy Effort Nets Lockheed Martin." Earth Techling. N.p., 16 Sep 2011. Web. 22 Oct 2011. http://www.earthtechling.com/2011/09/oregon-wave-energy-effort-nets-lockheed-martin/.

Locations



The Oregon buoys will be anchored 2 ½ miles off the coast, but distances vary in order to find optimal conditions. Different locations around the globe have higher energy potential than others as is shown in the map to the left. This is largely dependent on how much open ocean is available for waves to build before they reach the coast unbuffered. The best places thus far are the coasts of Australia, southern Africa, South America, Northern Canada, Scotland, and the Pacific Northwest of the US. (DeFreitas) These areas are ideal because there are long expanses of open ocean available for powerful waves to build up before they break on the coast. These areas also have strong prevailing westerly winds that contribute to the wild waves. (Murray)

Locations for wave farms are different from wind farms. While wind turbines are put in locations that will have a steady medium range of wind, wave farm locations are chosen because they have the most violent weather and rough seas. These aspects are not crucial to the production of energy, but they will produce *more* energy. The trick is engineering a system that can withstand such rough seas (see How it Works).

In the last month, two international energy corporations, Fortum and DCNS have agreed to collaborate on a wave energy project in France. Fortum is already involved in two wave power projects in Sweden and Portugal. (Planchais) Also, Tangaroa Energy/the Langlee Wave Power project has just received a grant of $312,000 to construct a 20 kilowatt buoy off the coast of New Zealand, making Stewart Island considerably less dependent on the expensive and inefficient energy that is transported to the island via an underwater cable. (Fensome) As can be seen on the map above, these are all excellent areas with prime wave power availability.

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Wave Energy >

Politics

The biggest problem that wave power projects are facing is increased government procedures. Since 2006, when ocean power was becoming a new and upcoming energy source, the government, both Federal and local, have put road blocks up everywhere, rather than embracing this new environmentally friendly energy source.

The Bureau Of Energy Management was created as well as the Bureau of Safety and Environmental Enforcement. When a group wants to build a wave energy farm, they must first acquire permits from these two organizations and a lease from the BOEM. Then there is the Federal Energy Regulatory Commission that is in charge of overseeing wave energy projects. One must get a Commercial lease from them before starting construction, but they stipulate that first, a company must get a lease from the Minerals Management Service. The MMS has jurisdiction over all Federal waters that are up to 3 miles off shore, and much of that is habitat sanctuaries, for which they will give no lease. (Banse)

Consequently, the FERC canceled all its permit applications for building in Federal waters, leaving only state-owned waters left. There is already a clash between overlapping state and Federal jurisdiction of offshore property, and it can be a nightmare for developers to try to construct a wave farm in these areas. (Murray)

In 2008, the city of San Francisco started a study to look into wave energy feasibility off its coast. The entire area was claimed as a habitat sanctuary, except for a small zone 7 kilometers off shore, where San Francisco's waste was deposited. Looking into this zone, it provided the perfect location to develop a 30 megawatt wave farm, that would power 10% of San Francisco's houses. However, when they began the application process for a permit from FERC, they quickly found themselves caught in a petty quarrel between the FERC and the MMS for who had control of the outer continental shelf. The application was promptly denied, not because it was a bad plan, but because the two organizations refused to allow each other control over the designated area. (Murray)

Between 2006 and 2009, there were 21 projects proposed. By 2009, only 13 of those remained on the list as still potential, and only 3 had received a preliminary permit or license. (Banse)

If wave energy is going to work, the government needs to make it easier for projects to be permitted.

State or Federal Jurisdiction?

In 2008, the state of Oregon and the FERC went to court to settle the dispute of who has jurisdiction over waters off the Oregon Coast. The ultimate conclusion was that Oregon has jurisdiction, but applicants must still get their permit through FERC. Consequently, the two entities must work together in as time efficient a manner as is possible. Fortunately, the Memorandum of Understanding that came out of this, states that both parties are mutually interested in the timely processing of applications, because both parties are interested in seeing Ocean Energy instated in Oregon. As a good first step, the memorandum has made it significantly easier for wave power projects to get licenses to install short-term experimental and pilot projects in order to study the location and the environmental effects of a buoy on the designated area. This memorandum is one of the first steps taken toward making wave power development easier and smoother. (Memorandum) The tables below shows some of what a wave power project applicant must go through to be allowed to build a wave farm.

Authorization	Primary Legal Authority	Lead Agency	Participating Agencies	Anticipated Process Time
Preliminary Permit	Federal Power Act, EPAct 2005	FERC	Relevant federal and state agencies	At least 60 days
Federal Hydroelectric License	Federal Power Act, EPAct 2005	FERC	Relevant federal and state agencies	3+ years
ACOE §404 Permit	Clean Water Act	ACOE	EPA, USFWS, NMFS	60-120 days, more if need EIS[14]
ACOE § 10 Permit	Rivers & Harbors Act	ACOE	USFWS, NMFS	60-120 days, more if need EIS[14]
Private Aids to Navigation Permit	Coast Guard Regulations	USCG	ACOE, state resource agencies	Average 3 months
Coastal Zone Consistency Certification[15]	§307 CZMA, Ocean Resources Management Act	OR DLCD	ODFW, DSL, DEQ, WRD, OPRD	45-90 days, or up to six months
§401 Water Quality Certification[15]	§401 Clean Water Act	OR DEQ	WRD, ODFW	1 yr[16]

To acquire a Federal permit (Hampton)

Authorization	Primary Legal Authority	Lead Agency	Participating Agencies	Anticipated Process Time
State Hydroelectric License	ORS 543, Hydroelectric Projects	WRD	ODFW, DLCD, OPRD	At least 8 months
Ocean Energy Facility Lease	OAR 141-140	DSL	ODFW, ODOJ	6 months
Temporary Use Permit	OAR 141-140	DSL	ODFW, ODOJ	6 months
Removal-Fill Permit	ORS 196.795-990	DSL	ODFW	90-120 days
Ocean Shore Alteration Permit	ORS 390, OAR 736-020	OPRD	All affected federal, state & local agencies	At least 60, up to 105 days
Coastal Zone Consistency Certification	§307 CZMA, Ocean Resources Management Act	OR DLCD	ODFW, DSL, DEQ, WRD, OPRD	45-90 days, or up to six months
§401 Water Quality Certification	§401 Clean Water Act	OR DEQ	WRD, ODFW	1 yr[4]

To acquire a State permit (Hampton)

The Memorandum also reminds wave power projects that they need to get around several other Federal laws, including the Coastal Zone Management Act, the Clean Water Act, the National Historic Preservation Act, and the Federal Power Act, the Energy Policy Act, the Endangered Species Act, the Marine Mammal Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act, as well as countless others. Most of these are Federal laws, so the interesting part of the Memorandum is that it surrenders enforcement of these acts over to the state of Oregon. This could be a good or a bad thing, depending on the leniency of the State compared to the Federal Government. The State would probably be more capable of ignoring or bypassing these laws because they would not have to be as concerned about setting national precedents. However, They would also probably be more concerned with the state of their local environment than the Federal government would be.

Solutions

Perhaps an alternative arrangement can be reached. As can be seen above, most of the hurdles have to do with environmental protection. The state government, in whose hands Oregon ocean power technology now lies, must be convinced that these buoys are not only environmentally harmless, but also beneficial to the environment, as they would be replacing coal energy and decreasing harmful carbon emissions. If this could be proven, then perhaps the state of Oregon would only need to push one project through all of these barriers rather than every project that applies. Perhaps they could even just develop an exedited permitting process, making it easier and quicker for these projects to get licensed. After all, wave energy fulfills what these laws demand at a basic level. An expedited permitting process does not even need to involve going clear around these barriers, it could just mean making it quicker and easier to pass the standards required of these projects. Wave energy is what Oregon needs most to become environmentally clean, and it is ironic that it is environmental protection laws that are getting in the way of clean energy.

Whose permission do we need?

Another problem that slows down the application process is how many governmental agencies there are and how little they work together. The whole process could be sped up significantly if these parties met and organized a single application process that would satisfy all of their needs. Instead, there is the redundency of applying to meet the same requirement again and again for each consecutive agency. Our government needs to take wave energy seriously enough to gather representatives from each concerned party and ask them what their agency would demand of a wave energy company. That way a single application could be streamlined such that it could take years off of the current tedious application process.

Local Concerns

There are also concerns from local coastal towns, because while the buoys may be invisible and unimposing, the power must get to the coast, and once it does, it must be distributed out from that point in the form of power lines that go in every direction. There is the initial few years of construction of it all that will be unpleasant and ugly for a small coastal town. Then once it is all set up and working, there is routine maintenance that will be in and out of the town frequently. While this provides these towns with jobs and business, many small communities would fervently oppose such industry disturbing their peace.

The harbor in Reedsport

Many of these small towns have fishing as a key industry. These wave farms will be marked off by barriers that do not allow fishing, because fishing lines may get tangled in the equipment. Clearly fishermen would not take kindly to this, especially when the zone that is blocked off is a part of their fishing area, as it most likely would be. Most buoys are anchored between 60 to 600 feet, and the best fishing holes, the places where the fish can be found, tend to be between depths of 50 to 300 feet. on the local level fishermen seem to be the main party that opposes wave farm development. (Aanestad)

There is also the general fear, wariness, and hatred of large corporations or industrial giants. Many of the applicants applying for permits to build wave farms are these such corporations, like PG&E, Chevron, and Lockheed Martin. (Aanestad) Maybe we are right or maybe we are wrong to fear such powerful corporations, but we need to look at what they are doing for the environment, and for us. Renewable energy still has only one foot in the door and we need to do all we can to help it, rather than giving it one more obstacle to hurdle.

Government Assistance

While there is ample government assistance available for land-based renewable energy, the government has not put much toward wave energy yet. There are a large amount of government subisidies available for wind, solar, and hydropower, as well as government funded incentives for utilities to purchase their power from renewable sources.

In the late 1970's, the OTEC system was invented as the first potentially feasible ocean power technology. It stands for Ocean Thermal Energy Converter, and it takes advantage of the difference in temperature between the warmer water at the surface and the colder water at the bottom of the ocean. It was a genius model, and the US government stepped forward immediately to offer their assistance. They passed the OTEC Act that made NOAA in charge of overseeing the projects and also made it so that OTEC projects did not have to obtain a lease, or pay royalties to the US government for using the zone. This is the kind of government assistance we need now to help our modern wave technology along. Unforntunately OTEC technology was not efficient enough to make a profit, and it went out of business, collapsing the OTEC Act. (Murray) Wave energy however, is proven to be efficient enough, and could do with the booste.

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Electricity Fuel Resources

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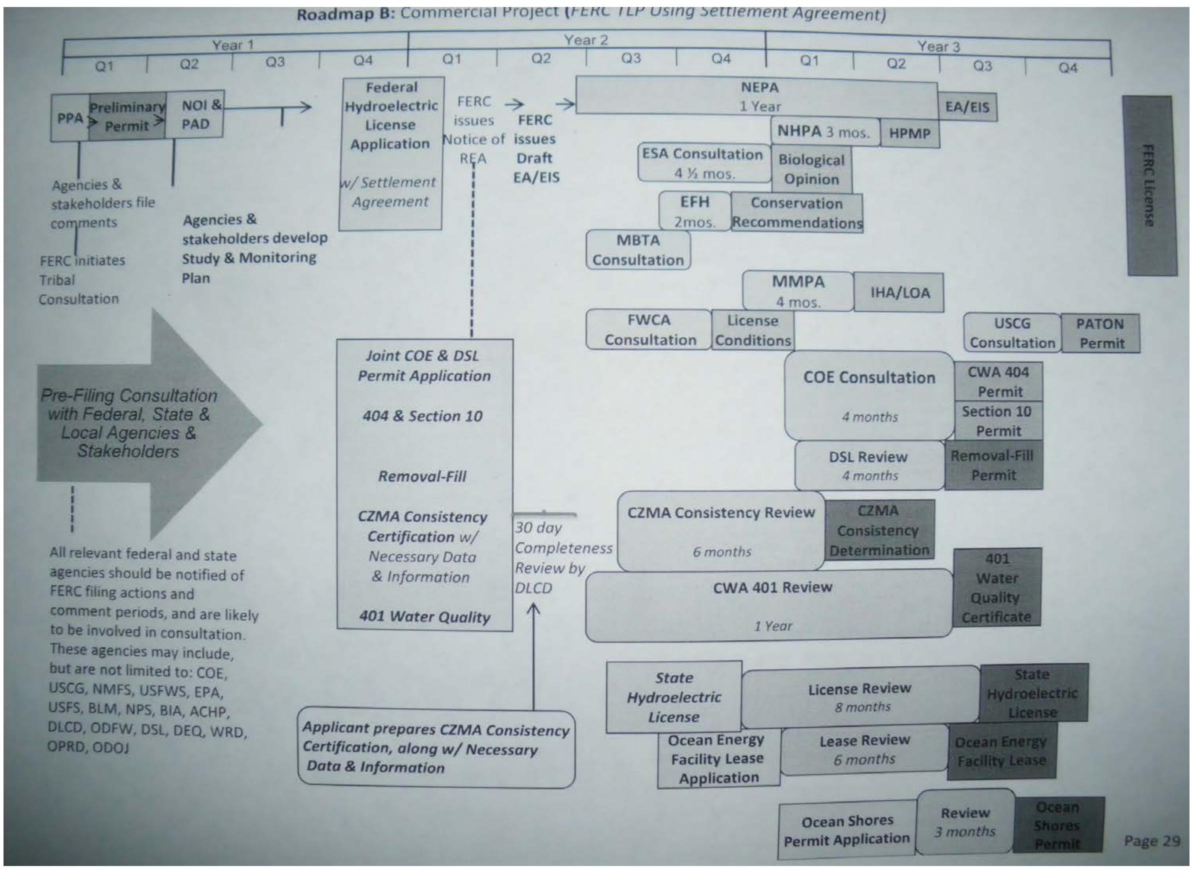
Conclusion

Wave Energy is clearly a growing industry, although just emerging. It is clean, renewable and environmentally friendly. Wave energy absorbers are capable of absorbing much more energy than solar or wind power per square foot, and they do so with considerably less cost to the environment. With today's technologies, we are capable of harnessing 140 to 750 Terawatt hours of Electricity per year from the oceans and this estimate is just what is economically feasible and profitable. Every year new technology is developed, and new models are emerging everywhere. With 75% of the world population projected to live within 40 miles of the coast by 2025, the ocean is the most feasible and accessible energy source we have.

There are only a few things blocking wave energy from thriving, the most threatening of which is a spiderweb of laws and government organizations that are in place to regulate wave energy projects. Most of them are environmental laws, some involve cultural or historical preservation, and some involve energy regulation. However, when an energy company wants to start a renewable energy project, a plan such as the one below is an immediate deterrent.



(Hampton)

What's more, this is only what the company would have to go through to get a permit to build a commercial wave farm, let alone get the permit for the pilot project, find the funding, and begin the actual project. Following this plan has no guarantee that a company will get their license, as a matter of fact, they are far more likely to have it denied at some point through this roadmap of applications. It is no wonder so many projects have failed.

What the government needs to do is create an expedited shortcut for Wave Energy, because at this stage, we cannot afford to put so many barriers up in front of wave energy and risk its collapse. Wave energy *can* compete in the global energy market but we need to help it become strong enough to do so.

I propose that a similar act to the OTEC Act of 1980 be reinstated, but this time for wave energy. If this were to happen, it would not be like the OTEC Act, where no full scale products ever came of it. There are already 20-30 projects proposed, and drudging through this painstaking process just to acquire a permit. If we expedited this system for them, wave energy could thrive and we would soon see wave farms all down the West Coast, flooding the power grid with clean, cheap, renewable energy.

Hampton, Therese. Oregon. Oregon Wave Energy Trust. Wave Energy Development in Oregon. Pacific Energy Ventures, Web. http://www.oregonwave.org/wp-content/uploads/Licensing-and-Permitting-Study.pdf.

Sitemap

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