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by

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Abstract

For decades people have been looking for a source of clean renewable energy to sustain mankind throughout future generations without further harm to the environment. Until recently the idea had not been widely accepted and was considered a costly, infeasible solution. This study reflects the advancements technology, infrastructure, and economic situation of the world to determine the true feasibility of solar technology in the present day.

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Work Breakdown

Jaime MacFall wrote the section entitled "Current Development on WPI's Campus," the conclusion, the abstract and also the associated Appendix 3. Eric Gauvin worked on the "History of Energy" section as well as the introduction and acknowledgments. Shane Slocum worked on the sections between Photovoltaic Energy and Centralized Collection of Solar Energy and the associated Appendix 1. Stefano DiFiore worked on the Economics section and the associated Appendix 2.

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Introduction

When the majority of people think of solar energy, they think of the sun and its conversion to electric energy but there is much more to solar energy. On earth it provides energy for everything thing that we do and allows life to exist. The sun not only provides light for photosynthesis but it provides us heat. It was through the sun and photosynthesis that we have the fossil fuels that are our common energy source today. If the sun provides most of our energy why don't we use it as a more direct source?

The sun is the ultimate energy source in our solar system much like a power plant provides electricity to your house. We have not always had the ability to flip a light switch and have a light bulb turn on. It was through invention, failures and progress that we have the technology that we use today. For solar energy to be used more effectively the same type of process must occur with it. The only difference is the energy is already here we just need to know how to harness it and use it efficiently.

Worcester Polytechnic Institute (WPI) is a community of students and professors that are known as innovators, scholars, leaders and teachers, yet WPI has only one solar array on campus. Why isn't there one on every roof? The goal of this paper is to research solar energy use at WPI and in the New England region. We will provide you with a background in energy history as well as solar technology. Economics on a global level as well as a feasibility study of solar energy at WPI will be provided. The sun has potential to provide WPI and human kind with vast amounts of energy; society has to invest itself, mentally and economically to achieve the goal of attaining energy from its most abundant source.

History of Energy

Since the beginning of human existence a basic need for energy has been present and throughout time humans have found many ways to produce it. Primitive methods such as the burning of wood for heat and cooking, up to the splitting of atoms to get energy at it rawest form are still used to this day. Understanding the history of energy will help human kind develop a plan for the future that can keep society progressing with technology while also producing energy in a manner that is healthy and beneficial to both humans and the earth. This section will show that the progression of energy from pre-industrial revolution to industrial revolution into the 20th and 21st century, by showing these different stages of energies we will get an understanding of human needs as well as where we can use past sources more efficiently with modern technology.

Initially humans' sources of energy were from themselves and the sun. The sun was their only source of heat until the domestication of fire occurred between 1.8 million and 1 million years ago.[1] While it is debated how humans first discovered fire it is known that they used it for heat, cooking and lighting. With fire early humans could move to colder climates and even survive through ice ages. The early fuels for fire were trees and other indigenous plants that were capable of burning. Thus combustion as a source of energy has been around for over a million years. "Besides using wood and their own muscles, people took advantage of the energy that the sun, wind, running water, hot springs and even animals could provide; to do work, to travel, and for recreation."[2]

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[1] United Nations Educational, Scientific and Cultural Organization (UNESCO)

[2] Nemzer, Marilyn L, Deborah S. Page and Anna K. Carter. Energy for keeps : electricity from renewable energy : an illustrated guide for everyone who uses electricity. Tiburon CA, Energy Education Group, 2005

The earliest known evidence of the use of wind energy would be the depiction of a sailboat on an Egyptian vase dated about 3500 BC.[3] The first verified seaworthy vessels came from the Mediterranean region around 1000 BC. Due to the use of wind power Mediterranean culture spread faster than most societies. The Greeks and Romans could travel faster and used the boats for trade with other cultures. This is an early example that shows controlling energy provides both power and influence over other cultures. These influences can be cultural and economical. The Chinese first then the Europeans used large sailing vessels to explore the world and make contact with other cultures. Zheng He, of China, had a fleet of 300 ships including 62 large treasure ships in which he completed 7 voyages, from 1405 to 1433, that were commissioned by the Ming dynasty.[4] In these ships China established a worldly presence, imposed imperial control over trade, and impressed foreign peoples in what is now know as the Indian Ocean basin. Colonization of the "New World" by Europeans is another example of energy control and ownership providing power to governments. The Age of Sail ran from approximately 1571-1863 AD in which advances in seafaring and navigational charts allowed for the beginning of a global economy that centered on trade but relied on the wind for energy.

> Since ancient times, man has harnessed the power of the wind to provide motive power for transportation. Likewise, the technique of grinding grain between stones to produce flour is similarly ancient, and widespread. Quite where and when these two came together in the first windmill is unknown, but a likely scenario suggests a Persian origin, from where (tradition has it) the knowledge spread back into Northern Europe as a result of the Crusades. However, since the Persian mills were quite unlike the early European

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[3] Casson, Lionel. Ships and Seamanship in the Ancient World. Princeton, NJ, Princeton Univ Pr, May 1971

[4] Viviano, Frank (2005). "China's Great Armada". National Geographic, 208(1):28–53, July.

designs it seems just as likely that the adaptation of wind as a power source was independently discovered in Europe, albeit at a later date.[5]

Wind was not the first source of energy for grinding grain either; animals as well as water wheels were used before hand. Water wheels in ancient Rome and ancient China found many practical uses in powering mills for pounding grain and mining projects. Due to a shortage of labor the water wheel went into broad use during the Middle Ages. Water as the lifting force, allowed ships to carry much heavier weights than would be possible on land going vessels.

During these times while exploring other fuel sources the sun had not been forgotten. Maintaining a society dependent on labor and trade required innovative thinkers as well as an abundance of resources. A society noted for some of the world's greatest thinkers had solutions for this problem long before any modern energy crisis.

> During the fifth century BC., the Greeks faced severe fuel shortages. Fortunately, an alternative source of energy was available - the sun. Archaeological evidence shows that a standard house plan evolved during the fifth century so that every house, whether rural or urban, could make maximum use of the sun's warm rays during winter. Those living in ancient Greece confirm what archaeologists have found. Aristotle noted, builders made sure to shelter the north side of the house to keep out the cold winter winds. And Socrates, who lived in a solar-heated house, observed, "In houses that look toward the south, the sun penetrates the portico in winter" which keeps the house heated in winter. The great playwright Aeschylus went so far as to assert that only primitives and

[5] Berry, Mark. History of Windmills. 24 Feb 2004 <http://www.windmillworld.com/windmills/history.htm>

barbarians "lacked knowledge of houses turned to face the winter sun, dwelling beneath the ground like swarming ants in sunless caves."[6]

The Romans improved the designs with use of glass and mica windows on south facing winter rooms to help keep heat in. Europeans as well as Romans would use drapes and canvas to cover the windows at night in a form of insulation to keep heat in. The natives of the American continents also built their homes with the sun in mind. They would build on top of plates and would build so that every home could have winter sun.

The natives and non native settlers of New England used a lot of the energy sources mentioned above. With the abundant forests that New England offered wood was the primary source of heat during the harsh winter months. Cooking was also done of wood stoves and in wood heated ovens. The settlers of New England would soon learn to harness the power of the rivers in the region as well because of techniques they had brought over with them from Europe.

The idea that the native culture was one of harmony with the environment is a misconception because the Europeans did not arrive on touched lands.[7] The impact of the human population on the local ecosystems was small and consistent yet existed. This impact rate accelerated upon the arrival of Europeans. To accommodate the greater crop and livestock stores for commerce and safety against harsh winters, the Europeans cleared a large percentage of the local forest and domesticated animals became more of a burden on the local ecosystems. The burning of wood is commonly accepted to be carbon neutral in modern times due to the fact that burning wood releases the same amount of CO_2 as the wood rotting would so human actions of

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[6] Perlin, John SOLAR EVOLUTION: *The History of Solar Energy*. 2005, California Solar Center, <http://www.californiasolarcenter.org/history_passive.html>

[7] Cronon, William. Changes in the Land: Indians, Colonists, and the Ecology of New England. 1st Edition. Canada, Harper Collins Canada Ltd, 1983

this time period would have played a minimal role in global warming.[8] Documented wars have happened over territory and trade rights dating back to the Egyptians, Greeks and Romans and it can be assumed that tribal feuds happened long before that. The fuel crises of these times spawned innovation and began a cycle of humans looking for an easier and more effective way to produce energy and survive. The shortages of wood as a fuel during this time led Europeans to look for another source and they found it in coal. Coal burned hotter than wood and helped jump start the industrial revolution in England.

The common name of the era "industrial revolution" is misleading to many, considering the fact that it was not an overnight change in the way people live nor did it happen at the same time for all countries. The western world was well rooted in its agriculture and trade based society and would trade their harvest for textiles from India. The first in Europe to begin down the road of major industry was the United Kingdom; the cause of this was the lack of wood remaining on the Island but their abundance of coal would soon supplant wood in heating and soon be used in many other applications. Textile as an industry can be considered the first major industry to push the United Kingdom away from a poor farm based society. Britain would soon take over the trade of textiles from India. "From the 1820s British machine-spun yarn began to be exported to the subcontinent itself, commencing the deindustrialization of nineteenth-century India. And from mid-century, the cotton cloth of Lancashire began to be imported in enormous quantities to the home of cotton, the Indian subcontinent."[9]

The passage from an agrarian system to that of an industrial system occurred due to increasing populations and their lack of ability to use the solar radiation reaching the earth to its

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[8] Wood Burning and the Environment. http://www.canren.gc.ca/prod_serv/index.asp?CaId=103&PgId=586 Canadian Renewable Energy Network. September 2002

[9] Parthasarathi, Prasannan. From Cotton to Coal. Boston College, Research Paper May 2006

full potential. Due to increasing populations in the United Kingdom and Germany the forests were depleted to provide fuel and materials for expansion of farm lands. That population growth remained a background yet important reason for the switch to fossil fuels. Fossil fuels allowed for the middle class or merchant class to expand in society, the middle working class could produce and sell goods or work for another that was producing goods and still provide what at the time would be considered a comfortable life. Working the coal mines can be considered one of the worst jobs of the day for ones health. In the late 1600s coal was a more popular fuel source than wood in England. Yet the British had flooding problem in their coal mines due to ground water coming through the rocks. In 1698 Thomas Savery invented a steam engine that was soon attached to water pumps that helped and virtually solved the flooding problem.[10]

The new steam engines of the early 1700s required larger amounts of coal to heat water for steam, so the coal-mining industry was a prosperous business. New industrial centers soon were attracting traditional farmers away from their life long jobs to work in factories and mines, places where people endured hardship for the promise of personal progress. Populations increased rapidly in areas where there was employment.

In 1709, Abraham Darby set up a coke-fired blast furnace to produce cast iron. Coke's superior crushing strength allowed blast furnaces to become taller and larger. The ensuing availability of inexpensive iron was one of the factors leading to the increasing number and qualities of steam engines and other machines of the time. By the late 1700s and early 1800s steam engines were powerful enough to enter the transportation industry and would allow people to more easily and with more reliability than wind power.

[10] Nemzer, Marilyn L, Deborah S. Page and Anna K. Carter. Energy for keeps : electricity from enewable energy : an illustrated guide for everyone who uses electricity. Tiburon CA, Energy Education Group, 2005

The sterling engine was an alternate idea developed around the same time that the steam engine was becoming widely popular and was widely over looked until recent times. One style of sterling engine and most common is the alpha style in which one cylinder is hot and one cylinder is cold. The cylinders are connected by a passage, whose opening may or may not be blocked by one of the pistons. The passage may contain a regenerator, a material through which gas must flow if it passes from one to the other cylinder. This material can absorb heat from and return it to the working gas to increase the efficiency of the engine. A sterling engine could use the heat from the sun to expand and contract air to move an engine without using any fuel. If the Sun's energy was concentrated enough the engine could be quite useful and powerful. Figure 1 shows a sterling engine cycle.

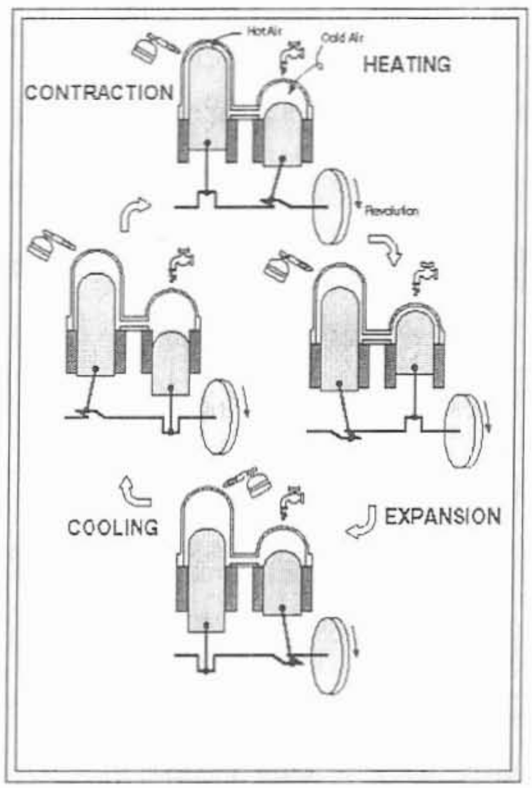

Figure 1

Steam power was useful but not easily adaptable for household uses in mass quantity. Electricity was a potential replacement. Early electrical research dated back to the 1550's with

Italian physician Girolamo Cardano distinguishing, perhaps for the first time, between electrical and magnetic forces. In 1600 the English scientist William Gilbert, in De Magnete, expanded on Cardano's work and coined the New Latin word electricus from elektron, the Greek word for "amber". The first usage of the word electricity is ascribed to Sir Thomas Browne in his 1646 work, Pseudodoxia Epidemica. In 1660 by Otto von Guericke invented an early electrostatic generator. Stephen Gray classified materials as conductors and insulators in 1729.

The Leyden jar, a type of capacitor for electrical energy in large quantities, was invented at Leiden University by Pieter van Musschenbroek in 1745. William Watson, experimenting with the Leyden jar, discovered in 1747 that a discharge of static electricity was equivalent to an electric current.[11]

Benjamin Franklin promoted his investigations of electricity and theories through the famous, though extremely dangerous, experiment of flying a kite during a thunderstorm. Following these experiments he invented a lightning rod and established the link between lightning and electricity. Franklin's observations aided later scientists such as Michael Faraday, Luigi Galvani, Alessandro Volta, André-Marie Ampère, and Georg Simon Ohm whose work provided the basis for modern electrical technology. The work of Faraday, Volta, Ampere, and Ohm is honored by society, in that fundamental units of electrical measurement are named after them.[12]

Volta discovered that chemical reactions could be used to create positively charged anodes and negatively charged cathodes. When a conductor was attached between these, the

[11] Whittaker E T. *A History of the Theories of Aether and Electricity* vol 1 1951 (London: Nelson)

[12] Nemzer, Marilyn L, Deborah S. Page and Anna K. Carter. Energy for keeps : electricity from renewable energy : an illustrated guide for everyone who uses electricity. Tiburon CA, Energy Education Group, 2005

difference in the electrical potential (also known as voltage) drove a current between them through the conductor. The potential difference between two points is measured in units of volts in recognition of Volta's work. In the 1800s Volta constructed the first wett cell battery and possibly the first device to produce electric current.[13]

By the end of the 19th century electrical engineers had become a distinct profession, separate from physicists and inventors. They created companies that investigated, developed and perfected the techniques of electricity transmission, and gained support from governments all over the world for starting the first worldwide electrical telecommunication network, the telegraph network. Pioneers in this field included Werner von Siemens, founder of Siemens AG in 1847, and John Pender, founder of Cable & Wireless.

In the 1830's it was discovered that electricity and magnetism could be converted into one another. These principles led to the invention of the dynamo generator which was the first generator capable of powering industry. The dynamo uses electromagnetic principles to convert mechanical rotation into an alternating electric current. A dynamo machine consists of a stationary structure which generates a strong magnetic field, and a set of rotating windings which turn within that field. On small machines the magnetic field may be provided by a permanent magnet; larger machines have the magnetic field created by electromagnets.[14]

The late 19th and early 20th century produced such giants of electrical engineering as Nikola Tesla, inventor of the polyphase induction motor; Samuel Morse, inventor of a long-range telegraph; Antonio Meucci, an inventor of the telephone; Thomas Edison, inventor of the

[13] Nemzer, Marilyn L, Deborah S. Page and Anna K. Carter. Energy for keeps : electricity from renewable energy : an illustrated guide for everyone who uses electricity. Tiburon CA, Energy Education Group, 2005

[14] Nemzer, Marilyn L, Deborah S. Page and Anna K. Carter. Energy for keeps : electricity from renewable energy : an illustrated guide for everyone who uses electricity. Tiburon CA, Energy Education Group, 2005

first commercial electrical energy distribution network; George Westinghouse, inventor of the electric locomotive; Charles Steinmetz, theoretician of alternating current; Alexander Graham Bell, another inventor of the telephone and founder of a successful telephone business.

The rapid advance of electrical technology in the latter 19th and early 20th centuries led to commercial rivalries, such as the so-called War of the Currents between Edison's direct-current system and Westinghouse's alternating-current method. Westinghouse's system became the system of choice due to its ability to be transported over a much longer distance than direct current. Industries could now be placed in areas that before hand were found not suitable due to a location not on a water way.

The modern history of petroleum began in 1846 with the discovery of the process of refining kerosene (used for lighting) from coal and the first modern oil well was drilled in 1848 by Russian engineer on the Apsheron Peninsula. Ignacy Łukasiewicz discovered a means of refining kerosene from the more readily available petroleum in 1852 and the first rock oil mine was built in southern Poland in the following year. These discoveries rapidly spread around the world, and Meerzoeff built the first Russian refinery in the mature oil fields at Baku in 1861.[15]

The United States history of oil begins in 1859 with Edwin Drake drilling the first well in the US. In 1860 gasoline was refined from oil and used in an early internal combustion engine.[16] An Engine of this kind would lead the way to easier transportation for humans through motorized bicycles and automobiles. The first automobile was made by Karl Benz in 1885 and

[15] Petroleum. The Encyclopedia Britannica 11th Edition. 1910-1911

[16] Nemzer, Marilyn L, Deborah S. Page and Anna K. Carter. Energy for keeps : electricity from renewable energy : an illustrated guide for everyone who uses electricity. Tiburon CA, Energy Education Group, 2005

helped change the way people traveled.[17] By the late 1890s mass production of automobiles had begun in Europe and the United States. While oil and gasoline were becoming more popular coal soon took over the seas and steam powered ships became the fastest ships on the water.

Even while these commonly know and used technologies were growing in popularity the study of solar had begun to be studied as well. The first solar steam engines used mirrors to direct solar heat towards water to bring it to a boil in the 1860s. The first design by Auguste Mouchout could produce a half horse power of energy and thus had less power than the gasoline engines being invented around the same time. Mouchout's initial experiments involved a glass-enclosed iron cauldron: incoming solar radiation passed through the glass cover, and the trapped rays transmitted heat to the water. While this simple arrangement boiled water, it was of little practical value because the quantities and pressures of steam it produced were minimal. Mouchout discovered that by adding a reflector to concentrate additional radiation onto the cauldron, he could generate more steam. In late 1865, he succeeded in using his apparatus to operate a small, conventional steam engine.

Napoleon III offered financial assistance for developing an industrial solar motor for France, this is an early example of a country looking economically assitating technology that could give the nation an advantage over its rivals. Mouchout also constructed a tracking mechanism that enabled the entire machine to follow the sun's altitude and azimuth, providing uninterrupted solar reception. After about 900 observations the government deemed the device a technical success but a practical failure. France had recently improved its system for transporting coal and developed a better relationship with England who provided the coal for much of Europe. The price of coal had dropped making alternative energy sources a lower priority.[18]

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[17] Setright, L. J. K. *Drive On!: A Social History of the Motor Car*. Granta Books 2004

[18] History of Solar. <http://southface.org/solar/solar-roadmap/solar_how-to/history-of-solar.htm> Southface

William Adams thought it impractical to construct a larger version of this to create more than a half horse power. Adams was convinced that a reflector of flat silvered mirrors arranged in a semicircle would be cheaper to construct and easier to maintain. In 1878 Adams constructed his design by gradually adding 17-by-10-inch flat mirrors and measuring the rising temperatures, he calculated that to generate the 1,200û F necessary to produce steam pressures high enough to operate conventional engines, the reflector would require 72 mirrors. To demonstrate the power of the concentrated radiation, Adams placed a piece of wood in the focus of the mirrored panes where, he noted, "it ignited immediately." He then arranged the collectors around a boiler and connected it to a 2.5-horsepower steam engine that operated during daylight hours.[19]

This design known as the Power Tower concept is used in most modern tower-type solar plants. They follow Adams's basic configuration: flat or slightly curved mirrors that remain stationary or travel on a semicircular track and either reflect light upward to a boiler in a receiver tower or downward to a boiler at ground level, thereby generating steam to drive an accompanying heat engine.[2021]

In 1885 Charles Tellier installed a solar collector on his roof similar to the flat-plate collectors placed atop many homes today for heating domestic water.[22] The collector was composed of ten plates, each consisting of two iron sheets riveted together to form a watertight seal, and connected by tubes to form a single unit. Instead of filling the plates with water to produce steam, Tellier chose ammonia as a working fluid because of its significantly lower boiling point. After solar exposure, the containers emitted enough pressurized ammonia gas to

[19] Kryza, F. The Power of Light : The Epic Story of Man's Quest to Harness the Sun. McGraw-Hill; 1 edition (February 13, 2003)

[20] National Solar Thermal Test Facility <http://www.sandia.gov/Renewable_Energy/solarthermal/nsttf.html>

[21] Kryza, F. The Power of Light : The Epic Story of Man's Quest to Harness the Sun. McGraw-Hill; 1 edition (February 13, 2003)

[22] FlaSolar. http://www.flasolar.com/active_dhw_flat_plate.htm

power a water pump he had placed in his well at the rate of some 300 gallons per hour during daylight.[23]

John Ericsson's work was inspired by a fear shared by virtually all of his fellow solar inventors that coal supplies would someday end, similar to today's fear that oil supplies will soon be depleated. By 1870 Ericsson had developed a solar-powered steam engine that greatly resembled Mouchout's devices, employing a conical, dish-shaped reflector that concentrated solar radiation onto a boiler and a tracking mechanism that kept the reflector directed toward the sun.[24]

Ericsson invented a method for collecting solar rays known as the the parabolic trough. A parabolic trough focuses solar rays in a line across the open side of the reflector. This type of reflector offered many advantages over its circular (dish-shaped) counterparts: it was comparatively simple, less expensive to construct, and, unlike a circular reflector, had only to track the sun in a single direction (up and down, if lying horizontal, or east to west if standing on end), eliminating the need for complex tracking machinery. The downside was that the device's temperatures and efficiencies were not as high as with a dish-shaped reflector, since the configuration spread radiation over a wider area, a line rather than a point. Still, when Ericsson constructed a single linear boiler (essentially a pipe), placed it in the focus of the trough, positioned the new arrangement toward the sun, and connected it to a conventional steam engine, he claimed the machine ran successfully, though he declined to provide power ratings.[25]

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[23] Kryza, F. The Power of Light : The Epic Story of Man's Quest to Harness the Sun. McGraw-Hill; 1 edition (February 13, 2003)

[24] Kryza, F. The Power of Light : The Epic Story of Man's Quest to Harness the Sun. McGraw-Hill; 1 edition (February 13, 2003)

[25] Kryza, F. The Power of Light : The Epic Story of Man's Quest to Harness the Sun. McGraw-Hill; 1 edition February 13, 2003)

Aubrey Eneas began his solar motor experimentation in 1892, formed the first solar power company (The Solar Motor Co.) in 1900, and continued his work until 1905. Eneas tried a couple approaches but decide to focus on Mouchouts's idea of a cone shaped reflector, this approach resulted in higher temperatures, but Eneas was still unhappy with the machine's performance. His idea was to make the bottom of the reflector's truncated cone-shaped dish larger by designing its sides to be more upright to focus radiation onto a boiler that was 50 percent larger. Its reflector contained 1,788 individual mirrors and its boiler held 100 gallons of water. After exposure to the sun, Eneas's device boiled the water and transferred steam through a flexible pipe to an engine that pumped 1,400 gallons of water per minute from a well.[26]

Henry E. Willsie believed that a nonreflective, lower-temperature collection system similar to Tellier's invention was the best method for directly utilizing solar heat. The inventor also felt that a solar motor would never be practical unless it could operate around the clock. Thus thermal storage was the focus of his experimentation. To store the sun's energy, Willsie built large flat-plate collectors that heated hundreds of gallons of water, which he kept warm all night in a huge insulated basin. He then submerged a series of tubes, or vaporizing pipes, inside the basin to serve as boilers. When the sulfur dioxide passed through the pipes, it transformed into a high-pressure vapor, which passed to the engine, operated it, and exhausted into a condensing tube, where it cooled, returned to a liquid state, and was reused.[27]

Willsie created the first solar device that could operate at night using the heat gathered during the day. Beside offering a way to provide continuous solar power production, Willsie also furnished detailed cost comparisons to justify his efforts: the solar plant exacted a two-year

[26]Looking Back. Popular Science. 1934
<http://www.popsci.com/popsci/lookingback/60333b034ac84010vgnvcm1000004eecbccdrcrd.html>

[27] Kryza, F. The Power of Light : The Epic Story of Man's Quest to Harness the Sun. McGraw-Hill; 1 edition (February 13, 2003)

payback period, he claimed, an exceptional value even when compared with today's standards for alternative energy technology.[28] Refer to appendix A1 Table 5: Return on Investment Per Technology Page 99.

Frank Shuman, a solar engineer of the early 20^{th} century decided improvement needed to be made in heat conservation. In 1910 Shuman improved the collector's insulation properties by enclosing the absorption plates with dual panes separated by a one-inch air space similar to modern windows. He also replaced the boiler pipes with a thin, flat metal container similar to Tellier's original greenhouse design. The apparatus could now consistently boil water rather than ether. Unfortunately, however, the pressure was still insufficient to drive industrial-size steam engines, which were designed to operate under pressures produced by hotter-burning coal or wood.[29]

Shuman decided he would have to redesign the engine to operate at lower pressures. He enlisted the help of E.P. Haines, an engineer who suggested that more precise milling, closer tolerances in the moving components, and lighter-weight materials would do the trick. Haines was right. When the reworked engine was connected to the solar collectors, it developed 33 horsepower and drove a water pump that gushed 3,000 gallons per minute onto the Talcony soil. Shuman calculated that the Talcony plant cost $200 per horsepower compared with the $80 of a conventionally operated coal system considering that the additional investment would be recouped in a few years because the fuel was free he believed it to be a wise investment. Like other inventors before him he believed this machine to be perfect for the African region.

Shortly after testing in Africa was completed Archduke Ferdinand was assassinated in the Balkans, Starting World War I. The fighting quickly spread to the upper regions of Africa and

[28] Kryza, F. The Power of Light : The Epic Story of Man's Quest to Harness the Sun. McGraw-Hill; 1 edition (February 13, 2003)

[29] Klemm, F. History of Western Technology. MIT Press 1964

the solar irrigation plant was destroyed and the engineers returned to their respective countries work on war related technology. This shows how a governments focus can also affect the advancements of technology.

After the war these solar technologies were not focused on or revisited for many years due to the great advancements in gasoline generator technology that had occurred during the war. A question that can not easily be answered is whether or not solar energy technology would be further along had the war not happened? We believe it would be due to the fact that investors were showing great interest in the free energy that the sun had to offer. Next we will take a lot into the region where WPI is situated to see how energy has been used during the industrial revolution.

"The Blackstone River Valley of Massachusetts and Rhode Island is the 'Birthplace of the American Industrial Revolution,' the place where America made the transformation from Farm to Factory."[30] Pawtucket, Rhode Island on the Blackstone River was the place where the first large textile Mill in America was built. The Blackstone river was the source of water power. Samuel Slater was hired to help with the project; he had spent seven years working in a textile mill in England. Because of the availability of job in the region investors were eager to build mills as well as communities. Homes, schools and churches were built for the workers of the mills. The next problem to conquer was transportation and a group of business men set out to build a canal from Worcester to Providence.

The Blackstone Canal began construction in 1825 and was completed in 1828. The canal provided transportation to the ocean for the regions abundant industry and allowed Worcester to grow into a major manufacturing city in the United States. The canal was faster than roads as

[30] Birth Place of the American Industrial Revolution. <http://www.nps.gov/archive/blac/discover/history.htm> Blackstone River Valley National Heritage Corridor Commission

well cheaper. The canal and next the Railroad allowed the industrial revolution to develop rapidly throughout the Blackstone Valley and New England. The Boston to Worcester and Providence and Worcester Railroad allowed for faster transportation of goods and are actually still in use today. Rail service allowed the conversion of the textile mills of the valley from waterpower to steam power due to the availability to move away from the rivers and still have power and transportation. It should also be noted that due to the explosion of Industry in the Worcester area Worcester Polytechnic Institute was established to teach and train the workers of the region in the techniques needed for manufacturing.

The sad truth of the advancement of the area was the neglect of the industries to take care of the resources they were using. The rivers were abused both by being polluted and by being changed to meet the needs of the factories. Rivers were rerouted and dammed to meet the needs of production with no consideration to the wild life that were killed and affected by such changes. The pollution in the river has been recounted in many stories told be the regions population that was around in the early 20^{th} century. It has been stated that you would know the color of cloth that was being produced in the mills based on the color of the river down stream. About 140 years after start of the industrial revolution in the area the Blackstone river is just becoming clean enough to fish in again and is becoming a part of the landscape that can be appreciated by the regions inhabitants.

The Early 20^{th} century was a time of change in the United States with the ability to transport electricity over large distances power plants were beginning to dot the landscape and provide power to both industrial endeavors but to house holds as well. Early electric companies were somewhat inefficient and redundant in the services they provided. Separate companies provided electricity for different needs such as street illumination, industrial power, residential lighting, and street car service. They frequently operated under nonexclusive franchises, often in competition with one another. Companies used different equipment, voltages, and frequencies, so their systems were not compatible. In order to operate, the companies had to acquire franchise rights from the local municipality similar to the way cable companies need to negotiate franchises in Massachusetts. The franchise process although great for competition slowed progress and ingenuity.[31]

Regulations were soon adopted to help fix costs and lower the price of electricity for consumers. As the structure of the electric industry evolved, electric utilities began to assume certain common characteristics. These include: Assignment of Franchise or Service Territory. A franchise allows an electric utility to serve customers within a designated geographic area, known as its service territory, for a specific period of time; In return for its franchise, an electric utility is required to serve all existing and future customers equally and at reasonable cost; A single company providing electric service is more economically efficient because it eliminated duplication of service and equipment.

Due to some deregulation of the electric system electricity retailers now provide fixed prices for electricity to their customers and manage the risk involved in purchasing electricity from spot markets or electricity pools. Customers can now choose from a number of competing suppliers. They may also opt to pay more for "green" power, which includes, but not limited to, photovoltaic. Refer to section on Technology on page 27 for more details.

During the early 20th century energy was produced primarily from fossil fuels. Fossil fuels are used in steam power plants, the combustion of such heats water to create steam, which

[31] Hirsh, R. Technology and Transformation in the American Electric Utility Industry. Cambridge University Press; New Ed edition (April 24, 2002)

turns a turbine, which, in turn, generates electricity, waste heat, and pollution. There are three main types of fossil fuels: coal, petroleum, and natural gas.[32]

Because it is based on the simple process of combustion, the burning of fossil fuels can generate large amounts of electricity with a small amount of fuel. Gas-fired power plants are more efficient than coal fired power plants. Fossil fuels such as coal are readily available and are currently plentiful. Excluding external costs, coal is less expensive than most other sources of energy because there are large deposits of coal in the world. The technology already exists for the use of fossil fuels, though oil and natural gas are approaching peak production and will require a transition to other fuels and/or other measures. Commonly used fossil fuels in liquid form such as light crude oil, gasoline, and liquefied propane gas are easy to distribute.

The cons of fossil fuels include, the fact that the combustion of fossil fuels leads to the release of pollution into the atmosphere. The means of getting the fuel out of the ground tend to lead to changes in the landscape and potential pollution of the drilling or mining area.

Nuclear power stations work similar to fossil fuel power plants, except for the fact that the heat is produced by the reaction of uranium inside a nuclear reactor. The reactor uses uranium rods, the atoms of which are split in the process of fission, releasing a large amount of energy. The process continues as a chain reaction with other nuclei takes place. The heat released heats water to create steam, which spins a turbine, producing electricity.

The cost of making nuclear power, with current legislation, is about the same as making coal power, which is considered very inexpensive. Nuclear power does not produce any air pollution or release carbon dioxide and sulfur dioxide into the atmosphere. Therefore, it does not contribute to global climate change or acid rain although waste produced from nuclear fission of

[32] Warkentin-Glenn, Denise. Electric Power Industry in Nontechnical Language. PennWell Corp.; 2 edition (March 5, 2006)

uranium is both poisonous and highly radioactive, requiring maintenance and monitoring at the storage sites. Moreover, the long-term disposal of the long-lived nuclear waste causes serious problems, since it takes from one to three thousand years for the spent fuel to come back to the natural radioactivity of the uranium ore body that was mined to produce it.

In large part due to the availability of these other technologies solar energy research was limited until a fuel shortage became more than just a potential problem. The 1973 oil crisis began in earnest on October 17, 1973, when the members of Organization of Arab Petroleum Exporting Countries (OAPEC, consisting of the Arab members of OPEC plus Egypt and Syria) announced, as a result of the ongoing Yom Kippur War, that they would no longer ship petroleum to nations that had supported Israel in its conflict with Syria and Egypt (i.e., to the United States and its allies in Western Europe). Since oil demand falls little with price rises, prices had to rise dramatically to reduce demand to the new, lower, level of supply. Anticipating this, the market price for oil immediately rose substantially. The crisis was further exacerbated by government price controls in the United States, which limited the price of "old oil" (that already discovered) while allowing newly discovered oil to be sold at a higher price, resulting in a withdrawal of old oil from the market and artificial scarcity. The rule had been intended to promote oil exploration. This scarcity was dealt with by rationing of gasoline (which occurred in many countries), with motorists facing long lines at gas stations.

In the U.S., drivers of vehicles with license plates having an odd number as the last digit were allowed to purchase gasoline for their cars only on odd-numbered days of the month, while drivers of vehicles with even-numbered license plates were allowed to purchase fuel only on even-numbered days. Although the energy crisis made it economically hard for the population of the United States it also promoted the conservation of energy and helped plant the seeds for the need to study other sources of energy.

The energy crisis led to greater interest in renewable energy, especially wood fuel and spurred research in solar power and wind power. Solar power in the later half of the 20^{th} century and the early 21^{st} century is starting to become a realistic alternative to fossil fuels and economically it is becoming more affordable for house hold use. The technology section of this paper will discuss the numerous options available today.

The environmental consequences of human's energy use in the 20^{th} century are just starting to be understood. The object of this paper is not to debate the cause of the current climate change the earth is going through but it is known that the levels of carbon dioxide and water vapor have increased and it can be attributed to human production. If it could be proven that this is not the cause of the climate change it would still make sense to look for sustainable energy that in the long run will cost consumers considerably less money.

History is taught so that we have an understanding of actions and their consequences, to help humankind avoid past mistakes and to understand from which we came. Learning the history of our energy use will do much more than that though it shows us what we have done to our environment around us and allows us to set goals for what humans want in the future. With coming availability of many solar technologies we have a wide range of choice to make and directions we can head in.

Technology

History of Photovoltaic Technology

In 1839, the photovoltaic effect was first discovered by a French physicist by the name of Alexandre Edmond Becquerel. In 1873, Willoughby Smith discovered photo electric effects in selenium. Three years later, William G. Adams and his student R. E. Day discovered that a junction of two metals can exhibit a photovoltaic effect. This research was the foundation for the first selenium solar cell construction in 1877.

In 1904, Albert Einstein developed theories explaining the photovoltaic effect, which would lead him to his Nobel Prize in 1921. By the 1950s, many PV cell technologies had been developed employing several different compounds and materials. In the mid 50s, the maximum efficiency solar cell technology had risen to about 6 percent with commercial solar cells having efficiencies of merely 2 percent. Later in the decade the efficiency continued to rise and the cells were researched for implementation into both satellite design and prototype automobiles.

It took until the 1970s for the technology to reach a point of widespread consideration into large scale implementation such as in villages and isolated broadcasting stations. In the 1980s, solar power plants began to emerge around the globe. At this point the efficiency of PV cells had risen to 20 percent.[33]

Today, many technologies have breached the 20 percent efficiency mark but still have many limitations. There is usually a tradeoff between the efficiency of conversion from light energy to electrical energy, and maximizing the amount of light captured by the device. For example, dye-sensitized photovoltaic cells have a conversion efficiency of more than 80 percent. Unfortunately, the compounds used in these cells have a tendency to reflect a large portion of the

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[33] History of Photovoltaics, March 29, 2007, pvresources.com, April 26, 2007, <http://www.pvresources.com/en/history.php>

sun's energy which limits the overall efficiency of the cell to around 30 percent. Cells with these efficiencies are not commercially available at this point in time.

Along with the utilization of energy grid storage it is possible for the majority of homeowners to utilize photovoltaic modules to lessen energy costs. Even a single photovoltaic module can reduce energy costs. Deciding which technologies are a viable choice and provide a good return on investment is important and will be investigated in the following sections.

Theory of Photovoltaic Operation

The photovoltaic (PV) effect denotes the physical phenomenon allowing light-electricity conversion. What this means for the consumer is that a photovoltaic device will convert light energy into electrical energy. This light can come from many sources, the most affordable option being the sun, and can be used to power anything from a calculator to an international space station. Although the physics governing the operation of photovoltaic cells can be complicated, the basic theory can be explained rather simply.

A photovoltaic device is often called a photovoltaic cell. When a photon, or "packet" of light, hits a solar cell, an electron in the material is separated from its atom. This electron is now able to move about the material. Due to the properties of the material, the electrons collect on one surface of the solar cell. This imbalance of electrons creates a difference in potential energy between the two surfaces of the cell. Whenever there is a difference in electric potential, or voltage, across an object, there is the opportunity to use the electric energy stored in the object.

The amount of electrical energy collected from a light source depends on many factors, such as how much light energy hits the PV cell, which types of light the cell is most sensitive to, how much of that light is absorbed, and how well the material converts the light to electricity.

The amount of light energy hitting the PV cell is dependent on the light source as well as anything that may hinder the transmission of the light from the source to the cell. In the case of the sun, some hindrances could be atmospheric gases, clouds, obstructions, and even the glass and plastics used to encase the PV cell.

The physical characteristics of the light also have a large effect on how much electrical energy is produced. Certain colors of light will produce more energy than others. Which colors of light will work the best is largely dependent on the design of the PV cell.

Once the light comes in contact with the PV cell, a portion of the light may be reflected away. Only absorbed energy can be converted into electrical energy. Most cells use anti-reflective coatings to counter this effect. The color of the materials used to make the cells also play a large role in how much of the energy is absorbed.

After the light is absorbed by the material, some of the energy is lost to heat. The cell technology as well as the quality of materials plays the largest part in keeping the conversion efficiency high.

There are several prominent technologies that allow for the conversion of light energy to electrical energy. Each technology has its advantages as well as its disadvantages. The availability of each type of technology differs greatly. Some types of cells are still in early phases of research and development, while others have been on the market for many years.

The Electromagnetic Spectrum

The color of the sky is more important than meets the eye. The blue sky shows that the atmosphere affects various colors of light very differently. The sun's light contains infrared light, visible light, and ultra violet light.

Infrared light, which has the longest wavelength and lowest amount of energy, is able to penetrate the atmosphere easily. Therefore, direct sunlight contains a large amount of infrared light.

Ultraviolet light, having the shortest wavelength and highest amount of energy, does not penetrate through the atmosphere as well. The light gets absorbed and redirected by the gases and particles in the atmosphere. This means that the UV light that makes it to the ground is only a small portion of what was it was before it entered the atmosphere.

The visible portion of the light spectrum contains the colors of light we can see. On the low end near infrared, is red light, and close to ultraviolet at the top, is blue light. Like infrared light, red light travels through the atmosphere easily and is strongest in direct sunlight. Blue light, much like ultra violet, gets absorbed and scattered by the atmosphere and has the appearance of coming from all around. This makes the sky appear to be blue.

Different types of PV cells absorb different portions of the light spectrum. Most technologies are more sensitive to the red portion of the spectrum. This is a good trait for cells that are used in direct sunlight, but for areas having obstructed light and overcast skies, sensitivity to blue light is more desirable.

Importance of Efficiency

Sunlight is free, but collecting the energy from the sunlight is not. The term externality describes the non-monetary costs or benefits received by external parties from an external transaction. Externalities can include costs such as air pollution or contaminated run-off, as well as benefits like new inventions and by-products that can be used in the production of other goods. The externalities involved in the production of solar cells, along with the direct costs make the efficiency of solar cells very important. More efficient cells will keep the number of cells per application low, and in turn, lower the externalities involved in the manufacturing of a given technology. Another important aspect of the collection of solar energy is physical space. This is also a cost that can be minimized with high efficiency cells.

Due to the small amount of direct sunlight in some areas, as well as the fact that most locations only receive light for a portion of the day, makes the efficiency of solar collection very important. When all factors are considered, the poor efficiency of a solar cell can eliminate solar power, in some situations, as a viable option. This could be due to roof space limitations as well as the cost of the number of cells required to produce the desired amount of power. Weather can also play a large role in the cost analysis of solar collection. Regions that have a higher percentage of overcast or cloudy days would need a more efficient cell to be a feasible choice. The ratio of physical, external and monetary cost to the amount of power produced by a solar panel is the deciding factor in most applications. Different PV technologies will exhibit different ratios.

How Green is a Solar Panel?

One of the biggest lures of solar energy aside from the monetary benefits is the benefit to the environment. During operation, solar panels do not produce any harmful emissions or pollution. However, in the manufacturing process, the energy and materials used can produce greenhouse gases.

Fossil fuels can emit greenhouse gases in quantities of over 200 g/kWh with the help of pollution limiting techniques. Nuclear power plants typically produce numbers in the range of 25 - 30 g/kWh. The manufacturing of cells using common solar technologies also shows numbers in the 25 – 30 g/kWh range. Wind energy is the cleanest energy producer with only 10 – 15 g/kWh.[34]

These numbers show that solar panels can produce as much as 8 times the energy of fossil fuels while producing the same amount of greenhouse gases. This doesn't, however, take into account the recycling of the panels after they have reached the end of their usable life. One of the biggest problems with nuclear power is the recycling of the nuclear waste. Some types of solar panels are almost as problematic. Cadmium telluride solar cells contain the toxic material cadmium. Great care must be put into the disposal and recycling of these cells. Some types of cells have been made out of organic materials or polymers that are very easy to recycle.

When discussing green energy, the pollution generated from the production of solar panels should be an important topic. Although solar energy is one of the greenest ways to produce energy, it still has an impact on the environment.

Wafer-Based Photovoltaic Cells

Overview

Wafer-based photovoltaic technology refers mainly to three different types of silicon PV cells. These cells use silicon crystals to employ the photovoltaic effect. There are three configurations of silicon crystal technology that are currently available on the market.

Single-crystal solar cells are made from wafers of pure, mono-crystalline silicon. These cells are the most efficient wafer-based PV cell, but also the most expensive. They are most sensitive to infrared light and thus are most useful in direct sunlight. Because infrared light is

[34] Photovoltaics Energy Payback Times, Greenhouse Gas Emissions and External Costs: 2004 – early 2005 Status, Published online in Wiley InterScience, 2006, pv.bnl.gov, April 26, 2007, <http://www.pv.bnl.gov/abs_199.pdf>

relatively low in energy, the cells do not take full advantage of the light coming in contact with them, and therefore could be more efficient.

Polycrystalline PV cells are made from carefully formed sheets of silicon that are cut into wafers. They consist of many different sections of crystalline silicon which are all fused together as one piece. These cells are significantly cheaper to produce than mono-crystalline cells, but also lose efficiency in the boundaries between different sections of crystal.

Cells made from ribbon silicon are less efficient than polycrystalline cells but save on production costs using more efficient manufacturing methods. There is less wasted silicon and no need to cut the material into wafers in this process.

Benchmarks

In order to determine if this technology is a practical option for collecting solar energy, the current status of the technology and the products encompassed must be determined. Characteristics such as efficiency, cost, and aesthetics can all be important depending on the application.

The efficiency of polycrystalline cells can be as high as 20 percent, but commercially available modules are only around 12.5 percent efficient. BP Solar produces a cell that is 12.5 percent efficient at a cost of $750 per panel.[35] Based on a 12,000 kWh usage scheme, for a 4 person household[36] with a common amount of roof space[37], these panels would only yield 77 percent of the total 12,000 kWh requirement. This is based on a system using 45 panels, the maximum number of panels for a common 4 person household with an ideal roof exposure.

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[35] BP Solar 125 watt Soalr Panel BP 3125S, wholesalesolar.com, April 26, 2007, <http://www.wholesalesolar.com/products.folder/module-folder/bp/bp3125-SIN.html>

[36] Energy Consumption and Expenditures RECS 2001, November 18, 2004, eia.doe.gov, April 26, 2007, <http://www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html>

[37] 45 sq. m. of roof space with proper sun exposure. Based on common 4 bedroom houses in the NE region.

Disregarding installation costs as well as other equipment such as power inverters and meters, a system using 45 panels would cost approximately $33,750. This system would only save approximately $1,155 per year in electricity bills; therefore, the return on investment for this system would be 29.2 years. The installation costs and accessories can as much as double the total cost in some situations.

Since most solar panels do not last more than 20 years at best, a 29.2 year return on investment would not be economically practical. A homeowner may disregard the economic impracticality of this type of system and argue that the cost of this green energy is worth the money because of the pollution it prevents. Although the production of these PV cells produces its own pollution, these numbers, as previously shown, are as little as a sixteenth of some of the alternatives.

A disadvantage to using solar panels is the aesthetic aspect. Many people find solar panels to be very unattractive and a poor addition to the roof of their house. Wafer-based are generally packaged in boxy rectangular enclosures.

Single-crystal cells, although more efficient, are much more expensive and less aesthetically pleasing. If cost and aesthetics are not a concern, mono-crystalline panels can often fill the entire electricity need, but with an even longer return on investment.

These cells, both single and multi-crystal, tend to be fragile. The cells are composed of wafer-thin semiconductors encased in glass. The amount of damage they can withstand is also quite low. If a panel cracks, it is likely that the whole module will need to be replaced. Some other technologies can withstand many punctures and tears without many ill effects.

Conclusion

Wafer-based PV cells need to progress further in order to meet the needs of consumers in field use. Though some cells have impact resistant enclosures, the durability of the cells could also stand to be improved. If commercially available cell efficiencies reach the 15 – 20 percent range, and reduced costs lower the return on investment to a reasonable level, it is likely wafer-based cells will become a common sight.

Thin-film Photovoltaic Cells

Overview

Photovoltaic cells can also be made from different thin-film materials. Some of the advantages in using thin-film cells are the ability to use multi-layered cell construction as well as reduce the amount of light absorbing material required to produce each cell. Some thin-film cells have the disadvantage of reduced conversion efficiency over those made from bulk materials. Thin-film PV cells can be made out of many different materials, but most of these cells can be split up into two categories.

Single-layered thin-film cells are typically less efficient than their wafer-based counterpart. They are, however, less expensive to produce and can be made in a flexible format. The cells are so flexible that the PV material can be purchased in rolls or even PV shingle cells. The PV shingles are very durable and can be installed on a roof with nails and simple wiring. Thin-film technology is typically more sensitive to shorter wavelengths of light which means it performs better in overcast condition than other types of cells. However, it will not produce as much electricity in direct sunlight as the other cells.

Some thin-film cells use multi-layer construction, which allows for greater efficiencies. The cells can be built with different layers designed to absorb different colors of light. For instance, the top layer may absorb more blue light, while the bottom layer might absorb more red light. This will allow the cell to be very efficient in both direct sunlight and overcast conditions. This type of cell construction allows for conversion efficiencies higher than that of wafer based cells.

Benchmarks

Again, the current status of the technology and the products must be determined in order to see if this technology is a practical option for collecting solar energy.

The efficiency of multi-layered thin-film cells is typically lower than that of wafer-based cells. Many panels that are commercially available exhibit efficiencies of about six to seven percent. Uni-Solar manufactures a panel that is 6.4 percent efficient at a cost of $323 per panel.[38] Based on the same 4 person household with a 12,000 kWh usage scheme as the last example, a 45 panel system would provide just fewer than 40 percent of the total yearly electrical usage.

Again disregarding the cost of installation and accessories, the cost of the panels alone would be about $14,500 with a yearly savings of $590. The return on investment for this system would be a bit lower than the previous example. It would take 24.6 years for the savings to pay for the cost of the system.

Although these panels are not guaranteed to last any longer than 20 years, they are expected to have a slightly longer life than the fragile wafer-based panels. The durability of most thin-film panels is very good. Some manufacturers claim their products are virtually

[38] Uni-Solar US-64 64 Watt Thin Film Solar Panel, 2006, solar-electric.com, April 26, 2007, <http://store.solar-electric.com/unus64wathfi.html>

unbreakable since they contain no glass. The installation costs for these systems can also be lower since the products are easier to work with.

Many manufacturers are producing thin-film panels that look like roofing shingles. These PV cells are much more attractive and less noticeable than flat panel cells. They are manufactured in rolls and can be nailed to the roof much like normal asphalt shingles, and then be wired on the interior of the roof.

One promising technique in the design of thin-film cells that could be an important factor in the success of thin-film panels is multi-layered cell construction. These cells have different layers for different colors of light. While this does not always raise the efficiency of the cell, it raises the cells productivity. Each layer will provide efficiency in different situations, which, in turn, will allow the cell to operate at its peak efficiency in a wide range of conditions. This can be very useful on rooftops when both sunny and overcast conditions are possible.

Some thin-film cells use hazardous materials that can negatively affect the environment if not disposed of correctly. A common thin-film cell design uses cadmium, a hazardous material that can be poisonous it not dealt with appropriately.

Conclusion

The thin-film PV technology needs to progress further in order to meet the needs of most consumers. Although, thin-film panels are typically much cheaper than other wafer-based panels, they have significantly lower efficiencies. If commercially available cell efficiencies are able to reach the range of wafer-based cells while maintaining their low cost, it would bring the return on investment to less than 15 years. One possible way to produce greater amounts of energy using this technology would be to incorporate multiple layers in more commercially available panels. Combining the low cost, durability and aesthetically flexible features of thin-film solar technology, it may prove to be the optimal choice for widespread implementations.

Dye-Sensitized Photovoltaic Cells

Overview

Dye-sensitized photovoltaic cells, also called Graetzel cells after their inventor, Michael Graetzel, are a type of thin-film cell which have a very simple design and can have very high efficiencies. The cells are made from very common materials and are less expensive than wafer-based cells. These cells also have very broad applications and can be used in flexible materials.

Dye-sensitized cells are made from oxide semiconductors, most commonly titanium dioxide. Titanium dioxide is an extremely common compound used in everything from powdered donuts to sunscreen. To form one electrode, the oxide is deposited on a transparent, electrically conductive substrate, such as coated glass or plastic. This can be done by screen printing, which is a simple and inexpensive process. At this point the oxide must be dyed in order to absorb more light energy. Since titanium dioxide is white and most commonly used to reflect light, if the oxide is not dyed, the cell would reflect most of the solar energy that contacts its surface. Another conductive substrate is used to form the other electrode. This counter electrode is coated with an electrolyte to enable conduction and regenerate the dye. The two electrodes are assembled and sealed which completes the cell.

The proportion of light energy that is converted to electrical energy by the titanium dioxide compound is nearly 80 percent. However, due to the reflective properties of the material, the total efficiency of the cells is less than 33 percent.

Other advantages of dye-sensitized cells are their flexibility in applications. Since both sides of the cell can be made from transparent materials, and the oxide is only deposited in a thin layer, electricity producing tinted windows can be created. These cells can also be made from flexible substrates such that the PV cell can be integrated into textiles and polymers. These abilities allow for a very wide market for the dye-sensitized cell.

The dyes used in making dye-sensitized cells can come from many places. They can be synthetic dyes or organic dyes. In demonstrations, grape, blackberry or other dark colored jelly is used to dye the titanium dioxide. Both synthetic and organic dyes, however, are vulnerable to heat and UV light. The efficiency and lifespan of the cell are limited by the life of the dye and how long it can absorb energy.

Benchmarks

Dye-sensitized PV technology is a newer technology that has yet to mature enough for commercial applications. After several overly optimistic attempts to produce commercially available modules, it seems that 2010 would be a realistic goal for the commercial appearance of this technology. Some companies, however, are still trying to produce a cost effective line of these modules. The British company G24 Innovations plans to begin production of one product line in the first quarter of 2007.[39] The company expects their products will be available early in the second quarter of 2007.

Conclusion

Due to the lack of available products utilizing this technology, it would not be economically impossible to implement this type of photovoltaic system. However, the potential of this technology may provide the best outlook for PV solar collection. With high theoretical efficiencies and flexible applications, dye-sensitized photovoltaic systems may soon be the most

[39] G24 Innovations, April 26, 2007, <http://www.g24i.com>

cost effective, efficient, and aesthetically pleasing choice for those who opt for photovoltaic power. With the right amount of time, money and research, it may not be long before dye-sensitized roofing, windows and even clothing become commonly available products.

Organic Photovoltaic Cells

Overview

Organic PV cells are another thin-film based technology. These cells are made from organic dyes, carbon based materials, and polymers. Organic cells are inexpensive, easy to produce, lightweight and are very adaptable in design. The cells can be made on many substrates and can be flexible and easily integrated into fabrics and other materials.

Although organic PV cell technology has many benefits, the cell efficiencies are very low. The highest efficiency organic cells are around 5 percent. This technology is a relative newcomer and will likely show many improvements in the near future.

Benchmarks

Due to the low efficiency and relative age of the technology, there are no commercially available organic cells. However, the low production costs, flexibility and lightweight quality of the cells show the potential of this technology. These cells are anticipated to soon be used for applications such as lightweight sensors and other applications where cost and weight are a concern.

Conclusion

The low efficiency as well as limited availability of these cells inhibits widespread use for large scale collection of energy at this point in time. Once these cells become commercially available, the prospect of their use in homes and businesses will be greatly improved. When the technology finally hits efficiencies matching that of other technologies or even better, these cells may be the way to power everything from calculators to office buildings.

History of Solar Thermal Technology

The oldest form of collecting solar energy is to harness the thermal energy from the sun. Ancient people had various ways of capturing the sun's energy using low-tech means. Solar collectors have been implemented using the simplest techniques, such as the use of darker colors and using objects like rocks to store heat.

One of the first wide-spread uses of solar collectors was the development of greenhouses. The greenhouse effect is a very simple implementation of solar collector technology. The rays from the sun radiate through the greenhouse's sheathing to heat the ground inside the structure. While the ground absorbs an equivalent amount of heat energy inside the structure as it does outside the structure, the sheathing insulates the air contained inside the greenhouse from transferring the heat energy back to the atmosphere. This is how the temperature inside the greenhouse stays higher than the ambient temperature.

A very similar principle is used in some modern solar collectors, such as evacuated tube technology. In the middle of the double wall tube are dark colored materials and a heat pipe to absorb the heat radiated into the tube from the sun. Between the two walls of the tube is a near vacuum insulator to prevent captured heat energy from escaping. The heat energy is then concentrated to one end of the tube where it is transferred to another medium, such as water. Other collector technologies use simpler means to collect the sun's thermal energy. One of the simpler technologies uses only dark colored tubing to transfer the heat energy to water or another medium.

Flat-Plate Collectors

Overview

Flat-plate collectors stem from a very simple design of solar collection. Most flat-plate collectors are little more than a heat exchanger inside a compact greenhouse. A heat exchanger is a device that transfers heat from one medium to another (a radiator is a type of heat exchanger.)

In a flat-plate collector, the sun's energy enters the collector through the glazing. Glazing, as in greenhouses, is a covering that allows radiation to pass through, but prevents thermal conduction. The glazing is usually glass or plastic. After passing through the glazing, the light energy heats up a dark absorbent layer of material lining the collector, raising the temperature inside the collector. The higher temperature inside the collector warms the medium, generally liquid, flowing through the heat exchange pipes in the collector. The system usually contains some kind of pump to circulate the liquid medium.

Generally, the heat collected from sun through a flat-plate collector is not enough to meet all of the water heating needs of a dwelling. Due to this, the collectors often operate as a pre-heating system for the water to reduce the cost of the primary water heating system. In some regions, flat-plate collectors can provide all of the space-heating needs for a home or building.

The temperature difference across an efficient flat-plate collector ranges from 10-20°C. This means that a flat-plate collector can raise the temperature of incoming water 10-20°C. However, depending on how the system is designed, multiple collectors can raise the temperature even more.

Benchmarks

The efficiency of flat-plate collectors is typically in the 70 – 80 percent range. Many collectors that are commercially available exhibit efficiencies of about 75 percent. SunMaxx manufactures a collector that is 78.1 percent efficient at a cost of $700 per collector.[40] These collectors are twice the area of the PV panels used in previous examples. Since flat-plate collectors provide heat to be used for hot water and space-heating, different energy requirements exist from that of the PV systems. A common 4 person household would use approximately 24,000 kWh of heat energy per year.[41] Because these collectors are twice the size of previous panels, only 22 collectors could be used in this application. Even still, this type of system could produce as much as 240 percent of the home's yearly needed heat energy. However, much of this energy is wasted during the summer months when space-heating is unnecessary.

Again disregarding the cost of installation and accessories, the cost of the panels alone would be about $15,400 with a yearly savings of up to $3000. The return on investment for this system would be much faster than that of the PV systems. It would take about 5.1 years for the savings to pay for the cost of the system.

These panels also have a longer lifespan than most of the PV systems. Most flat-plate collectors are expected to last more than 20 years. The durability of some flat-plate collectors can also be very high. Flat-plate collectors can be manufactured with impact resistant glass or plastic to avoid breakage. Many manufacturers, in an attempt to enhance the appearance of the collectors, are designing slimmer, more streamlined units that can blend in with the roof more easily.

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40 Flat Plate Solar Collectors, siliconsolar.com, April 26, 2007, <http://solarhotwater.siliconsolar.com/flat-plate-solar-collectors.php>

41 Energy Consumption and Expenditures RECS 2001, November 18, 2004, eia.doe.gov, April 26, 2007, <http://www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html>

Unfortunately, the installation and accessory costs can be much higher than those of PV systems. Most solar thermal systems require a pump, heat exchanger, and extensive piping in order operate correctly. This can drive the total system cost much higher.

Flat-plate collectors are generally made from common materials that are readily available. The use of readily available materials can often reduce the amount of greenhouse gases released in production. Additionally, they do not usually contain hazardous materials which may cause problems in their disposal and recycling.

Conclusion

Flat-plate collectors utilize a very mature technology that allows for high efficiency at low cost. In comparison to PV systems, flat-plate collectors can provide a much larger amount of the energy needed for a home. Unfortunately, there are no existing grid systems to store the excess energy in times of low demand. If an end user wishes to store the excess energy, a complex system is required at an additional cost. Even still, the high efficiency and low costs allow for a consumer to utilize a system of flat-plate collectors in conjunction with grid connected energy and reap the benefits of a low return on investment. Although this technology boasts high efficiencies, low cost, and potential durability, this technology has reached a point where improvements have become harder and harder to develop.

Evacuated Tube Collectors

Overview

Evacuated tube collectors use an array of parallel tubes to collect the sun's energy. Each tube is actually two glass tubes, one inside another, with a vacuum in between them. Inside the inner tube is an absorbent material, often black chrome, attached to a heat pipe. This heat pipe transfers the heat to a small bulb at the top of tube. The bulbs of many tubes plug into what is called a header. The header is an insulated enclosure with one main tube and many connected tube sockets running through it. The system pumps a medium, again a liquid, through the main tube and the liquid absorbs the heat from the tubes.

Each tube can generate heats of over a hundred degrees Celsius while the glass tube stays cold to the touch. Since the tubes are round, it allows for a wider range of angles of absorption. This allows for greater absorption efficiencies throughout the day, but in absolute direct sunlight, the absorption may be lower than that of a flat-plate collector.

Evacuated tube collector systems can provide most if not all of the heating and hot water needs of homes and buildings in many areas of the globe. Generally though, the collector system works in cooperation with a more consistent system such as electric, gas, or oil heating.

Benchmarks

The efficiency of evacuated tube collectors is typically a small amount lower than that of flat-plate collectors in direct sunlight, but allows higher efficiency at many different angles. This is mostly due to the curved shape of evacuated tube. Many collectors that are commercially available exhibit efficiencies of about 70 percent. SunMaxx manufactures a collector that is 71 percent efficient at a cost of $800 per collector.[42] These collectors are three times the size of those in PV systems and 50 percent larger than common flat-plate collectors. Based on the same heating requirements used in the flat-plate collector example, a common 4 person household would use approximately 24,000 kWh of heat energy per year. Because these collectors are three times the size of PV panels, only 15 collectors could be used in this application. Even still, this type of system could produce as much as 246 percent of the home's yearly needed heat

[42] Evacuated Solar Tubes, siliconsolar.com, April 26, 2007, <http://solarhotwater.siliconsolar.com/evacuated-solar-tubes-20.php>

energy. Just like with the flat-plate collectors, much of this energy is wasted during the summer months when space-heating is unnecessary.

Again disregarding the cost of installation and accessories, the cost of the panels alone would be about $12,000 with a yearly savings of up to $3000. The return on investment for this system would be much faster than that of the PV systems and even less than for flat-plate collectors. It would take about 4 years for the savings to pay for the cost of the system.

These arrays also have a unique feature for lengthening their lifespan. If a single or multiple tubes were to break from impact, they can be individually replaced for minimal cost. Some companies sell replacement tubes for less than $50.[43] Regardless, the tubes are made from impact resistant glass and the systems are expected to last as long at 30 years. The appearance of evacuated tube collectors tends to be very striking. Due to a bulky header and multiple glass tubes, these arrays can be quite visible and, to some, unattractive. Many companies are attempting to make low profile headers and more appealing tubes.

Like flat-plate collectors, the installation costs of evacuated tube systems can be significantly higher than for PV systems. These solar thermal systems also require a pump, heat exchanger, and extensive piping in order operate correctly. This can drive the total system cost much higher.

Evacuated tube collectors are generally made from common materials that are readily available, although manufacturing is somewhat more complex than for flat-plate collectors. The use of readily available materials can often reduce the amount of greenhouse gases released in production. Additionally, these collectors do not usually contain hazardous materials which may cause problems in their disposal and recycling.

[43] Evacuated Solar Tubes, siliconsolar.com, April 26, 2007, <http://solarhotwater.siliconsolar.com/replacement-evacuated-tubes.php>

Conclusion

Evacuated tube collectors utilize a newer technology than flat-plate collectors. This technology gives efficiencies that are nearly as high as flat-plate collectors in direct sunlight, while higher than flat-plate collectors for indirect sunlight. These systems also tend to be less expensive than flat-plate systems. In comparison to PV systems, evacuated tube collectors can provide a much larger proportion of the energy needed for a home. Like flat-plate systems, these systems suffer from the lack of a preexistent storage system. Even still, the high efficiency and low costs allow for a consumer to utilize evacuated tube collectors in conjunction with grid connected energy and reap the benefits of a low return on investment. Combining high efficiencies, low cost, and cheap tube replacement options, this technology is a very promising choice for implementation. With more development in the aesthetic appearance of these tubes and headers, this technology may become most effective and desired form of solar energy collection.

Residential Use

Although there are several commercially available solar collection technologies to chose from, few PV systems have progressed far enough to allow full dependence on the energy from the sun in residential applications. Currently, solar thermal collectors are a more efficient and complete way to utilize solar energy. Photovoltaic cells lack the efficiency to provide enough energy to completely eliminate dependence on fossil fuels.

Though it is possible to design energy efficient homes that can be completely off grid and can convert all of their energy from the sun, it is not the most practical way to harness the sun's power. In order for a solar energy system to eliminate all dependencies on grid energy and fossil fuels, a costly energy storage system for both heat and electricity must be designed, installed, and maintained.

A much more feasible alternative to an off grid scenario would be the utilization of grid energy storage. This concept allows a home with solar arrays to produce excess energy on clear sunny days, and use energy from the grid to provide power during dark nights and rainy days. Instead of having a large storage medium for the heat collected by solar thermal collectors, the systems capacity could be sacrificed in order to make room for more photovoltaic panels that can meet the additional needs of the thermal system using grid storage and high efficiency electric heaters. The thermal collectors would act as a preheating system, ideally never producing excess energy that could not be stored.

The most efficient and cost effective system would incorporate a careful balance of PV solar panels and solar thermal collectors, allowing for the least amount of wasted energy and least dependence on fossil fuels.

As the development of photovoltaic technologies progress further this task will become more viable. A point may be reached at which power plants no longer generate energy from fossil fuels, but instead store energy produced by the solar panels on each home.

Commercial Use

The use of solar energy in commercial applications relates closely to residential applications. While commercial buildings use far greater amounts of energy, the buildings generally have large, flat roofs, for solar arrays, as well as many windows that, with the advances of some technologies, may enable every exterior surface of these buildings to collect the sun's energy. The increased amount of surface area for most commercial buildings can often accommodate the higher energy needs.

Most any commercial building can benefit from decreased energy bills with a long lasting solar collection system. Due to the dependency of a commercial entity on both electricity and heat, off grid systems for commercial application may not be a feasible option in the near future. Many new office buildings are being designed with green energy in mind and are incorporating large solar arrays in their aesthetics. Even most green buildings cannot rely on solar energy to be their complete source of energy.

The largest energy demand for most businesses is electricity to power lights, computers and other communication devices. Until PV technologies can exhibit high enough efficiencies to supply the required electrical power, businesses will continue to rely on fossil fuels as their primary power supply.

Centralized Collection of Solar Energy

One potential application of solar energy that could drive the development of solar technology would be centralized implementations of solar collection. If an initiative was developed to design a centralized solar power plant, the potential for profit may encourage many companies to invest research and development funds to the development of higher efficiency PV cells. A defined goal for this technology could stimulate great advances in a short amount of time, much like the Manhattan Project. Sometimes defined requirements are necessary to the progress of technology.

In order to supply 3.5 trillion kWh or electricity, a majority of the countries annual electricity requirement, it would take a cumulative total of 17,000 sq. km. of 12.5 percent efficient panels to generate that amount of electricity. That is larger than Connecticut, but only 6 percent of the area of Colorado. This number of panels would cost nearly 13 trillion dollars plus the cost of installation and implementation. This does not take into account 6 – 10 percent losses in converting the electricity to AC for use with the current power grid, or the 7 – 10 percent losses in the transmission of the electricity over the power lines. Although this idea may not be entirely realistic, a plan of action for working towards improvements to enable a similar concept may spark innovation for solar conversion technologies.

Economics

For one to comprehend why solar energy has not caught on in most countries, a better understanding of the economies that fuel these countries is necessary.

Market Economies

United States

The economy of the United States has been characterized as a capitalist mixed economy. It is a capitalist economy but the government does intervene at times in order to limit concentration of power and to address certain problems as they arise, hence the "mixed economy" label. Americans have traditionally believed in personal freedoms and therefore stress the importance of private ownership in their policy decisions. This is also reflected in America's economy which was built on the beliefs that an economy should be run according to a supply and demand scheme. This is best achieved by the promotion of privately owned businesses opposed to government owned businesses. The reasoning behind this is that in an economy where most businesses are controlled by the government, the ultimate structure of the economy would not be ruled by a supply and demand scheme but would rather be focused in whichever direction desired by the government itself. A government owned business has two sources of income, governmental tax revenues and the actual profits of the business. Because of the revenues gained from taxes, the business is not solely dependent upon profits and therefore the production of the business is unaffected by the market, and would violate the structure of a supply and demand free market economy.

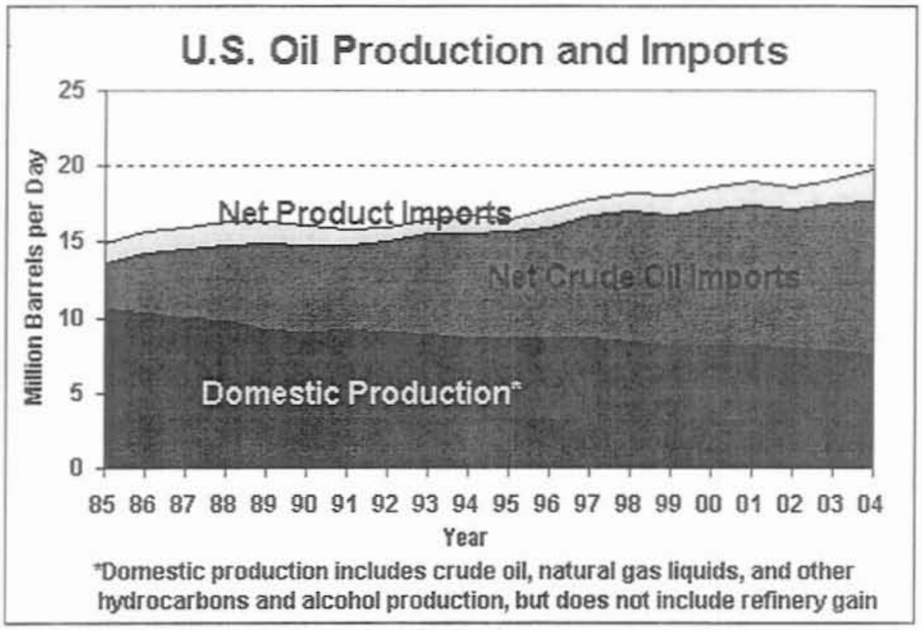

Figure 2

(Source: Energy Information Administration, <http://www.eia.doe.gov/>)

The United States is the world's largest energy producer as well as the world's largest consumer of energy. The U.S. is also the world's largest net importer of energy. As of 2004, it is home to the eleventh largest oil reserves, the sixth largest natural gas reserves, and the largest coal reserves in the world. Since the collapse of oil prices in 1985, oil production in the United States has been steadily declining, while demand has increased, causing a greater dependence on foreign oil; as a result oil importation has steadily increased over the same timeframe. In 2005, oil production in the Gulf Coast was halted due to Hurricanes Katrina and Rita. Before these events, it was expected that this region would see an increase in oil production because of new offshore fields and because it had just about fully recovered from the destruction of Hurricane Ivan, which hit the area no less than a year earlier. Alaska's oil production is also in decline.

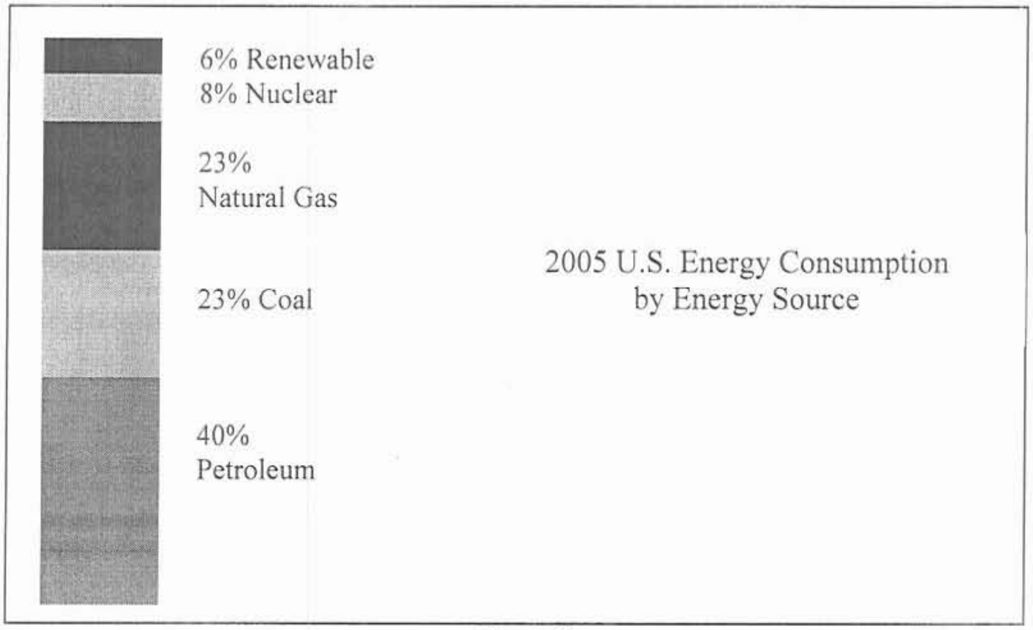

Figure 3

(Source: Environmental Protection Agency,

<http://www.epa.gov/climatechange/emissions/downloads06/07Energy.pdf>)

The United States is the world's largest single emitter of carbon dioxide from the burning of fossil fuels. They are also responsible for large amounts of acid rain in parts of Canada and the United States due to air pollution caused by fossil-fueled electric power plants. In addition, the United States has water pollution problems from the runoff of chemical pesticides and fertilizers. Motor vehicles represent the single largest man-made source of air pollution in the United States. In recent years, the shift away from cars towards larger vehicles, such as sports utility vehicles (SUVs), is responsible for a reversal of years in fuel efficiency improvements to U.S. motor vehicles. Fuel efficiency technology improvements generally have not been sufficient to compensate for the increasing popularity of SUVs and other relatively fuel-inefficient vehicles. These vehicles produce, on average, one-third more carbon dioxide per mile than the average passenger car.

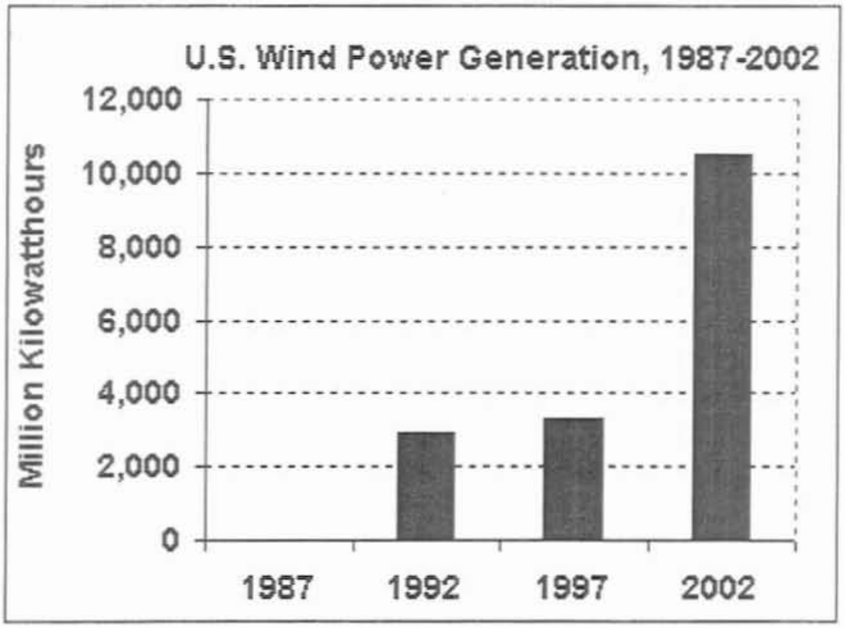

Figure 4

(Source: Energy Information Administration, <http://www.eia.doe.gov/emeu/cabs/usenv.html>)

As of October 2005, twenty states had adopted renewables portfolio standards (RPS) or mandates aimed at increasing the share of renewable power in the energy mix. Several other states are considering adoption of RPS, while others with RPS already in place are looking for ways to accelerate the development of renewables. Growth in renewable energy continues to be challenged by little or no development of new hydroelectric sites, a slow but lengthy decline in the use of biomass for non-electric purposes, and the high capital costs of most renewable energy production facilities, relative to fossil-fueled alternatives. Overall, hydropower provided around forty-five percent of total U.S. renewable production in 2004, with biofuels (including wood and waste), solar, wind, and geothermal making up most of the remainder. Wind, solar, biomass, and geothermal power, although growing, continue to supply a tiny fraction of total U.S. energy needs. Both Cape Cod and Iowa are areas of the country considered to have significant wind energy potentials. The first U.S. offshore windmill park, with a peak capacity of 420 MW from 130 turbines, has been proposed for construction off the Cape Cod coast. The project (by Cape Wind) could power more than 200,000 homes in Cape Cod, but has been opposed by local residents who believe the project would mar the area's landscape. On November 9, 2004, the US Army Corps of Engineers (USACE) issued a draft environmental impact statement on the Cape Cod wind project, finding that the positives of the project outweighed any possible negatives. Meanwhile, Iowa's largest utility (MidAmerican Energy) has announced plans for a 310-MW wind power facility; the country's largest to date.

Germany

The economy of Germany has been characterized as a Social Market Economy. The German government intervenes in the economy a lot while, at the same time, promoting competition and free enterprise in the economy. The government owns different sectors of the economy but, in recent years, has made efforts to transition to an economy with less government intervention and ownership and more private ownership. The government has restructured the railroad system, the national airline, telecommunications, and postal services. The German economy is heavily based on exports, accounting for more than one-third of national output. Germany is the world's third-largest economy and the largest economy in Europe. Even though the German economy has not performed very well in the past five years, there was much improvement in 2006 due to the economic reforms and strong worldwide economic expansion.

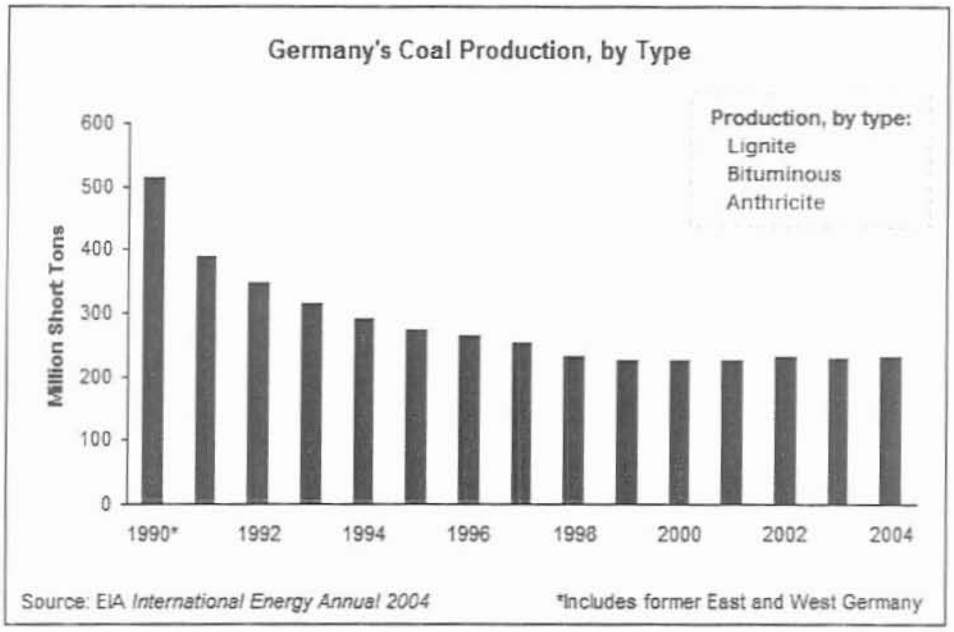

Figure 5

Germany is the world's fifth largest consumer of energy, most of which must be imported due to the lack of resources, with the exception of coal. Germany is the fourth largest consumer and the seventh largest producer of coal in the world, but production has been declining rapidly since around 1990. Over time, coal mines start to deteriorate and become less efficient, leading to some of these mines being closed, this is the main cause of the decline in coal production. Some of Germany's coal deposits are deep below the ground, making the extraction expensive and challenging. The government has given large subsidies to the coal industry in order to combat this and for the industry to be sustained.

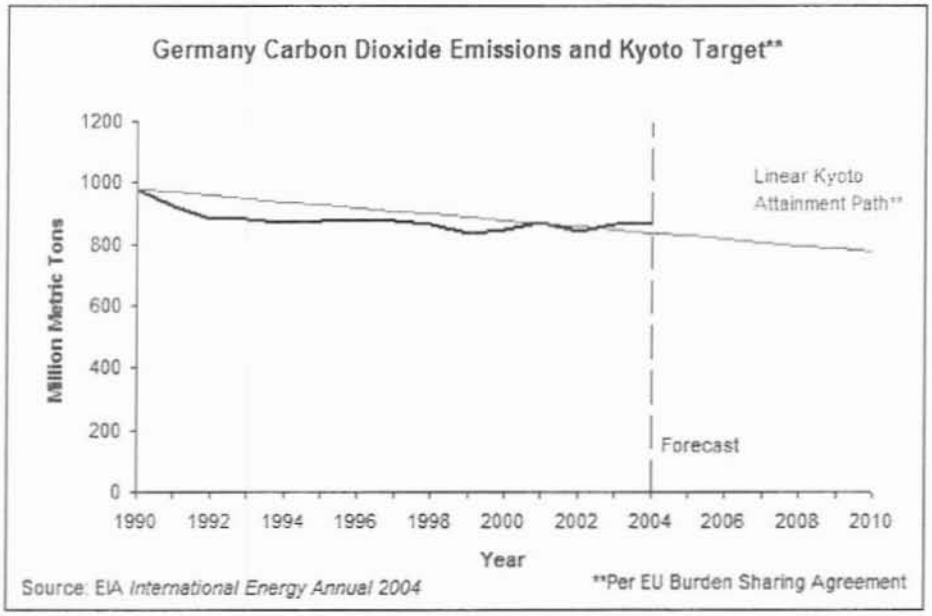

Figure 6

Germany is the third-largest carbon dioxide emitter in the Organization for Economic Co-operation and Development (OECD) behind the United States and Japan. Germany's reliance on coal, particularly brown coal, for electricity generation and the heavy industrialization of the economy has lead to serious problems with air pollution, acid rain, and habitat degradation. These problems are particularly severe in the former East Germany.

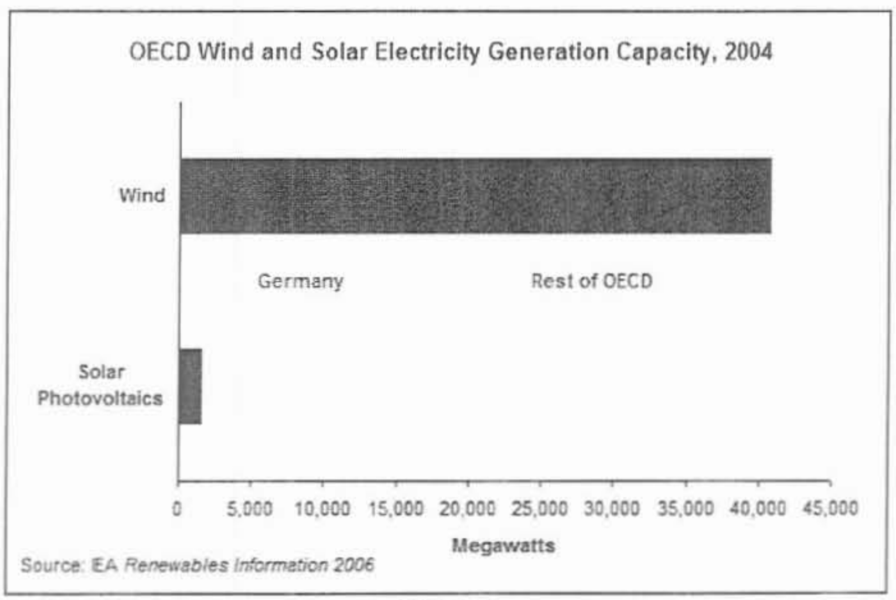

Figure 7

Germany is also one of the world's largest operators of non-hydro renewables capacity in the world, including the world's largest operator of wind generation. Germany has a strong commitment to protecting its environment. It has actively promoted the use of renewable energy, both under the Kohl government with the Electricity Feed Law, and now under Schroeder's government with eco-taxes. Germany ratified the Kyoto Protocol on climate change on May 31, 2002. The EU has decided to meet its Kyoto obligations as a whole, rather than as individual signatories. Under the EU's burden-sharing program, Germany must cut its carbon dioxide emissions by twenty-one percent, relative to the 1990 baseline, during the 2008-2012 commitment period. The EU expected Germany to make such deep cuts, because the country has already experienced a sharp decline in carbon dioxide emissions following reunification.

Japan

Japan's economy has been characterized as an industrialized free-market economy. It is very productive and competitive in international trade, but much less efficient in other areas of its economy such as agriculture. Japan's economy is the second-largest in the world. Japan had one of the highest economic growth rates in the world from the 1960s through the 1980s, but slowed significantly in the early 1990s, when the economy basically collapsed with stock and real estate prices plummeting. Japan's economy has matured greatly since then turning it into the industrial juggernaut that it is today. Japan has very few natural resources, and must rely on foreign trade to purchase raw materials for its economy. Japan's future outlook is considered to be very good, and it has largely recovered from its worst period of economic stagnation. Japan's economy grew slowly in the 1990s compared to the fast rate of growth in the 1980s. The growth rate in recent years has risen from that of the 1990s and is expected to continue to rise through the end of the decade.

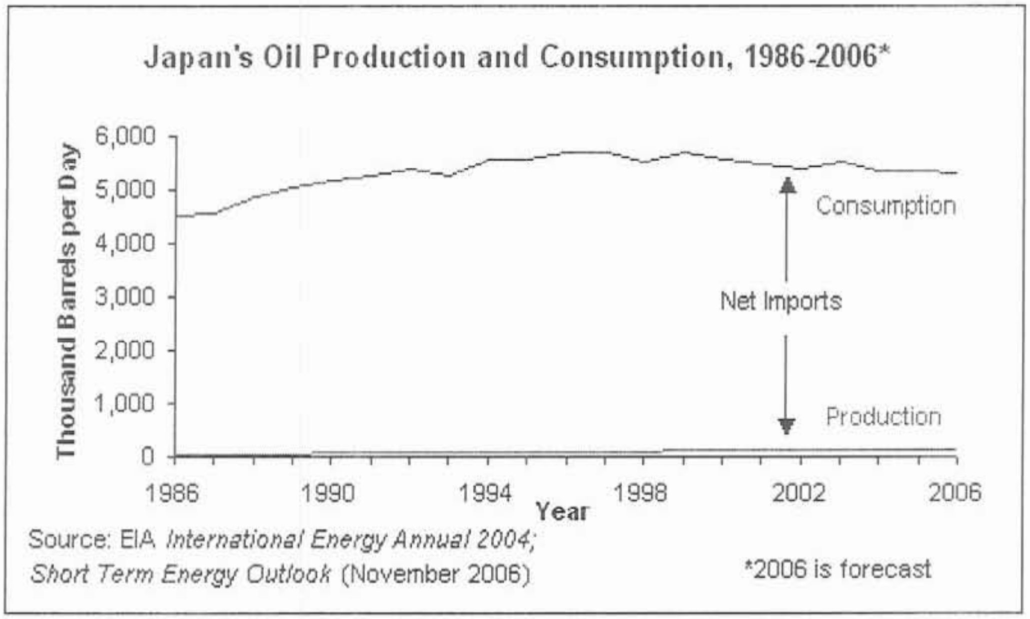

Figure 8

Japan is the third largest consumer and the second largest net importer of oil in the world. Since it is so heavily dependent on imported energy, Japan has aimed to diversify its sources. Since the oil crisis of the 1970s, Japan has reduced its dependence on petroleum as a source of energy from more than 75 percent in 1973 to about 50 percent in recent years and this trend is expected to continue into the future. Japan has attempted to seek out oil development all over the world, such as the Middle East and Southeast Asia. Government owned as well as privately owned oil companies have made many explorations in an attempt to secure a stable supply of oil for Japan. Many of these explorations, however, have either failed completely or have had many setbacks and complications.

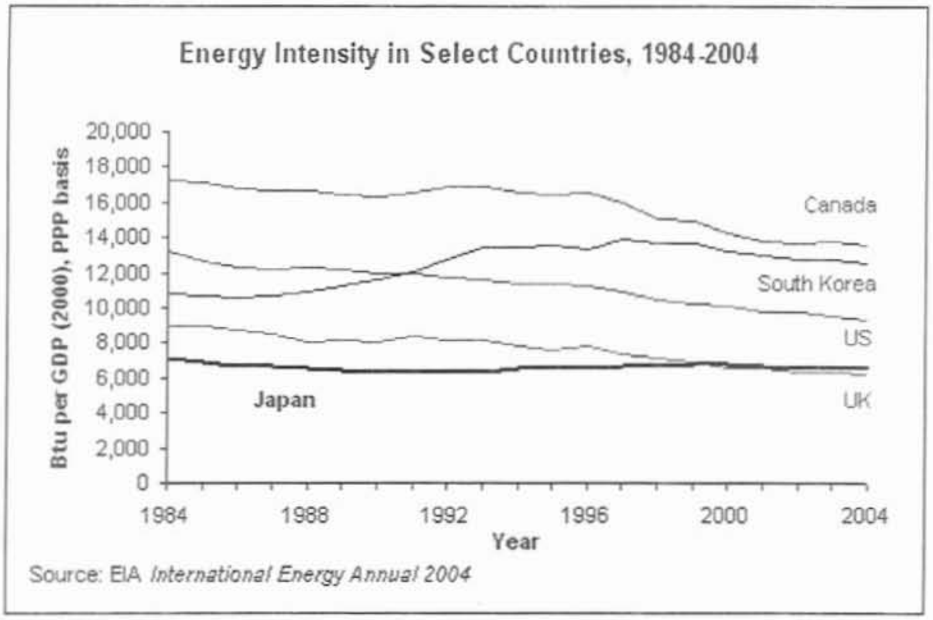

Figure 9

Japan has one of the lowest carbon intensity and energy intensity levels among the OECD countries. In the past few decades, Japan has significantly improved energy conservation and environmental protection. Since that time, Japan has become a world leader in the development and implementation of pollution control technologies and energy efficiency innovations. However, owing to its large economy, Japan remains one of the primary emitters of carbon dioxide in the world. Japan has been a strong supporter of efforts to combat global warming and played host to the conference that led to the Kyoto Protocol to the United Nations Framework Convention on Climate Change, which was finalized in December 1997. Under the Kyoto agreement, which took effect in February 2005, Japan has set out to reduce its carbon dioxide output to six percent lower than its 1990 emissions levels. However, despite these proposals and strong public support for the ideals set out in the Kyoto Protocol, Japan's carbon emissions have been on the rise in recent years. Furthermore, in 2004, the country's total carbon dioxide emissions were twenty-four percent higher than its 1990 levels.

France

The economy of France has been characterized as a State Capitalist Economy. With its considerable agricultural resources and large industrial base, France's economy is the fifth-largest in the world. France has a highly skilled workforce which stimulated the economic growth rate from 2000 to 2004, but in recent years that rate has fallen. To combat this decline, the government has made efforts to create jobs to reduce the high unemployment rate. The government has also been promoting investment. Because of these policies, French unemployment dropped from a high of 12 percent to below the 9 percent margin as of the end of 2006. Despite significant reform and privatization over the past 15 years, the government continues to control a large share of economic activity. The government also continues to regulate labor and product markets. The government is involved in many private corporations including banking, the energy industry, automobiles, transportation, and telecommunications. In 2000, the government shortened the legal work week from 39 to 35 hours for most employees. Recently, it has been evaluated that the reduction of the work week has not created more jobs as was the hope. New policies have been introduced increasing flexibility into the law, returning the country to a 39-hour work week in the private sector. Membership in France's labor unions accounts for approximately 5 percent of the private sector work force and is concentrated in the manufacturing, transportation, and heavy industry sectors. France has been very successful in developing dynamic telecommunications, aerospace, and weapons sectors.

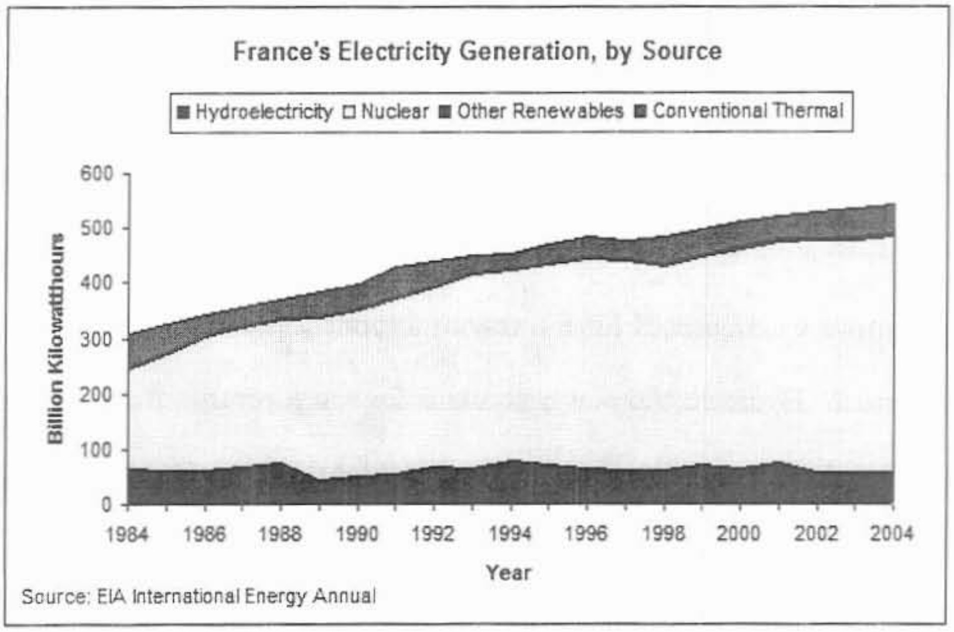

Figure 10

With virtually no domestic oil production, France has relied heavily on the development of nuclear power since the 1970s, which now accounts for about 79 percent of the country's electricity production. France is also the largest net exporter of electricity in Europe and the world's second-largest producer of nuclear power, per capita. France's nuclear power is very efficient and inexpensive. Almost the entire market for electricity generation and distribution in the country has been controlled by the French government in the past, but more recently, France has begun taking steps to privatize and deregulate its electric companies because of pressure and criticism coming from many of Europe's national governments. In 2004, the French government opened 40 percent of its nuclear power company's shares to the public. France has continued to expand its already huge nuclear power industry. By 2012, they plan on having the world's first third-generation nuclear reactor, which is less dangerous, a lot more efficient, and less vulnerable to terrorist attacks than second-generation nuclear reactors.

France's per capita carbon emissions are the lowest among the major Western European countries and are on the decline. Despite its nuclear power program, France still suffers from air pollution, especially in Paris and other major cities. Likewise, despite the country's reduction in its dependence on oil imports, France has been the unfortunate victim of several major oil tanker spills, with disastrous consequences for the country's tourism and fishing industries along the Atlantic Ocean coast. Hydroelectric power accounts for seven percent of the country's overall power consumption, but there is little in the way of additional potential. Although the country's consumption of geothermal, solar, and wind power has been increasing in recent years, it still makes up less than one percent of the country's overall energy consumption.

Planned Economies

China

The current economy of the People's Republic of China, more commonly known as China, has been characterized as a Socialist Market Economy. Since the late 1970s, the Chinese government has been reforming its economy from a centrally-planned system to more market-oriented economy, open to global trade. One of the more notable reforms was the government's sale of equity in its largest state banks to overseas investors. Immediate consequences of these reforms include the largest reduction of poverty in history and one of the most rapid increases in income levels ever. This does not mean that there are not currently hundreds of millions of people in China living in poverty, but that the problem is significantly better than it was in the past. Today, China boasts the world's fourth-largest economy and is the third-largest trading nation in the world behind the United States and Germany.

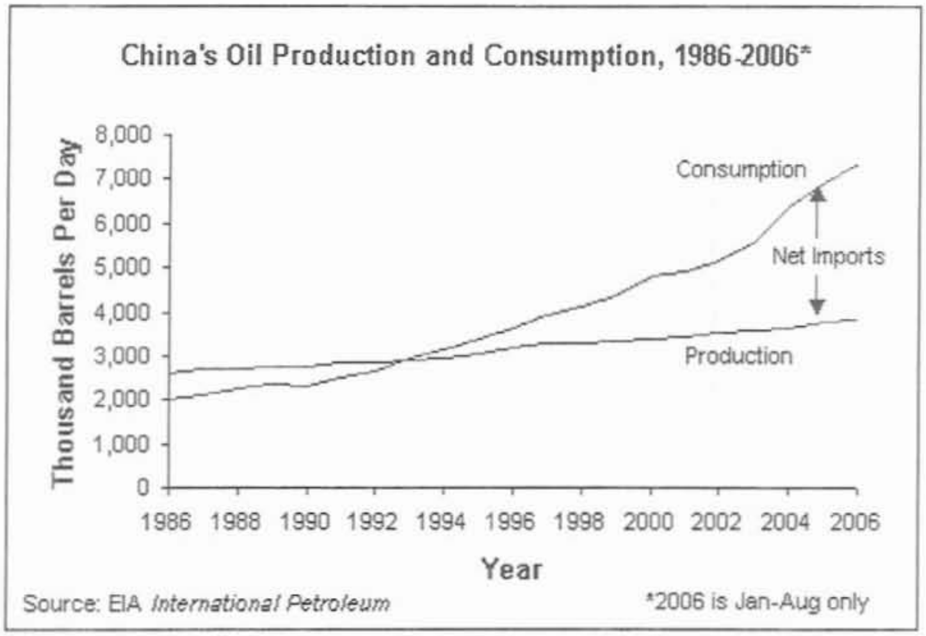

Figure 11

China is the second-largest consumer and third-largest net importer of oil in the world. The oil production industry has been opened to the public, though the Chinese government still holds majority stake in all of the oil production corporations through state-owned holding companies. As a net oil importer since 1993, China's oil industry is focused on meeting domestic consumption needs. Retail prices for oil products are regulated, with variations based on the type of consumer and their location. The Chinese government preserves domestic price ceilings on finished petroleum products which, despite a number of decisions to raise domestic prices over the last couple years, have not kept pace with price increases in global markets. The government also grants subsides to refiners in order to help bridge the gap between low domestic oil prices and high international rates.

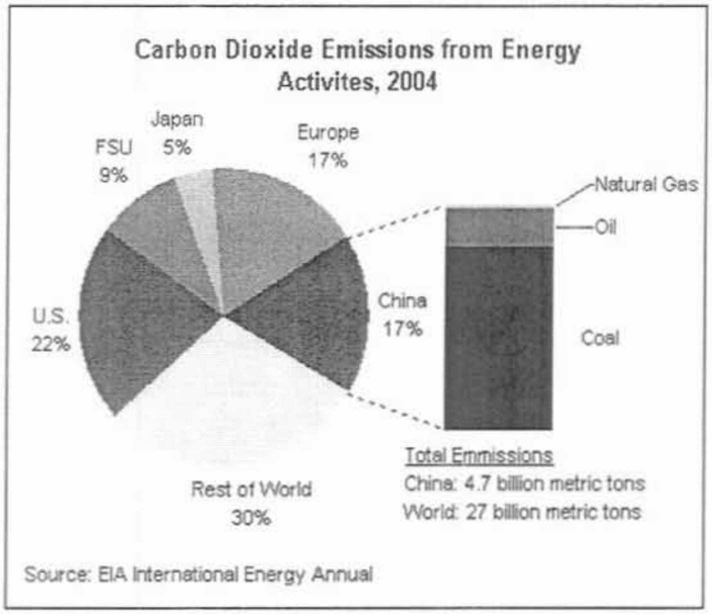

Figure 12

China is the world's second-largest source of carbon dioxide emissions. Environmental pollution from fossil fuel combustion is damaging human health, air and water quality, agriculture, and ultimately the economy. Many of China's cities are among the most polluted in the world. China is a non-Annex I country under the United Nations Framework Convention on Climate Change, meaning that it is not bound to any greenhouse gas emissions reduction targets set under the Kyoto Protocol. The Chinese government has taken several steps to improve environmental conditions in the country; the most important among these is the new law on renewable energy, which took effect on January 1, 2006. The new law seeks to promote cleaner energy technologies, with a stated goal of increasing the use of renewable energy to ten percent of the country's electricity consumption by 2010 (up from roughly three percent in 2003).

Cuba

The economy of Cuba has been described as a Socialist Mixed Economy; it is a state-controlled economy that abides by socialist principles. The government owns and runs most of the means of production in the country and employs almost the entire labor force. The economy is still recovering from its economic crisis between 1989 and 1993, which was due to the loss of Soviet aid and domestic inefficiencies. The Cuban government continues to balance the necessity for economic loosening against a desire for absolute political control. It has rolled back limited reforms undertaken in the 1990s to increase enterprise efficiency and lighten severe shortages of food, consumer goods, and services. The average Cuban's standard of living remains at a lower level than before the economic crisis of the 1990s. In 2006, high metal prices continued to increase Cuban earnings from the production of nickel and cobalt.

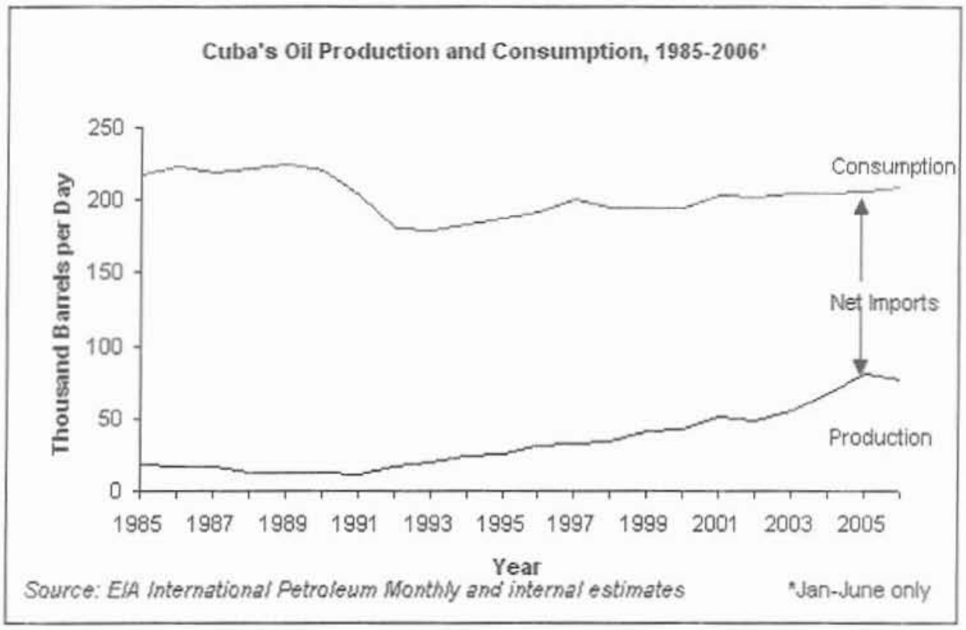

Figure 13

Cuba is not a significant producer of oil in the world; however, oil production is on the rise, for the most part due to the recent discoveries of offshore recoverable reserves. Currently, two Canadian companies, Sherritt International and Pebercan, are producing oil in Cuba, under joint-venture production agreements with the state-owned oil company Cubapetroleo (aka Cupet). Since the end of 2000, Venezuela has been providing Cuba with the rest of its oil needs under favorable financing terms. Cuba has been paying for the oil, in part, with the services of Cuban personnel, including about twenty-thousand medical professionals to help improve the Venezuelan health care system. Havana, the capital of Cuba, has continued to invest in the country's energy sector to lessen electrical blackouts that have overwhelmed the country since 2004.

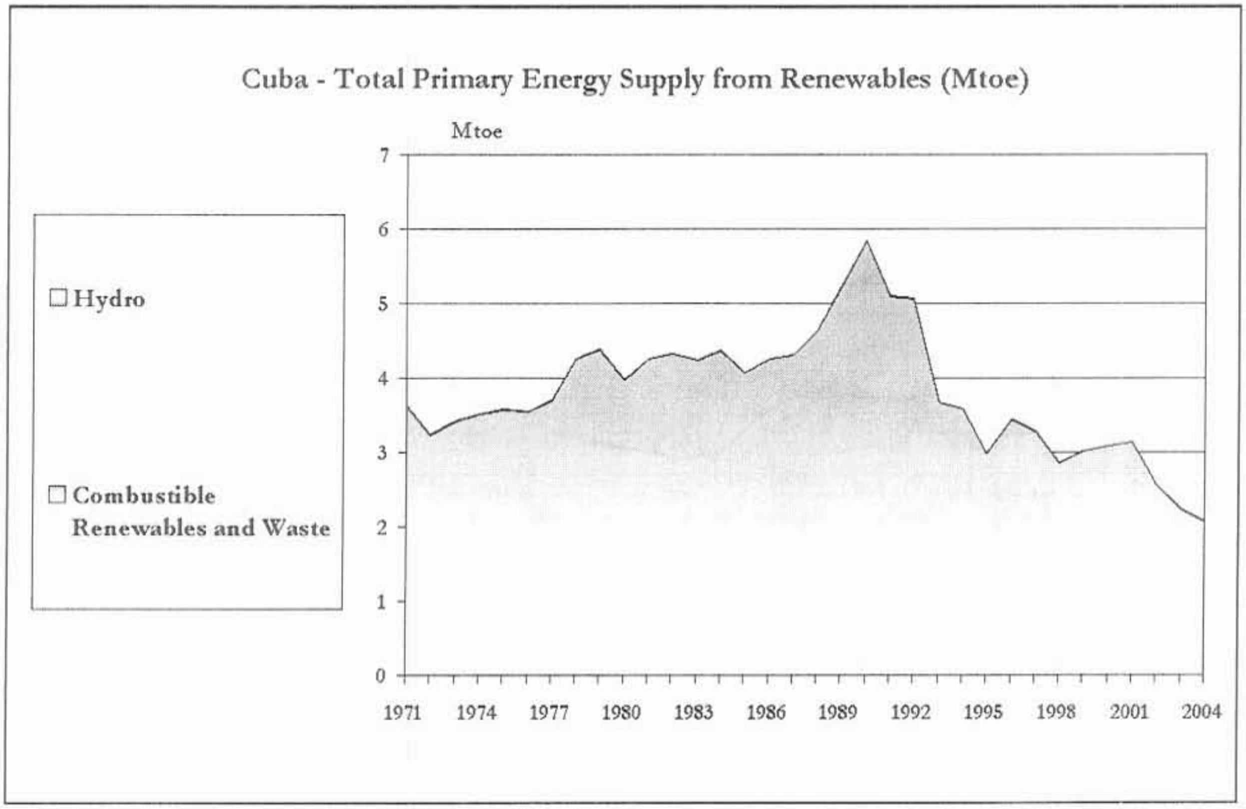

Figure 14

MTOE - Million Tons of Oil Equivalent

(Source: The International Energy Agency, <http://www.iea.org>)

India

India's mixed economy has been formed by its centrally controlled government which has been influenced significantly by Socialist and Marxist ideologies since independence from

Britain. India has been known for its strict government control over private sector participation, foreign trade, and foreign direct investment. However, since 1991, India has gradually opened up its markets through economic reforms and reduced government controls on foreign trade and investment. Privatization of publicly-owned companies and the opening of certain sectors to private and foreign participation have continued in the midst of political debate. India is the world's twelfth-largest economy and the third-largest in all of Asia. India is also the second fastest growing major economy in the world.

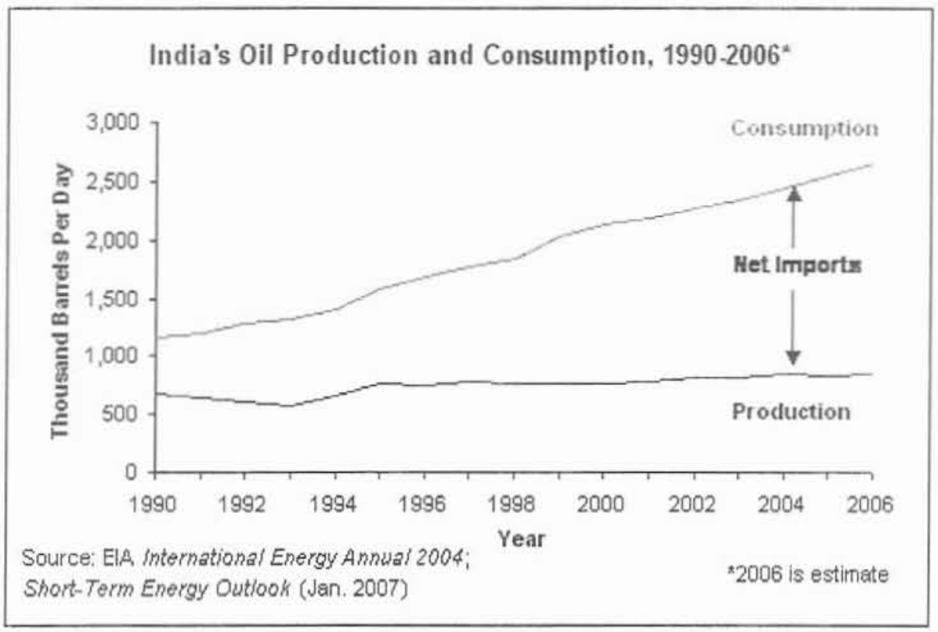

Figure 15

India is the fifth-largest consumer of oil in the world. With the combination of rising oil consumption and comparatively constant production levels, India is becoming increasingly dependent upon oil imports in order to meet its needs. To help meet the growing oil demand, India has been promoting various exploration and production projects over the last several years in an effort to boost domestic oil production and oil exploration activities. India's oil industry is dominated by state-owned companies, although the government has taken steps in recent years to deregulate the industry and support more foreign involvement. The largest state-owned company in the downstream sector operates ten of India's seventeen refineries and controls about three-quarters of the domestic oil transportation network. However, a private Indian firm by the name of Reliance Industries, opened India's first privately-owned refinery in 1999, and has gained a substantial market share in India's oil sector.

Energy conservation has surfaced as a major policy objective in India, so the Energy Conservation Act of 2001 was passed by the Indian Parliament in September 2001. This Act requires large energy consumers to abide by energy consumption standards, new buildings to follow the energy conservation building code, and appliances to meet energy performance standards and to display energy consumption labels. The Act also created the Bureau of Energy Efficiency to implement these provisions. The electricity industry has been restructured by the Electricity Act of 2003, which unbundled the electricity supply utilities in each state of India into a transmission utility, and a number of generating and distribution utilities. The Act also enables open access on the transmission system, allowing any consumer (with a load of greater than 1 MW) to buy electricity from any generator. Significantly, it also requires each Regulatory Commission to specify the minimum percentage of electricity that each distribution utility must source from renewable energy sources. The once-impoverished village of Muppandal benefited from the building of the nearby Muppandal wind farm, a renewable energy source, which supplies the villagers with electricity for work. The village had been selected as the showcase for India's two billion dollar clean energy program which provides foreign companies with tax breaks for establishing fields of wind turbines in the area, now huge power-producing windmills tower over the palm trees. The village has attracted wind energy producing companies creating thousands of new jobs, dramatically raising the incomes of villagers. The suitability of

Muppandal as a site for wind farms stems from its geographical location as it has access to the seasonal monsoon winds.

Current Development on WPI's Campus

WPI and Solar Power

With the rise in the popularity of solar power it might seem that this renewable source of green energy might be an idea that's "time has come." Many of the most adamant solar enthusiasts are making themselves known, particularly on college campuses. Although schools such as Worcester Polytechnic Institute have done a lot to prepare for the coming age of "new energy" there is a lot that needs to be done. The funding is available, the technology is there, the question that remains is who needs to do what to get the ball rolling on WPI's solar initiative and why should it happen?

What WPI has done so far

WPI has already made a serious commitment to green initiatives on campus. The University has proven an interest in sustainable design, and they have voluntarily contributed extra funding to projects with green initiatives thus proving that they are ready and willing to financially support an environmental initiative. The first and most noticeable way, that WPI has shown its support specifically towards green energy is through supporting numerous Interdisciplinary Qualifying Projects as well as Major Qualifying Projects. These are student designed, student run projects that are supported by the school or by volunteering outside organizations. There is a non-student advisor for the project who keeps the students on track and helps students though tough areas of the project work.

There have been several IQP's and MQP's in sustainable fields. One IQP included the installation of a solar panel on the roof of a WPI dormitory. Numerous other IQPs researched everything from solar powered refrigerators (05C020M: Solar Powered Refrigerator) to a renewable energy exhibit for the Museum of Science in London (01D168I: Renewable Energy Exhibit for the Science Museum) One project went so far as to study the installation of Solar Panels in developing countries which had no power grid to hook up to.

Other student projects have studied various other forms of green energy. One student group studied green engineering in the automotive industry (06D257I: Green Engineering and the Automobile Infrastructure). Another student project group studied green transportation alternatives in Worcester, MA (06C028I: Green Transportation in Worcester). A recent MQP group preformed a wind power feasibility study for a company in Greenfield, New Hampshire which is scheduled to be built upon obtaining funding. A final IQP that received extraordinary attention from the WPI community tied for first place in the Presidential IQP awards of 2007. This IQP preformed a wind power feasibility study for Holy Name High School in Worcester, MA.

In addition to supporting these various projects, WPI has also made a firm commitment to sustainable design through their current campus development. The Bartlett Center, completed in the summer of 2006, is a Leadership in Energy and Environmental Design (LEED) building. This means that the building incorporated some or all of the initiatives described by the strict guidelines used to determine a buildings LEED rating. Some areas that WPI chose to highlight were use of local building materials, increasing recycling of construction materials, reducing the future energy costs, and finally, making a better workplace for employees.

Although LEED criteria do separate out renewable energy as an excellent way to earn "points" on their rating system, they also incorporate many other aspects of sustainable design. Other things that WPI did to earn points were adding carpool spaces into the parking structure so that employees are encouraged to drive fewer cars thus adding less net CO_2 into our atmosphere. Additionally, the building was constructed using a full ventilation system and environmental envelope allowing for a completely airtight and watertight building. This not only reduced energy costs for maintaining the building, but also helps the building survive longer with fewer repairs, allowing the same building to be used longer so fewer materials are used in the long run.

These initiatives were a great accomplishment for WPI's students, faculty, and staff. They were the hard work of many key players in the development of WPI's environmental awareness. However, it is important to note that there is still a lot the campus is lacking, especially in terms of solar power. WPI still needs to divert some of its funding into this cause.

What WPI could still do

Currently WPI has only one array of photovoltaic solar panels on its campus and its contribution to our overall energy needs is unknown to the head of plant services. Additionally there are no solar thermal panels, and no plans to place any such renewable energy source on WPI's campus. This is disgraceful considering the amount of money the school could save, the school's responsibility to their environment, and the amount of energy that the campus is literally throwing away every day. Some other campuses in the United States, and even in the New England region have begun to do their part by setting a good example. These examples serve to show what people, universities, and even corporations can do to contribute their part to a solar initiative.

One excellent example of a campus responding to its duty to the environment is in Fresno California where California State University has just finalized plans with Chevron Energy Solutions, a subsidiary of Chevron Corporation, to create an array of photovoltaic that will produce one megawatt of electricity.[44] The array will be installed on top of a parking structure on the university's campus and will shade more than 700 parking spaces. The amount of energy produced should cover twenty percent of the universities current energy needs. One megawatt is also the amount of energy that it would take to power approximately 1000 residential homes in the same area. The project is one of the largest of its kind at any university across the United States. The work started in April 2007 and is scheduled to be completed in phases throughout the following fall. The total cost of the project is an estimated $11.9 million.

There are several other reports of similar events taking place all along the west coast. Another example is found at New Mexico State University's Institute for Energy and the Environment and College of Engineering where construction has begun on a photovoltaic parking structure that will be similar but much smaller than the one at California State University.[45] IEE's photovoltaic array is projected to produce 18 kilowatts which should power 10 percent of the university's energy needs, and provide for all the energy needs of the parking structure itself. The panels will shade 10-12 vehicle parking spaces. Similarly, Google plans on producing 30% of their energy needs through solar power in their headquarters about 35 miles south of San Francisco, California.[46] Google expects to produce 1.5 megawatts through 9,000

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[44] Solar Parking Lot Adds Big Green to Campus. April 9th, 2007. GreenBiz.com. April 15th, 2007. <http://www.greenbiz.com/news/news_third.cfm?NewsID=34867>

[45] IEE takes lead in renewable energy with solar-powered structure on NMSU campus. Therese Shakra, Melissa Hubbell. Dec. 11, 2006. New Mexico State University. February 20th, 2007. <http://www.nmsu.edu/~ucomm/Releases/2006/december/iee_canopy.htm>

[46] Google Sets Precedent for Clean Business Practices. October 23, 2006. RenewableEnergyAccess.com. March 15th, 2007.

solar panels. Supporters of solar energy expect this corporate move to really begin to bring solar panels into the eyes of other large companies as a viable alternative to traditional energy generation.

An example slightly "closer to home" but not nearly as grand in scale can be found on Cornell's campus where the students actively participate in a yearly solar decathlon.[47] The decathlon is a national competition where students from several universities spend a year, or several years, constructing a solar, commercially feasible, energy efficient house. The solar house project has also sparked the students' interest in on campus solar initiatives. In late 2006 a solar project was completed on Cornell's campus that will supply 15 megawatts of electricity through 54 solar panels.[48] All of the panels and funds for installation were voluntarily donated through friends, students and alumni. The fund is still active and the students continue to raise money for other solar initiatives on campus.

There are many examples of other organizations constructing similar projects in the New England region, however, none are quite as extensive as what is happening on the west coast. It has become very apparent that if the east coast schools, including WPI, want to keep up with the most up to date technology and be on par with the more environmentally conscious colleges, great action must be taken to increase the presence of photovoltaic on campuses.

One of the most accomplished demonstrations of the ability of solar power is shown all the why up in Cape Porpoise, Maine where a completely solar house lives off of the grid.[49] The most remarkable part of the house, however, is that the owners live a life of luxury. There are

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<http://www.renewableenergyaccess.com/rea/news/story;jsessionid=19F5E7D5315B710F4597872ABB1195E6?id=46264>

[47] Cornell Solar Decathalon. Cornell University. March 2nd, 2007. <http://cusd.cornell.edu/>

[48] Solar panels on Day Hall will make enough electricity to light the clock tower. Bill Steel. Dec. 22, 2006. Cornell University. <http://www.news.cornell.edu/stories/Dec06/DayHallSolar.ws.html>

[49] Maine Solar House. William and Deborah Lord. February 2nd, 2007. <http://www.solarhouse.com/index2.htm>

none of the highly popularized ill effects such as running out of heat, running out of electricity, or having to live in a really small house. Although this is not directly applicable to WPI's campus because it is a residential use, it has been on the cover of many green magazines and is one of the most published success stories of solar power in the New England region. This home shows, on a small scale, what WPI could produce on a large scale in terms of dormitories for students. Some of the key design characteristics that WPI could adopt are energy efficient appliances. The efficient appliances make for a lower energy drain overall so that the solar panels could produce enough electricity for the whole house load.

Another option that the Maine house added was energy efficient walls, there was extra insulation put throughout the entire exterior shell of the building, not only in the exterior walls but also in the floor and the roof of the house. This keeps the heat inside of the building during the winter and the cool air inside in the summer. This also lowers the overall load on the solar powered system that lowered load allows the system to completely provide for the needs of the house.

The house is designed with both solar thermal and solar power panels. This allows for a combination of electricity as well as heat to be absorbed by the house. The heat is used for heating the house as well as heating the hot water. Both of the systems are located on the roof of the house which faces the south east, allowing for maximum exposure. These combined systems provide the house with all of its energy needs, year round, with only the initial cost of installation instead of monthly utility bills. The owners of the house allow tours throughout the year so that places such as WPI can come visit and get ideas for producing a similar system in other locations throughout New England.

WPI has many reasons to pursue these solar initiative projects. These reasons are both monetary and non-monetary. The economical reasons to "go solar" do fit some of the schools requirements, however, the cost of not going solar and the other non-monetary reasons for a solar initiative are the true reasons that the school should consider the project funding.

Monetary Reasons for WPI to "Go Solar"

Currently WPI has no renewable energy incorporated into its campus utility usage. Both John Miller, director of plant services, and Judith Nitche, Head of the WPI 2007 Board of Trustees, explain that this is not due to a lack of interest on WPI's part but rather due to an overall cost benefit analysis. WPI is typically only interested in prusuing investments with a 5-10 year payback period. Although Nitche deferred the question of where such a "cost benefit analysis" might be located to John Miller, Miller admitted that there was no formal analysis done but rather the idea was lightly discussed and quickly discarded.

There are several ways that the campus could incorporate solar power into its design. One of the easiest ways would be for the school to participate in a program where they install solar panels and invest in green spending to contribute to the overall conversion of all power plants into "battery facilities" for storing green energy as described in the above technology section. However, as mentioned there, the infrastructure simply in not yet available for such a large operation. Instead the school would be better off installing solar panels to produce a large portion of the school's energy and for excess energy to be sold back to the grid. Based on very rough data, a loose cost analysis of this process was performed based on the Fiscal 2008 Utility Summary and a 2007 building summary of WPI's properties and their related square footages.

First the feasibility of photovoltaic power was reviewed. Based on a total square footage of 1,432,723, an estimated 3 floors per building and generally flat roofs an estimated 477,574 square feet of roofing can be assumed. A review of Worcester, MA weather data reveals an average of 3.87 KWH shined on WPI on a typical day.[50] Based on 11.34% efficiency[51] for a given solar panel we can produce approximately 7.1 Mil KWH per year, roughly 32% of our energy needs. The total cost of the system is therefore roughly estimated at $23.3 Million. This will save approximately $1 Mil per year with a payback period of a little over 23 years.

Although the campus may expand or contract throughout the next 23 years, plant services does not anticipate that this will make a great impact on the energy needs of the campus. All future buildings are expected to be energy efficient, creating the smallest energy drain possible. This administration will also renovate all currently buildings as they build new ones to lower the energy use of existing structures. This should create a neutral impact on the energy needs of the campus and, therefore, not affect the system payback periods.

Estimating the future cost of electricity can be tricky. A payback period can give the owner a rough idea of the time that it would take his or her investment to pay for itself. However, the cost of electricity can rise and fall making the payback period unpredictable. It is therefore, more accurate to predict a payback range. Based on the historical data for the cost of electricity (calculated in today's dollars) two different trendlines can be predicted. One trendline should be on the upper limit of a reasonable inflation for energy, and the other on the lower limit. These graphs are shown below in Figure 16 and Figure 17.[52]

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[50] Tracker vs. Fixed Mount Comparison: Solar Radiation Data for 239 US Sites. Watson Solar Trackers. March 18th, 2007. <http://www.wattsun.com/resources/insolation_data/>

[51] 110 Watt Solar Panel: GridMaxx Si. Silicon Solar Inc. April 1st, 2007. <http://www.siliconsolar.com/shop/catalog/110-Watt-Solar-Panel-GridMaxx-Si-p-16380.html>

[52] Annual Energy Review. July 27th, 2006. Energy Information Administration. March 15th, 2007. <http://www.eia.doe.gov/emeu/aer/contents.html>

Figure 16: Cost of Electricity Upper Historical Trendline

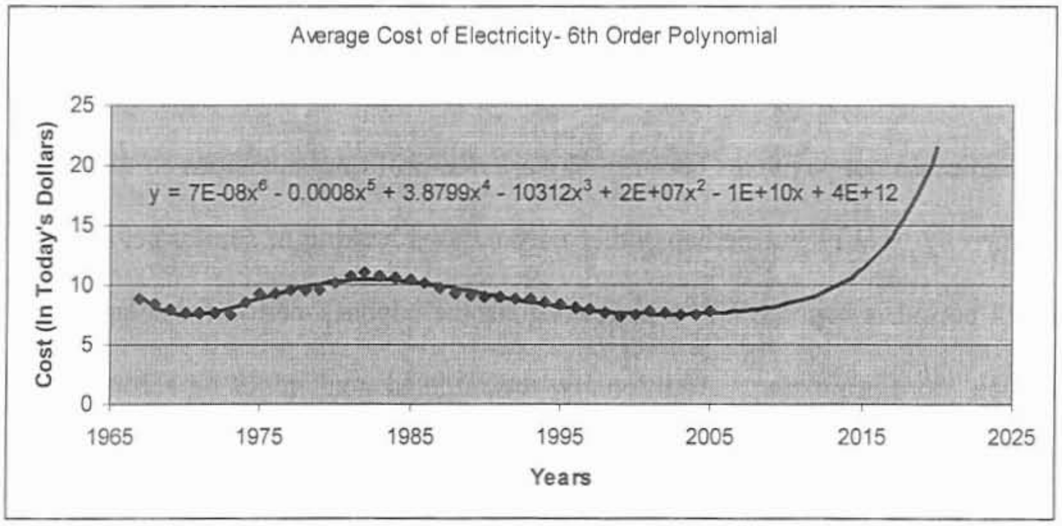
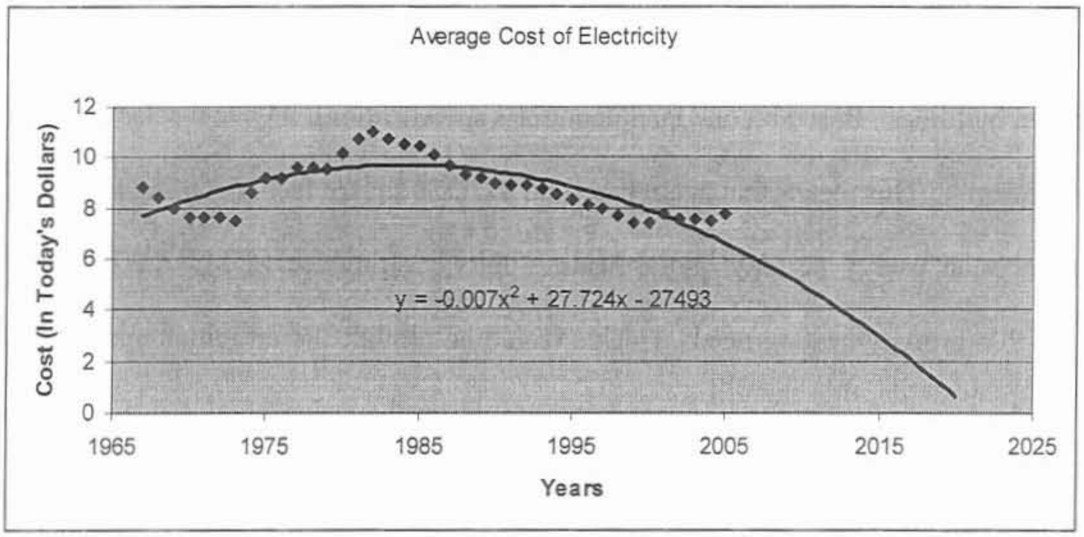


Figure 17: Cost of Electricity Lower Historical Trendline



Based on these graphs we can expect the price to rise up to 40% of its value in 2005 or to fall within 20% of its 2005 value. This will give us a reflected payback range of between 16.6 years with a 40% rise in market prices and 29 years with a 20% fall in market prices.

It is also worth mentioning that Massachusetts also offers tax incentives[53] as well as a $50,000 grant towards any solar project of this scale. However the tax credit would be hard to predict and the $50,000 would only have a small impact on the overall cost of the system. Also most universities do not pay taxes because they are non-profit organizations so this credit would not apply directly to WPI but perhaps other corporations looking at similar set-ups. Although this payback period is beyond WPI's targeted goal, the payback period for solar water heating units is much more promising. Additionally, the targeted goal might be reconsidered due to additional, non monetary, benefits of the system.

WPI uses three different types of fuel for heating its air and hot water. WPI does not make any distinction between which methods are used for air and which for hot water. Solar water heating is very efficient and can be used both as hot water and as a method of heating commercial buildings. Based on one manufacturer's specifications, a typical solar heating unit is 53.8% efficient.[54] This means that again based on 477,574 square feet of roofing and 3.87 KWH of potential solar energy per day[55] solar heating units can produce 18 Mil KWH/year, almost 65% of WPI's primary heating needs.[56] This would be provided at an initial cost of $13.4 Mil with a payback period of around 15 years depending on the rising cost of gas and oil. This fifteen year payback period could be within WPI's expected range and should therefore be more seriously considered as a viable option.

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[53] MTC - Small Renewables Initiative Rebate. September 18th, 2006. Database of State Incentives for Renewables and Energy. <http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=MA22F&state=MA&CurrentPageID=1&RE=1&EE=1>

[54] Skyline 20-01 Collectors. Solar Roofs Inc. April 1st, 2007 <http://www.solarroofs.com/going/features.html#SL2001>

[55] Tracker vs. Fixed Mount Comparison: Solar Radiation Data for 239 US Sites. Watson Solar Trackers. March 18th, 2007. <http://www.wattsun.com/resources/insolation_data/>

[56] Fuel Conversion Chart. Connecticut Natural Gas. April 1st, 2007. <http://www.cngcorp.com/customer_sales_service/fuel_cost_charts.html>

Similarly to the rise and fall of electricity costs, the price of natural gas is expected to rise and fall throughout the next twenty years. The anticipated range that it may rise and fall is again between a 40% increase and a 20% decrease. This will give us a range of payback periods between 11 years and 19 years. The following Figure 18 and Figure 19 will support this based on historical data for the price of natural gas.[57]

Figure 18: Cost of Natural Gas Upper Historical Trendline

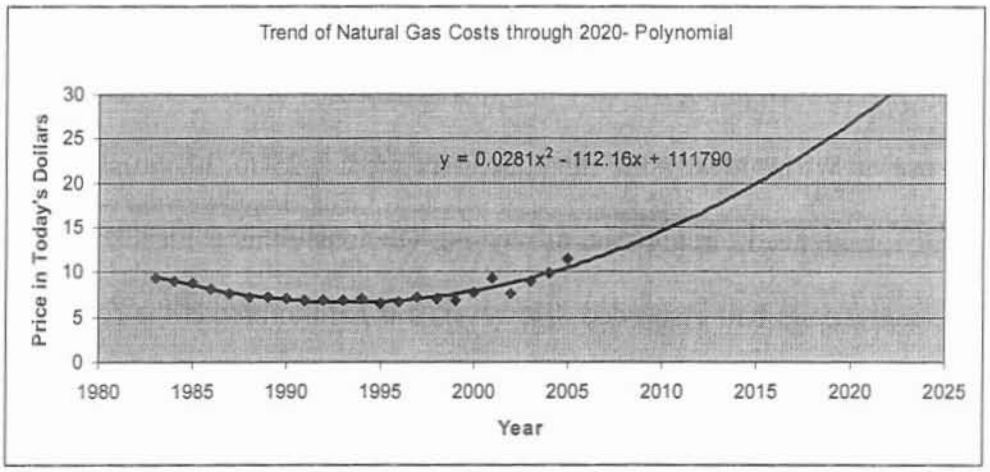
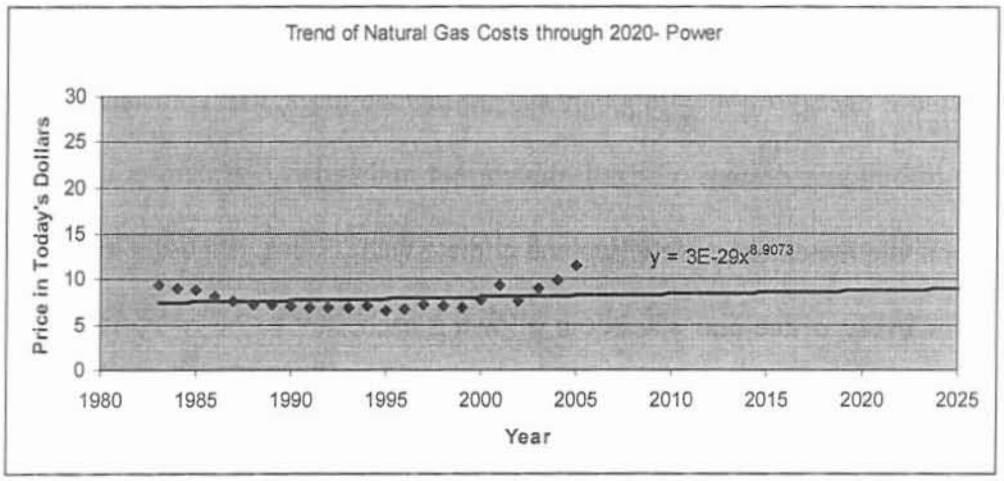


Figure 19: Cost of Natural Gas Lower Historical Trendline



[57] Annual Energy Review. July 27th, 2006. Energy Information Administration. March 15th, 2007. <http://www.eia.doe.gov/emeu/aer/contents.html>

Overall WPI has a lot of room for improvement in terms of its energy use mainly due to the complete lack of renewable resources currently in use. Much of the current infrastructure would not need additional renovation in order to install solar thermal or photovoltaic systems as they are non invasive in nature. Another option that could be considered is opting to pay a small extra fee per KWH of energy used in exchange for receiving energy from renewable resources through the grid. This would not have a payback period, however, as it is an optional gift and not and investment. Instead WPI should invest in further study of solar water heating systems.

Not much is known about the care and maintenance of the new systems that would be proposed for use at WPI. Ideally the manufacturers predict 25 to 30 years of uninterrupted perfect use without the need for any type of repairs. Obviously this is idealistic and it must be assumed that some repairs will be needed. However, it is hard to predict the cost and frequency of this assumption due to a lack of historical data. Therefore, this benefit leaves this term alone assuming that the care and maintenance of the systems will be similar, in cost, to the care and maintenance of the current system at WPI.

A final option for WPI to consider is spending some up front money on retrofitting the campus with more energy efficient appliances, heating/cooling systems, insulation and various other aspects of building design. Overall, the current maintenance system is not very efficient and does not handle the extreme New England climate well. Some proposals include individual thermostats for every office and classroom allowing each user to be as conservative as they choose. Although WPI has made a firm commitment to new construction, they have not shown that same ability when it comes to existing buildings. This minimal cost could significantly reduce the power needs of the campus thereby reducing the need for as many solar panels.

Fewer required solar panels would lead to a lower overall cost and a shorter payback period for a photovoltaic system.

Additionally, these energy reducing upgrades can have secondary money saving effects. For instance, certain health care providers will offer a lower corporate rate if the company uses a certain percentage of natural lighting. This is because natural lighting has been shown to reduce worker illness in many cases. Natural lighting also increases worker job satisfaction. This is the worker will generally feel more comfortable in the working environment. This can be used to reduce other worker benefits. Natural lighting can also make spaces feel bigger so that worker space can be reduced and more employees can be fit into smaller building space. Some companies have even been able to offer a lower average worker salary based on a more desirable work environment using natural lighting. Although this is clearly not the most humanitarian way to use solar power as an economic benefit, it has certainly been proven successful in many companies.

Non-Monetary Reasons for WPI to "Go Solar"

Although WPI may or may not find it financially feasible to invest in solar power for the campus, there are many other reasons for WPI to consider a solar initiative. One such reason is the greater cost to the world of *not* going solar. The main two fuels used by WPI are electricity and natural gas. Within the last year, pollution from power plants have cost Massachusetts residents 78,000 working days, 441 premature births, 104 hospital emergency visits and 8800 asthma attacks.[58]

Furthermore, some coal burning power plants produce electricity at the cost of many health risks to the coal miners including the infamous "black lung." Coal dust kills 2,000 miners

[58] The True Cost of Electricity. Cape Wind, Energy for Life. March 18th, 2007. <http://www.capewind.org/article32.htm>

every year and has cost the government $35 billion since the federal black lung disease benefits program of 1973. Scientists are also not sure how much coal is left below the earth's surface. This means that it is unpredictable how many addition years coal may last as a source of electricity.[59]

For WPI's campus there are many benefits to committing to such a leading edge technology. Not only would WPI reduce their reliance on commercially produced electricity thereby reducing their contribution to the negative impact those fuels have on society, but they may also attract new students and grow as a community. The admissions office has noticed a significant amount of incoming freshmen who are excited about environmentally friendly processes. As a result of this, the campus has committed to making all future buildings "Leadership in Energy and Environmental Design (LEED)" certified. The admissions office has reported that this simple commitment has already begun to attract brighter students.

If WPI announces to its students an initiative to encourage the students to experiment on campus with solar power and provides minimal funding for such projects the students will be exposed to a unique opportunity. Solar power is a leading edge technology that is on the tip of the tongues of many employers looking at WPI engineers. Should WPI choose to give its students such an edge it could raise the caliber of jobs WPI students get accepted to, attract brighter students to WPI and raise to overall reputation of the university. This is very similar to what is happening in both Europe and Japan where brighter students are produced by universities committed to new technologies which then encourage brighter students to attend the university in future years.

If WPI chose to go the route of re-engineering all of the campus's existing buildings to optimize efficiency there are many other secondary benefits that the school may begin to see.

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[59] Ibid.

One excellent way to reduce energy consumption is by maximizing the use of natural lighting. In addition to being absolutely free, natural lighting has also been proven to literally aid students in learning. The Pacific Gas and Electric Company, funded by the California Public Utilities Commission, proved that students in environments rich in natural lighting actually learned between 20% and 26% more than the students with traditional classroom lighting![60] Additionally, the *Metropolis/Saint Paul Business Journal* cited that natural lighting is one of the most effective ways to increase worker comfort and overall productivity.[61] Finally, the National Mental Health Association has cited natural lighting as an effective way of staving off Seasonal Affective Disorder.[62]

Other popular ways to reduce the energy needs of a building include improving air circulation with new heating and cooling units, replacing doors and windows, improving building insulation, or even simply keeping the building warmer in the summer and hotter in the winter. Coincidently improved air circulation was also cited by the *Metropolis/Saint Paul Business Journal* and an additional effective way of increasing worker comfort and productivity.[63]

Another aspect of "going green" that WPI needs to consider is how it affects their values as a university. Eventually, WPI might even be able to purchase solar panels through alumni

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[60] Daylighting in Schools. Heschong Mahone Group. August 20th, 1999. California Board for Energy Efficiency Third Party Program. April 7th, 2007.
<http://www.pge.com/003_save_energy/003c_edu_train/pec/daylight/di_pubs/SchoolDetailed820App.PDF>

[61] Green from the Ground Up. Jonathan Kalstrom. May 28th, 1999. Metropolis/St Paul Business Journal. March 20th, 2007.
<http://www.bizjournals.com/twincities/stories/1999/05/31/focus1.html>

[62] Seasonal Affective Disorder. Mental Health America. April 8th, 2007.
<http://www.nmha.org/infoctr/factsheets/27.cfm>

[63] Green from the Ground Up. Jonathan Kalstrom. May 28th, 1999. Metropolis/St Paul Business Journal. March 20th, 2007.
<http://www.bizjournals.com/twincities/stories/1999/05/31/focus1.html>

who learned about the field while studying at WPI. Through supporting solar panels in education and in purchasing, WPI creates a self re-enforcing feedback loop. WPI's interest in leading technology and its commitment to its students are just one more reason for the school to choose to go solar, it will unite its values as a university with its teaching and purchasing, a rare opportunity for the university.

WPI adopted a mission statement on May 22, 1987. This mission statement was approved by the board of trustees and was reviewed by WPI's faculty and staff. This statement alone practically screams the need to WPI to make a more aggressive effort to adapt solar technologies.

The second most value mentioned in the statement refers to civic contribution, "WPI educates talented men and women in … preparation for careers of …civic contribution." WPI claims to strive for civic contribution in their students, however, one of the hottest topics regarding civic duty today, refers to solar energy and the need for citizens to step up and take action to stop the destruction of our homes and habitats.

The next value that WPI mentions is leadership. Throughout WPI's mission statement, goals, and even its website the phrase "leadership through technology and innovation" is mentioned almost religiously. However, some of the faculty and the board of trustees do not seem to realize the true meaning of that statement. Solar energy is on the forefront of technology and innovation and yet WPI has done practically nothing to be a leader in bringing that technology to its campus.

Finally, the mission statement closes with a reference to dedication in creating, discovering and conveying knowledge to the students. WPI, however, does not create solar technologies to bring to campus and enrich the minds of its students. Neither does WPI convey through example the wealth that good solar energy could bring to the campus. WPI makes no efforts to teach its students about the benefits to humanity, the student's and the faculty's civic duty to research and explore solar technology, or the power that the knowledge of solar technology might hold.

How can WPI find the Funding to "Go Solar"

Although WPI does not have the funding allocated, it has been clearly shown throughout recent campus developments that enormous amounts of funding can be found with the right will power. The Bartlett Center project, completed in 2006, was fully alumni funded at a cost of $5 million raised over a short two year planning period. Given a similar drive to raise money for a solar initiative, the money for initial installation could probably be raised through various donations and grants such that the overall payback period to the school would be unimportant. Additionally, WPI might have some alumni or soon to be alumni that could offer the school discounted installation rates.

If WPI chooses to raise all or part of the money out of their campus budget they would have several choices. The first option would be to take out a loan to fund the initial cost and pay back the loan every year. The monthly payments to such a loan would either be slightly higher than the money they saved via not purchasing some part of their energy though the grid, or their payback period would be slightly longer than predicted based on the interest rate the school is awarded.

Another option for the school would be to fund the project from their yearly budget. At first opponents to solar energy might argue that such a cost would not significantly directly benefit the school and would therefore be hardly justified as a yearly expense. To this extent, there are several aspects of the school's budget that do not directly benefit the school any more or less than the addition of solar power. One part of the budget is the athletic department. School sports teams add another dimension to the student's experience at WPI. This dimension would be that of team spirit, athleticism, and physical activities. Similarly, solar power would add the dimension of civic duty, the opportunity for personal exploration in a leading edge field, and student interest in their impact on their surrounding environment.

The yearly budget for WPI's sports teams is a grand total of $1.7 million with $9,762 devoted to recruiting expenses alone and $192,000 delegated for the Men's football team. Similar schools such as MIT spend $2.6 million a year on sports teams. Boston University spends as much as $20.8 million on sports and almost $1 million on recruiting expenses! Surely with expenses of this magnitude in something that is simply a "recruiting technique" for the school, the cost of solar power is not unjustified.

Ideally, WPI would not replace its athletics or other extra curricular activities with an investment in solar energy but simply use these projects as an example of what the school has valued in the past. Perhaps it is time for WPI to take a firm stance on solar technology and recognize that it is just as important to a well rounded education as humanities, sports, and art. If WPI understands that a commitment to a better environment for current and future generations is something that should be embraced in a learning environment, WPI will have a clear competitive advantage. That competitive advantage will drive other schools to do the same thing through investing in green technologies just as an investment in sports teams or theater has done in the past.

Additionally, one of the most common ways for large non-profit organizations to fund solar projects is through government funding. On March 8^{th}, 2007 the United States Department of Energy submitted to congress a proposal for $168 million to be dedicated to solar research and installation.[64] The idea is that this investment will allow solar development to become more economical and widely available. Many loan organizations are also beginning to give new consideration to commercial projects using solar power. The idea is that utilities are a sound investment given the lengthy 20 to 30 year lifespan of the panels.

Major Players

In order for WPI to commit to environmental change, an agreement must be made on campus among several key players to push for funding to go towards a solar initiative in all future new development. Some of those key players have really helped WPI begin to go in the right direction with new LEED initiatives but just these few players need many others to join with them if the entire school should agree to go solar.

WPI's current solar effort is largely attributed to Judith Nitche. Her civil engineering design firm first brought green building technologies to her attention in various work for environmentally minded clients. Nitche takes a very active role on WPI's campus, serving on the board of trustees and also heading up the site design on all of WPI's new construction. The site design has thus far all been "sustainable design" mostly through Nitche's pressure on the board but also due to the minimal cost implications of the design.

Nitche successfully convinced the board to move even farther in terms of sustainable design through the creation of two green buildings on campus. However, Nitche has failed to really push for solar power on campus. It should be fairly easy based on her experience of fundraising as well as her connections with other persons on campus with the power to make construction and funding decisions. If Nitche pushes the board for solar funding in the same way

[64] DOE Selects 13 Projects to Receive $168 Million in Funding. Lowell, MA. Marhc 8th, 2007. United States Department of Energy. April 10th, 2007. < http://www.doe.gov/news/4855.htm>

that she pushed for LEED building and sustainable site design, the board should comply giving solar power the support it needs from at least one section of WPI.

The alumni are also very important players that must be heavily involved in a new commitment to solar energy. Most of the funding for all of WPI's new construction comes from generous donations from alumni and other outside donors. The department of alumni relations would probably need to survey the opinions of some of the school's largest donors to see what percent of them has a vested interest in solar technologies. If there is not a large enough support base then the department should start sending out various forms of public promotion for solar power. This should drum up a good deal of support. Also influential speakers should be brought into various alumni events to raise awareness. Unfortunately, there are at least 100,000 alumni, far more than can be reached through the alumni relations office, which means that a good portion of the support from alumni will depend entirely on the reputation mass media gives to solar power. Hopefully with the support of the media towards green energy, the support of the WPI's alumni base will follow.

Another factor that is necessary to the support of solar power on campus is the support of plant services. Although they will not provide direct funding to such a project, the support of key personnel is absolutely essential. The staff of plant services will need to be well educated in the care and maintenance of solar panels. Although most home owners would hire out maintenance, the school requires most of its equipment to be serviceable by onsite staff. If the maintenance crew does not believe that they can do all of the servicing for solar panels on site the school will not support funding the operation. However, if there is adequate training provided for plant servicing, winning their support for solar power should not be difficult.

Finally, one of the most important groups of people that need to support solar power is the student body. Although directly, the students will not have a significant impact on the purchase of the panels, they will be the driving force to drum up initial support though out all of the other major players. The students are very interested in what happens on campus because they live there, as a result, if the students support or do not support something on campus they will be very outspoken on the subject and use what little power they have to make a significant impact on the life of the project. Also, most of the students on campus will eventually be alumni who can help financially support the care, maintenance and updating of any solar facilities placed on campus do to their actions.

What Needs to Happen for WPI to Change

Opponents to solar energy can easily make up a dozen excuses for why solar energy is not currently as popular as traditional sources of energy. Some of the most common reasons are technological development, availability, initial monetary commitment, and payback periods. However, in the end it is all about the people who support solar initiatives and how hard they work to bring the new technology to campus. The beginning of change is easily accredited to those that make it happen.

A recent article in the *Boston globe* suggested that the initial force for change in a university first comes thorough the student body. Although the article goes on to admit that real change only happens once the faculty are involved and behind the plan, the students are the ones that must initially bring the idea to the table. One example of how students brought green concepts to campus was at Tufts University where Kyle Maxwell began in his freshman year to try to get the school's administration to buy renewable energy credits. The idea is that though buying the credits which are used to reduce the environmental impact carbon emissions and other sources of pollution are having on the earth, people can live a "neutral" lifestyle, if they buy enough credits, they can have zero impact on their surroundings.

Another example can be found at MIT where students competed in an environmental competition which they used to convince their school to "go green" and a completely unique way. The students proposed a design for a "refueling station" where the old cooking oil from the campus dining hall can be converted into bio-diesel that can then be used by the campus shuttle service. The students at Northeastern also used an environmental competition to impact their schools environmental stance. The students pitted the various residential halls against each other to see who could use the least amount of energy. The students ended up recording a significant reduction in energy use which they hope will carry on though out the year.

An excellent success story that started with the students but was finished with a combined effort by students, faculty and staff can be found at Harvard University. Harvard has 20 LEED projects on campus including both renovations and new construction. Harvard also invests $100,000 annually in renewable energy research and purchases energy credits to offset 7% of its energy consumption.

All of these changes were accomplished on campuses because of what the students, faculty, and staff all uniformly agreed were best for the school. This requires a great deal of money, as well as political alliance in investing in green energy and a campus cannot be of two minds about the situation. There needs to be unquestioned agreement about what the school wants to do any how it will affect the schools future before that school can even begin to discuss a commitment to a green lifestyle.

With the support of students throughout WPI's campus there should be unified support among the key players if the proposed solar panel plan meets the schools fiscal as well as moral vision. Although the addition of solar thermal panels to heat the campus's hot water are financially feasible, at least to some degree, and keep with the schools 5-10 year payback period, the addition of photovoltaic to provide the school with clean energy is not so promising. As a result there will need to be generous outside donations.

Although any form of outside income would suffice if provided in large enough quantities, one of the most feasible in addition to alumni and trustee donations is the idea of government incentives. In many states governments have provided a wealth of options for homeowners and businesses to afford solar power set-ups. In Massachusetts there are various tax rebates offered to include up to 50% of the initial cost of a solar investment,[65] however, for a non profit organization such as WPI these rebates do not lessen the financial burden. Instead, states need to become more proactive, offering not just rebates but outright subsidies to help finance such large projects. The government will easily see the returns though not having to subsidize public utilities, and less reliance on foreign oil. For WPI to go solar, higher government incentives will be absolutely necessary.

In addition to higher sources of outside income to finance a solar project, WPI would be more willing, and more likely to finance a solar project if the panels were more efficient. In recent years there has truly been a break through in panel efficiency; however, the current average of 11% efficiency simply creates a very long payback period. With higher efficiency, fewer panels would be needed and the total cost will be less. In the next few years photovoltaic technology with efficiency as high as 33% should begin to be commercially available, making

[65] MTC - Small Renewables Initiative Rebate. September 18th, 2006. Database of State Incentives for Renewables and Energy. <http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=MA22F&state=MA&CurrentPageID=1&RE=1&EE=1>

payback periods half of what they currently are resulting in much lower up front costs. This will also be necessary for WPI to take on a solar initiative.

If the appropriate key players are convinced of the benefits of solar power on WPI's campus, and the initial monetary investment of solar power has been subsidized by the government as well as adequate donations from the alumni and trustees there is no reason the campus should not go solar. This initiative must first be taken up by people who feel strongly about the introduction of solar power, most likely the student body, and must be carried out by all those convinced of the benefits, the trustees, the faculty, staff and alumni. If the program is supported by all the correct individuals there is no reason it should not be carried out.

How This Ties into New England as a Whole

WPI, although simply regarded as a school in this study, can easily serve as a microcosm that will present all of the benefits as well as hardships of installing solar panels in any building throughout New England. WPI has both residential and commercial buildings and serves the needs of its "citizens," or students. WPI also has financial conditions similar to both that of a home owner, a commercial company, and a city government. The university also has many differences ranging from its tax status, which varies greatly from that of a common resident or corporation, as well as its complex structure for decision making.

One of the first ways that WPI is similar to many other buildings throughout New England is that it has to serve many various needs, which in some way, relate to almost every type of building. WPI has to house its students in a type of residential facility to provide bedrooms, bathrooms, and eating areas. This can be compared to the home owners throughout the New England region. The energy needs per housed student will be similar to the needs of many of the average surrounding families. Although the actually needs per student will be considerable less that the needs per person in a household, the appliances and types of energy use are comparable. For instance, WPI can make simple fixes such as more energy efficient appliances or thicker insulation which will drastically lower their energy consumption. This is very similar to the typical fixes a home owner will have to make to a home in order to adjust to the energy output of solar panels.

WPI also has commercial buildings such as a campus center, various academic buildings, and a library. These buildings all serve as typical examples of the needs of a commercial building owner. The owner of a commercial building will find that new, larger, more efficient ventilation and heating systems will be necessary, and that the benefits to many higher efficiency changes, such as using more natural light in working areas, can have a dramatic impact on worker productivity. These are some of the intangible benefits to a solar campus that WPI will see, and hopefully similar results will be seen in other commercial buildings.

Another similarity between WPI and other buildings throughout New England is the sun exposure. Although WPI is located in Worcester, Massachusetts, the difference in sun exposure between the campus and other places throughout New England is very minimal. Although geographically, New England covers a fairly large region, the amount of sun that each part of the region receives throughout the day is very similar to what is shined on WPI.

Financially speaking, WPI is very similar to that of a corporation as well as a city. Similar to a corporation, WPI cannot easily operate based on the moral feelings of a few individuals. Instead, a board of trustees, or in the case of a company a board of directors, must all agree that the decision is financially sound. Therefore, the implementation of solar energy must be done conservatively with a fairly short payback period and an overall net gain.

Similar to a city, WPI must also answer to the need of its "citizens" or in the case of the school, its alumni as well as current students. This base of people, similar to a city, is very large and results in difficult decision making. Additionally, the group of people is so large and united on such few viewpoints that their support for the school is largely based on media bias. If the popular media are against solar energy, it is more than likely that the "citizens" will also be against the idea and it will never be put into action. However, if the "citizens" are in favor of solar energy due to media support then the town will be able to go through with the idea.

However, there are many differences between the school and the rest of New England that certainly must be taken into account when comparing the situations. One of the most important ones is that although WPI is very similar to a town in its tax status, it is vastly different from what most residences and commercial businesses face. While WPI cannot apply for or receive any current tax rebate programs offered in Massachusetts, and a town would not be eligible either, many home and business owners can receive such incentives. This can make a huge difference in the financial burden of a solar set-up.

For a home owner, the solar needs would often be quite small and the optional $50,000 per home available to them could make the system virtually free provided it properly applies to the yearly taxes that the home owner pays. For business owners, the 50,000$ could easily cover at least half the cost of a system, depending on the size of the building. Given the larger cost seen by the business owners, they are even more likely to receive the tax rebate because the solar panels will place them under a larger financial burden.

Another difference is the decision making process for WPI compared to that of a home owner. Although WPI is very similar to both business and municipal spending in that the main concern for a solar set-up is its payback period, home owners can be a little more "frivolous" with their spending. A business cannot usually make a purchase based on its morals or environmental impact because it is not popularly regarded as making good "business sense." However, the home owner does not have a board of directors to answer to allowing him or her to spend money with as much as a 30 year payback period, the typical duration of a home mortgage. The home owner could even go so far as to make purchase due to personal choice with no payback period at all allowing the installation of solar panels to be made even easier.

These differences should make it easier for the average home owner or business to invest in an initial solar program. If WPI can find the funding and the support for such a project, the reasons should be well laid out for how and why other similar places in the region should be able to initiate solar use. This is, in part, why it is so important for universities as other campus to take the lead in solar power and pave the way for all other buildings to follow suit.

Conclusion

The history of solar energy begins with the first energy produced by humans through burning fossil fuels. Progressively, people stepped closer to more carbon based fuels, from wood to coal to oil and then to natural gas. The technology is now ready for humans to start being more aware of how this method of harvesting energy affects their surroundings. People now have the unique ability to chart climate change, notice the causes and affects of their actions and change their impact on the environment. The relatively new idea of solar energy is finally starting to be developed into a viable energy alternative that is ready to be used.

There are various ways for people to use solar technology on large scales. One example being simple residential use with excess energy sent back into the grid. Another, more complex idea is to completely reinvent the idea of power plants as a facility for storing energy rather than producing it. Both of these ideas provide perfectly sound alternatives to conventional energy production. The main point, however, is simply that panels are capable of producing more than enough energy to sustain the current population at a reasonable expense.

The only thing that is left to consider is who will start the solar revolution. Countries around the world need to consider how their economic situations will allow them to excel or cause them to be left behind. Action must start on an individual level, with small scale conversions like a solar initiative at WPI. Similar to an initiative at WPI the students or the citizens must start the initiative. It is, at first, only a question of the right thing to do, the civic duty of every person. Although eventually green energy might easily be the most economic energy choice it has to start by simply being the right choice before the world will change.

Appendix A1- Technology

Table 1: A Wafer-Based System

Solar Radiance (kWh/sq.m./day)	4.5
Cost of Electricity ($/kWh)	0.125
Number of Panels	45
Cost per Panel ($)	750
Power Output (kW)	0.125
Total Yearly Output (kWh)	9239.0625
Percentage of Total Usage	73912.5
Savings per Year ($)	1154.882813
Total Cost	33750
ROI (yrs.)	29.22374429

Table 2: A Thin-Film System

Yearly Usage (kWh)	12000
Useable Roof Space (sq.m.)	45
Solar Radiance (kWh/sq.m./day)	4.5
Cost of Electricity ($/kWh)	0.125
Number of Panels	45
Cost per Panel ($)	323
Power Output (kW)	0.064
Total Yearly Output (kWh)	4730.4
Percentage of Total Usage	0.3942
Savings per Year ($)	591.3
Total Cost	14535
ROI (yrs.)	24.58143075

Table 3: A Flat-plate System

Yearly Usage (kWh)	24000
Useable Roof Space (sq.m.)	45
Solar Radiance (kWh/sq.m./day)	4.5
Cost of Electricity ($/kWh)	0.125
Number of Panels	22
Cost per Panel ($)	700
Power Output (kW)	1.6
Total Yearly Output (kWh)	57816
Percentage of Total Usage	240.90%
Savings per Year ($)	3000
Total Cost	15400
ROI (yrs.)	5.133333333

Table 4: An Evacuated Tube System

Yearly Usage (kWh)	24000
Useable Roof Space (sq.m.)	45
Solar Radiance (kWh/sq.m./day)	4.5
Cost of Electricity ($/kWh)	0.125
Number of Panels	15
Cost per Panel ($)	800
Power Output (kW)	2.4
Total Yearly Output (kWh)	59130
Percentage of Total Usage	2.46375
Savings per Year ($)	3000
Total Cost	12000
ROI (yrs.)	4

Table 5: Return on Investment Per Technology

Technology	**Return on Investment (yrs.)**
Photovoltaic	
Wafer-Based	29.22374
Thin-Film	24.58143
Solar Thermal	
Flat-plate	5.133333
Evacuated Tube	4

Appendix A2- Economics

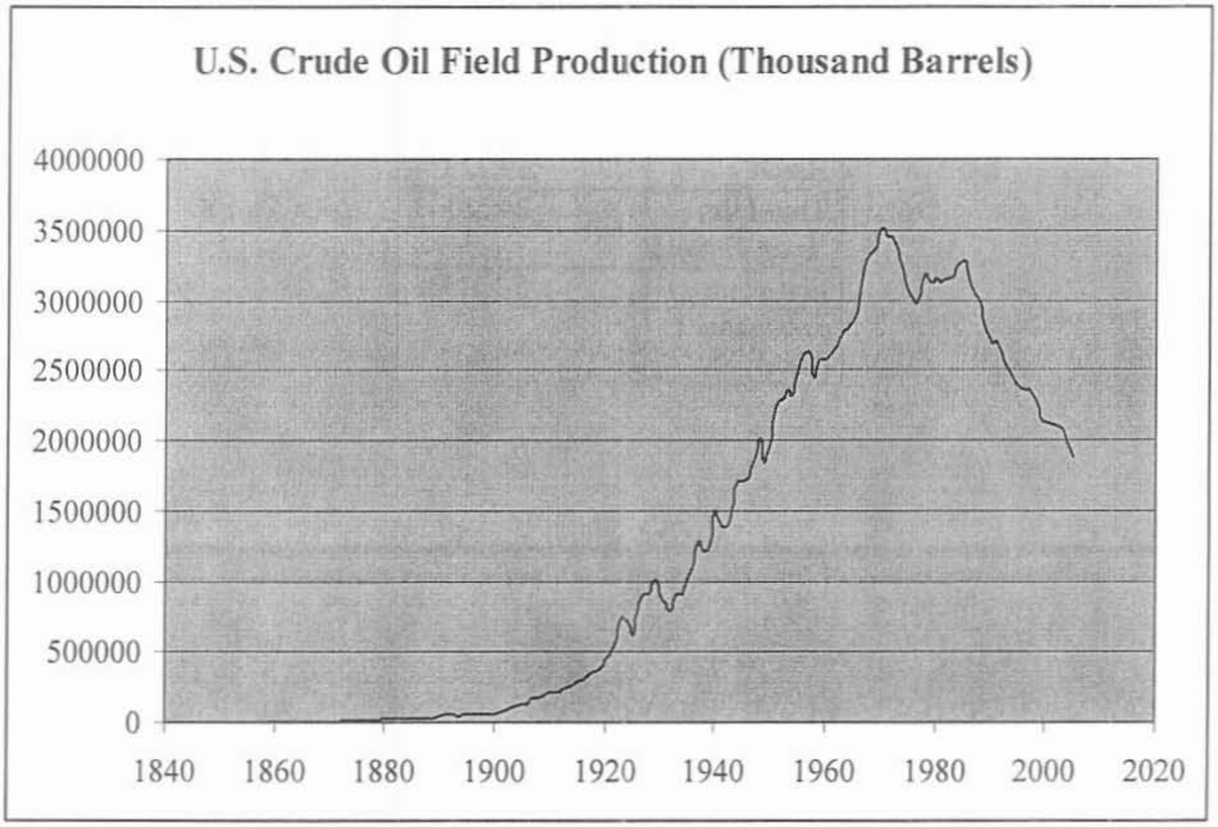
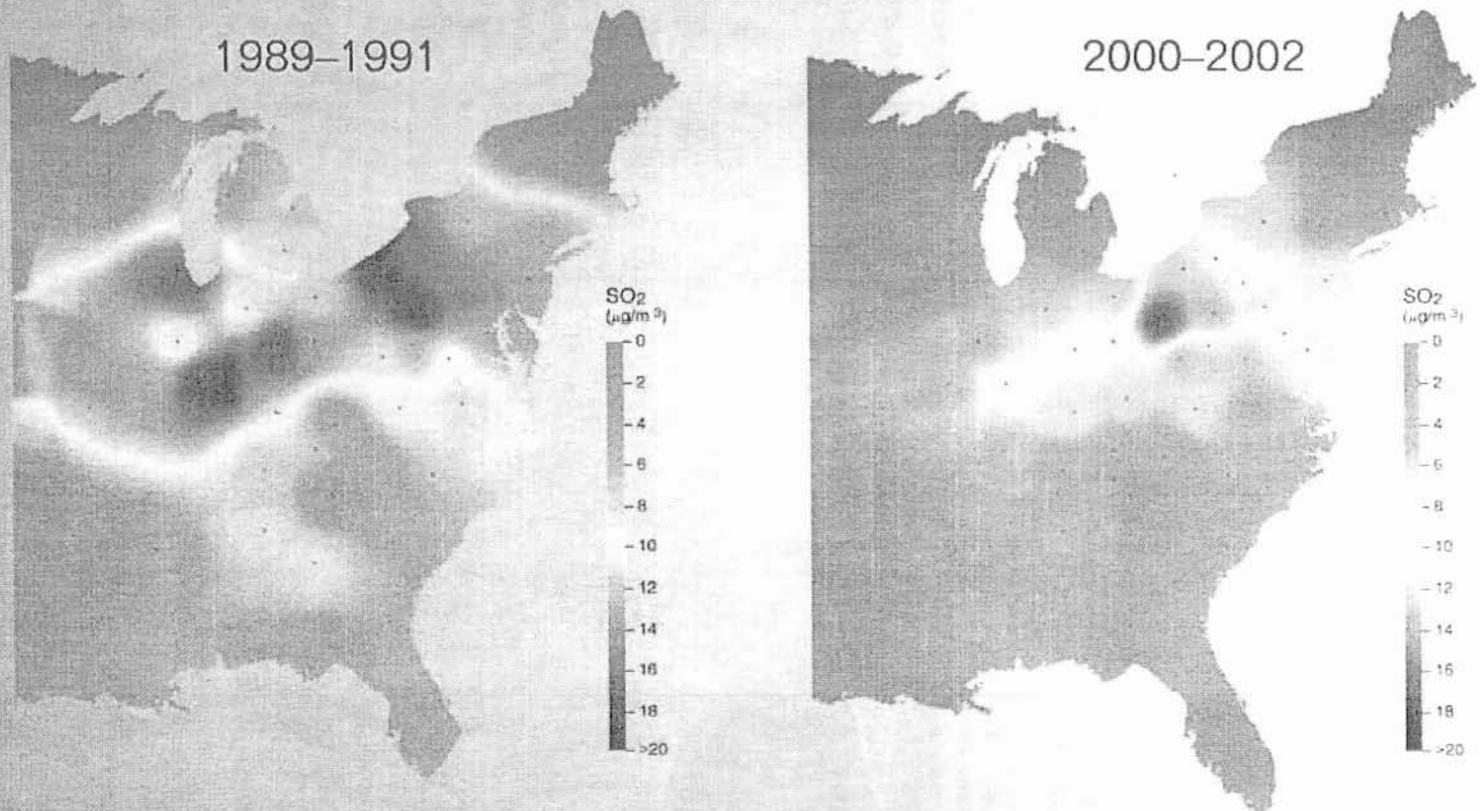


Figure 20
(Data from: Energy Information Administration,
<http://tonto.eia.doe.gov/dnav/pet/hist/mcrfpus1A.htm>)

FIGURE 16. Comparison of annual ambient sulfur dioxide (SO_2) concentrations in the rural eastern United States



Source: CASTNET

Figure 21

(Source: National Oceanic and Atmospheric Administration, <http://www.esrl.noaa.gov/csd/AQRS/reports/napapreport05.pdf>)

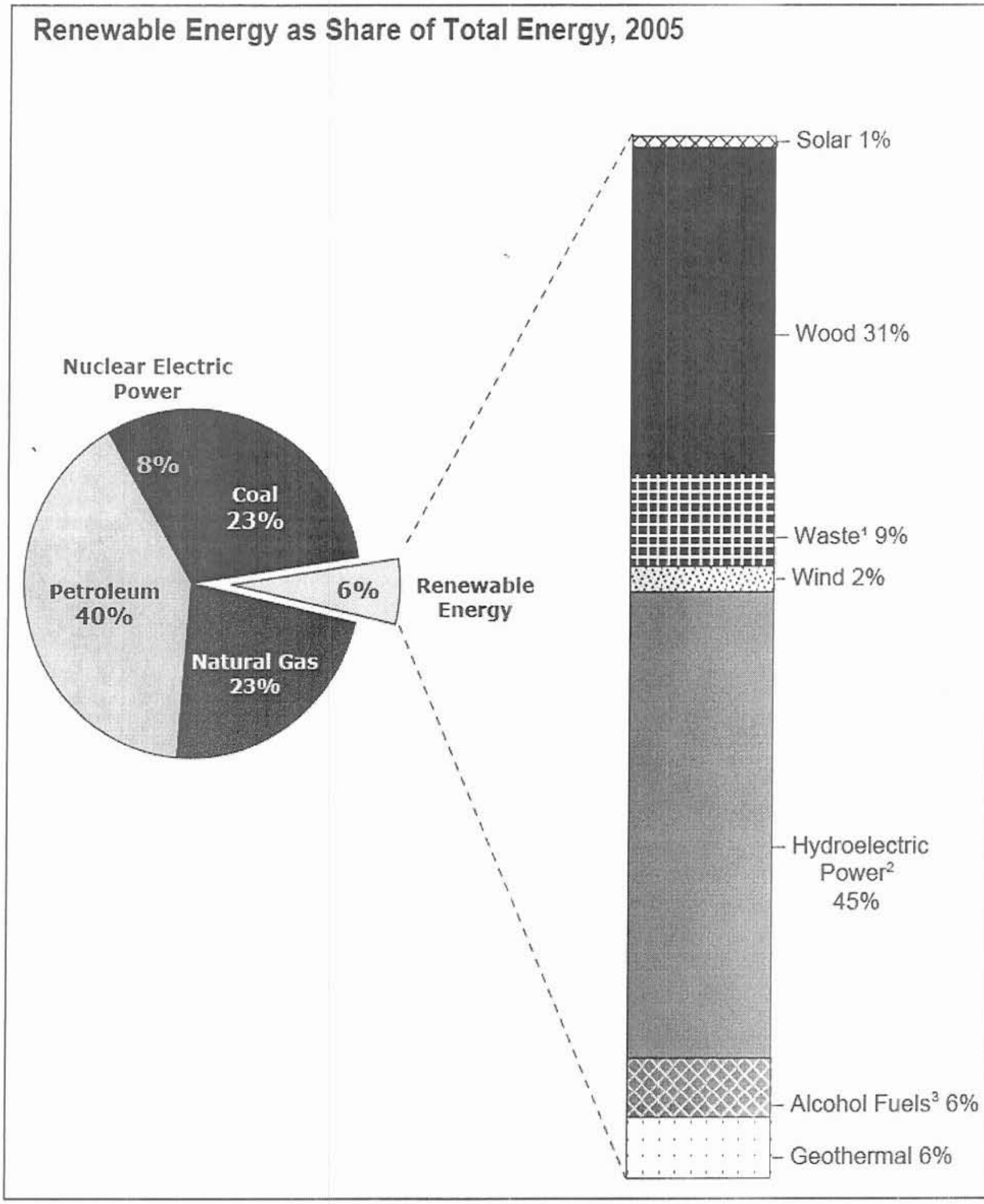


Figure 22

(Source: Energy Information Administration, <http://www.eia.doe.gov/aer/pdf/aer.pdf>)

Solar Thermal Collectors*

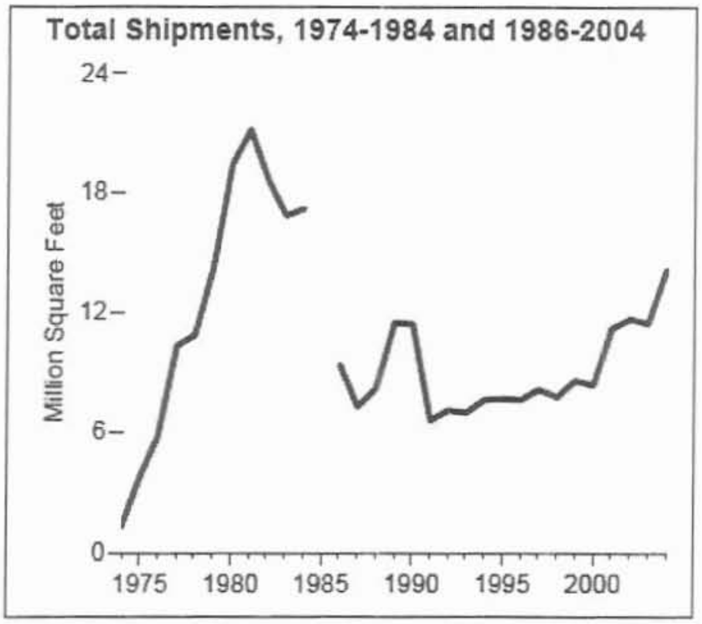


Figure 23

(Source: Energy Information Administration, <http://www.eia.doe.gov/aer/pdf/aer.pdf>)

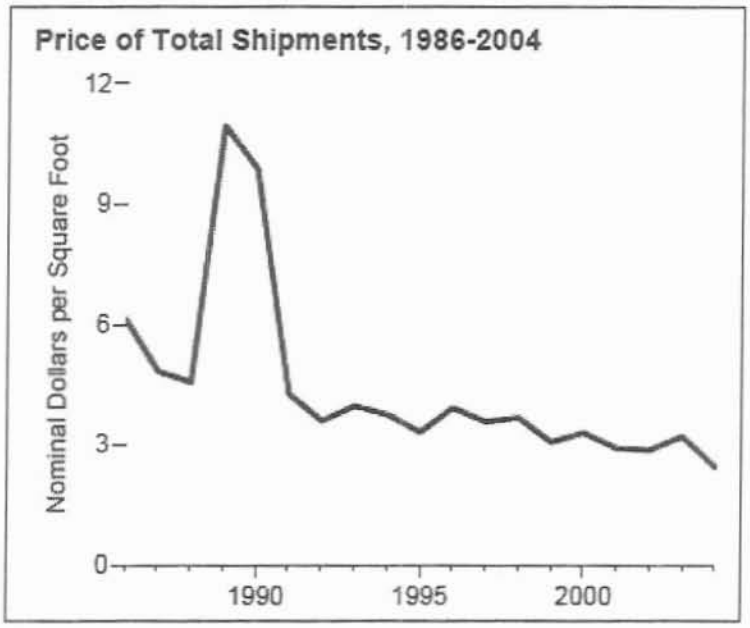


Figure 24

(Source: Energy Information Administration, <http://www.eia.doe.gov/aer/pdf/aer.pdf>)

*Data was not collected for 1985.

Photovoltaic Cell and Module

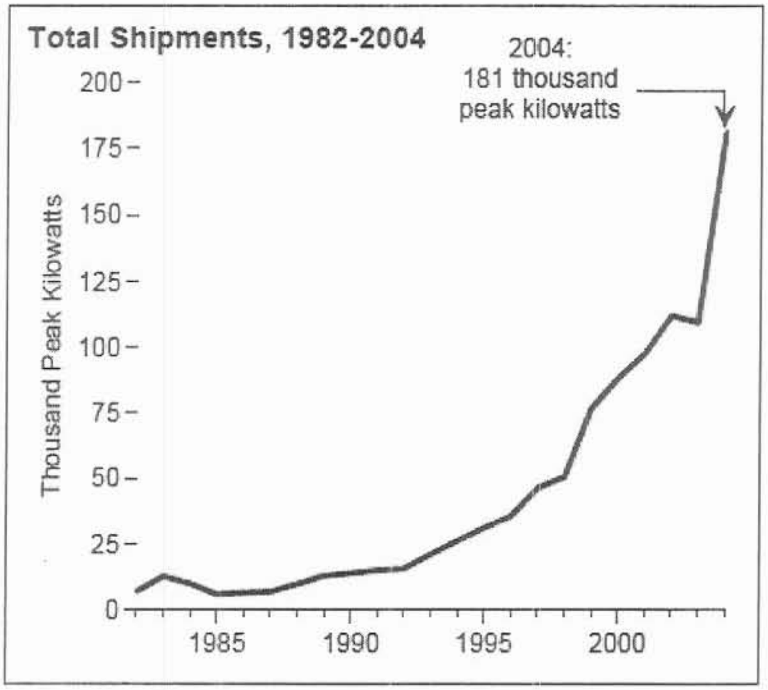


Figure 25

(Source: Energy Information Administration, <http://www.eia.doe.gov/aer/pdf/aer.pdf>)

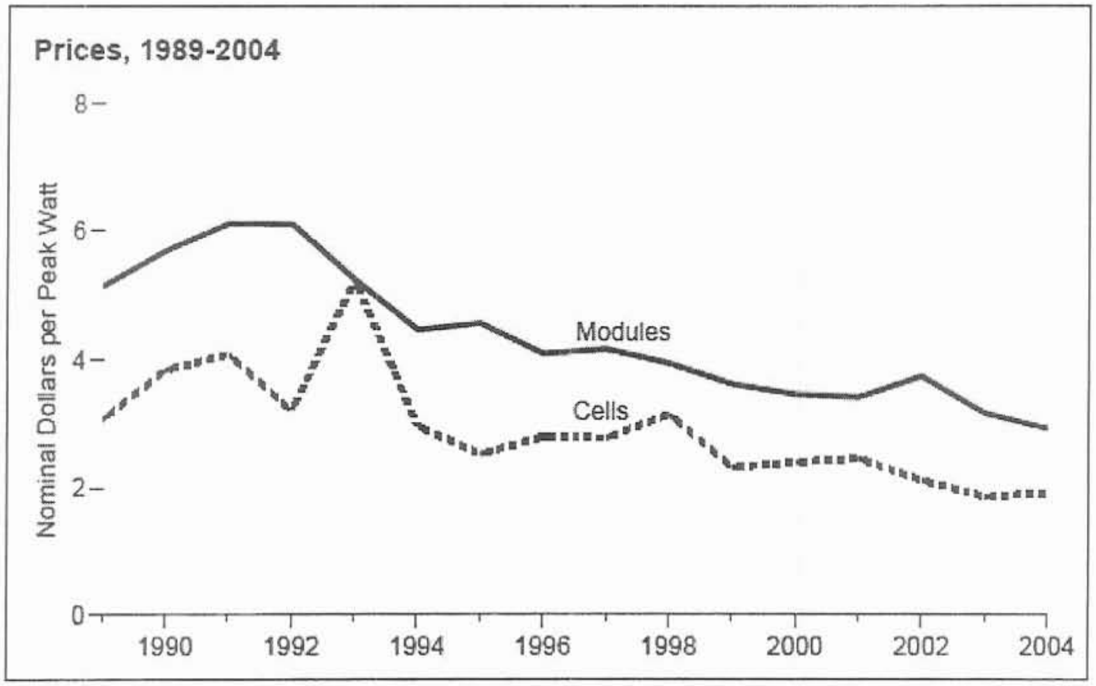


Figure 26

(Source: Energy Information Administration, <http://www.eia.doe.gov/aer/pdf/aer.pdf>)

Appendix A3- WPI Current Use

Table 6: Monthly Sun Data

Monthly Sun Data

January	1.90	KwH/m^2/day
February	2.80	KwH/m^2/day
March	3.80	KwH/m^2/day
April	4.70	KwH/m^2/day
May	5.50	KwH/m^2/day
June	6.00	KwH/m^2/day
July	5.90	KwH/m^2/day
August	5.20	KwH/m^2/day
September	4.20	KwH/m^2/day
October	3.00	KwH/m^2/day
November	1.90	KwH/m^2/day
December	1.50	KwH/m^2/day
January	3.90	KwH/m^2/day
Yearly Average	3.87	KwH/m^2/day

Table 7: Constants for Energy Calculations

Constants

Total Roof Space (Feet)	477574.3333
Total Roof Space (Square Meters)	44390.83259
Efficency of Solar Panels	11.34%
Size of Panel (Square meters)	0.94
Cost of Panel	$495.00
Size of Thermal Panel (Square Meters)	1.859
Efficency of Solar Thermal	53.79%
Total Number of Panels	23878.87713
Cost of Thermal Panel	$ 560.00

Table 8: Electricity Cost Analysis at WPI

Electricity Estimations		
Maximum Energy Produced Per Day	171,758.38	KwH
Maximum Energy Produced Per Year	62,691,806.99	KwH
Energy Produced Per Year (Reduced by Efficency)	7,109,250.91	KwH
Cost of Installation of Panels	**$23,376,023.54**	
Historical Cost of Electricity	$3,131,683.00	
Historical Electricity Demands	22,144,550.00	KwH
Percent Energy Usage is Reduced by	32.10%	
Savings Per Year	$1,005,390.50	
Payback Period	**23.25069066**	**Years**
Assuming the cost of electricity rises by 40%		
Savings Per Year	$1,407,546.70	
Payback Period	16.60763619	Years
Assuming the cost of electricity falls by 20%		
Savings Per Year	$804,312.40	
Payback Period	29.06336333	Years

Table 9: Gas Cost Anaylsis at WPI

Gas Estimations		
Energy Produced Per Year	18,140,493.18	Kwh
Current Gas Usage	980,000.00	Therms
Conversion Factor	29.30	Therms/KwH
Gas Usage	28714000	Kwh
Percent of Usage Produced	63.18%	
Historical Cost of Gas Per Year	$1,393,600.00	
Total Cost of Installation	**13,372,171.19**	
Total Savings Per Year	$880,427.36	
Payback Period	**15.18827306**	
Assuming the cost of gas rises by 40%		
Savings Per Year	$1,232,598.31	
Payback Period	10.84876647	Years
Assuming the cost of gas falls by 20%		
Savings Per Year	$704,341.89	
Payback Period	18.98534132	Years

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