Geothermal Energy:

A Feasibility Study on the Application of Ground Source Heat Pumps

An Interactive Qualifying Project Report
Submitted to the Faculty
of the
WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the
Degree of Bachelor of Science

By Jake Brown, Anna Maziarz and Brian C Mercer

_________________ _________________ _________________

Adviser: Professor Robert W. Thompson

____

Date: May __th, 2010

Abstract

The purpose of this report was to study the feasibility of ground source heats pumps as an alternative energy. Specifically this pertains to the application of ground source heat pumps in educational facilities, such as WPI, and residential areas in order to offset a portion of these building's heating and cooling duties. It was concluded that ground source heat pumps are an effective method for reducing the cost and energy use in building heating and cooling.

Executive Summary

In the current world economy the need for energy is the strongest driving force behind new economic development. The ever increasing global energy consumption must be continually met in order to ensure continued maintenance of quality of life and operation of industry and commerce. While there are many renewable energy technologies currently in use, the primary source of energy within the United States are fossil fuels. As a result of their origin from within the earth by processes such as anaerobic decomposition, fossil fuels are typically regarded as a finite resource. By continuing to harvest the current fossil fuel resources we are running the risk of depleting them enough to the point that it is no longer economically viable to utilize fossil fuels as our primary energy source. There will be a debatable amount of lag time between now and when we will reach the point where fossil fuels are no longer economically viable. During this time period it is vital to investigate new energy resources to exploit in order to offset the fraction of our energy consumption that is satisfied by fossil fuels. If we are unable to develop alternative energies to a significant level the US and Global economies stand to suffer catastrophic recessions as energy costs skyrocket.

Another concern with fossil fuels is their affect on the net world carbon balance. By extracting sequestered carbon mass within the earth's crust and liberating it to the atmosphere by combustion there is a net accumulation in the atmosphere. There are many theories concerning the effects of anthropogenic atmospheric carbon emissions, but there is a consistent concern over greenhouse gas effects caused by increased atmospheric carbon dioxide concentrations. By shifting to carbon neutral energy technologies it will be possible to mitigate some of the atmospheric carbon emissions in order to affect a net decrease in atmospheric carbon concentrations.

There are many alternative renewable energy technologies currently in various stages of development and deployment; including biomass, hydroelectric, solar, tidal, wave, wind and geothermal. There is also Nuclear Electric power, an already well established method of power generation. Each technology is well suited for particular applications, for instance biomass can be adapted to provide liquid fuels that can offset the traditional petroleum based gasoline and diesel fuels used for transportation. Nuclear power and hydroelectric

energy on the other hand are much more appropriately suited for large scale stationary power generation. While it is probable that a combination of technologies from the entire spectrum of alternative energies will be necessary in order to offset the United States' fossil fuel diet certain technologies have greater promise. In particular, the universally applicable and small scale nature of ground source heat pumps makes them a particularly attractive option. Since ground source heat pumps can be used nearly anywhere and installed at modest costs, they offer the potential for a systematic reduction in fossil fuel supply requirements.

In order to provide a full understanding of the necessity for alternative energies the information on geothermal power is prefaced with a background on the current state of World energy usage, US energy usage, climatic and energy security concerns with current energy sources, and finally an overview of the various other alternative energies currently in deployment and development. Next the science behind geothermal power and the various ways of harnessing it are outlined. This leads into a background on various design considerations for ground source heat pumps. An analysis of the economics of operation, basically a lifecycle analysis of the costs, issues and procedures during installation, operation and after a set buyback period of time, will provide insight into how much cost benefit there is in installing a ground source heat pump system. A section analyzing pre-existing GSHP installations provides a measure of real world results, which will preface our recommendations for new installations of GSHP equipment. Finally a concluding section that summarizes the key points from previous sections, analyzes the feasibility in both large scale and small scale applications, and investigates how environmentally friendly GSHP technology really is, will contain opinions on whether or not ground source heat pumps are a worth alternative energy technology to pursue.

Table of Contents

Table of Figures

Part 1: The Need for Alternative Energies

In order to understand why so much capital and effort is exerted into alternative energy technologies, an investigation into the need for alternative energies was conducted. Within this section a background on energy consumption within the United States, and throughout the World will be laid out. Expanding on this, an investigation into issues with the current energy economy, including climate change concerns and energy security, will be presented. Additionally, a brief background on the alternatives to fossil fuels will be included.

1.1 World Energy Consumption

The world's populace relies on energy to maintain quality of life and to sustain industry and commerce. Energy is what powers modern lives; it is the driving force behind technology, transport and economic development. Without a constant cheap and plentiful supply of energy the current age of rapid technological advancement and high standards of living will grind to a halt (Cipiti, 2007). Unfortunately, this supply is strained by expanding populations, and increasing energy demands. This condition will lead us to face, "the greatest engineering challenge of this century, [satisfying] our voracious appetite for energy resources without causing irreversible harm to our world" (Cipiti, 2007).

1.1.1 World Energy Consumption History

Over the past thirty years global energy consumption has grown steadily, and at increasing rates. From 1986 to 1996 Global energy production increased from 316.9 quadrillion BTU to 373.4 quadrillion BTU, representing a 17.8% increase, while from 1996 to 2006 world production increased from 373.4 quadrillion BTU to 469.4 quadrillion BTU, or a 25.7% increase (World Energy Overview, 2008). It follows that as energy production increases, so does consumption. Shown in Figure 1 is a graph based on Energy Information Administration data that plots total world energy production from 1980 until 2006; there is a clear sudden increase following the year 2002 that corresponds with the increasing rate of world energy consumption.

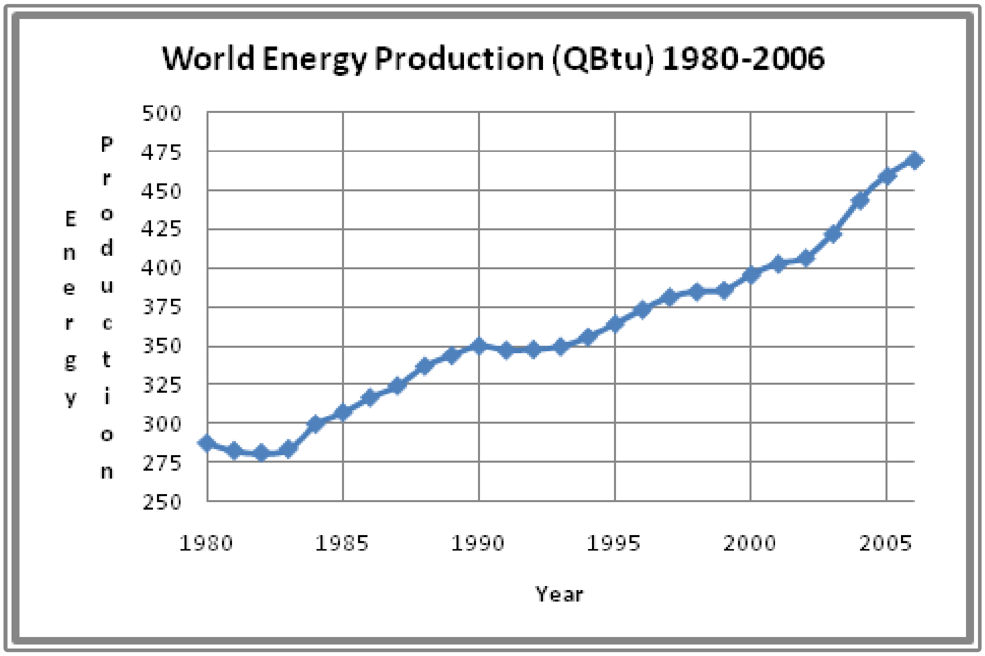


Figure 1 - World Energy Production - http://www.eia.doe.gov/pub/international/iealf/table29.xls

Clearly this exponential trend poses serious issues; by extrapolating out current consumption trends, the EIA has predicted that global energy consumption will reach 678 Quadrillion BTUs by 2030, a 44% increase over 2006 levels (World Energy and Economic Outlook, 2009). As shown in Figure 2 there will be a steady increase in energy consumption leading into 2030. Ever increasing energy consumption will strain energy supplies and cause an increased rate of finite energy resource depletion.

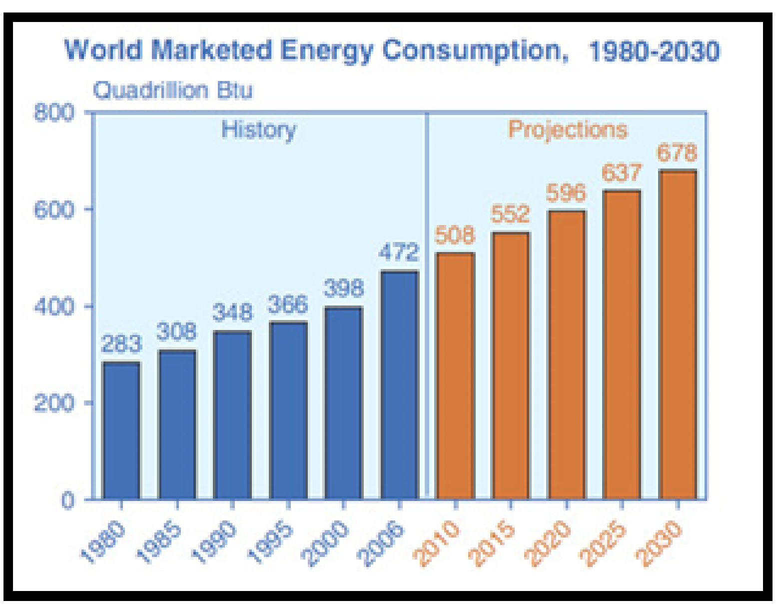


Figure 2–Global Energy Consumption History and Projections - http://www.eia.doe.gov/oiaf/ieo/world.html

1.1.2 World Population Growth

While the world energy consumption rate is a dynamic and complex system it is possible to assign consistently increasing industrial development and standards of living as the primary driving force. These two influences on energy consumption are significantly compounded by increasing global population. Based on UN estimates the world population is estimated to reach between 7.4 and 8.8 billion by 2030 (shown in Figure 3). This increase in population represents between a 13.9% and 35.4% increase in population over 2006 levels. Relative to the predicted 44% increase in energy consumption this is significantly lower, suggesting increases in energy consumption both from population increase and from expanding industrialization and increased standards of living in less advanced countries. Regardless the expanding world population will exert its strain upon energy resources.

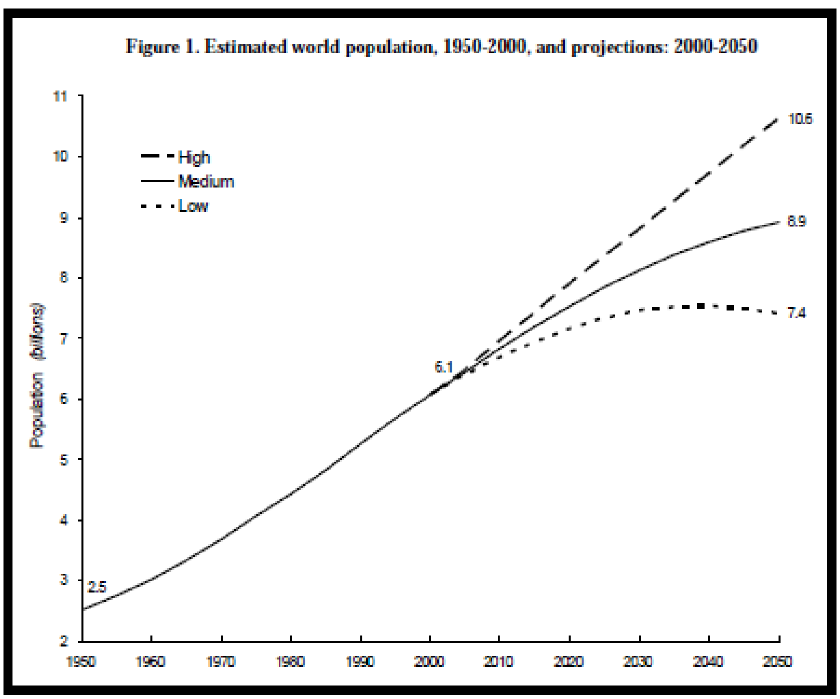


Figure 3- Expected World Population - http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf

1.1.3 World Industrialization

Another area of concern for global energy consumption is the effect rapidly industrializing developing nations, such as China will have. While not yet on par with the energy use of some of the other large world economies, China's economy, which has expanded exponentially since 2001, has caused a proportional increase in energy use. This trend is clearly shown in Figure 4, where the per capita energy consumption increased from roughly 50% of the World level in 2001, to roughly 80% of the World level by 2007. This is symptomatic of any expanding economy, and is a reason for concern. If this expansion of energy requirements is not modified the worldwide energy use will continue to increase as more nations begin industrialization and the assent towards greater living standards.

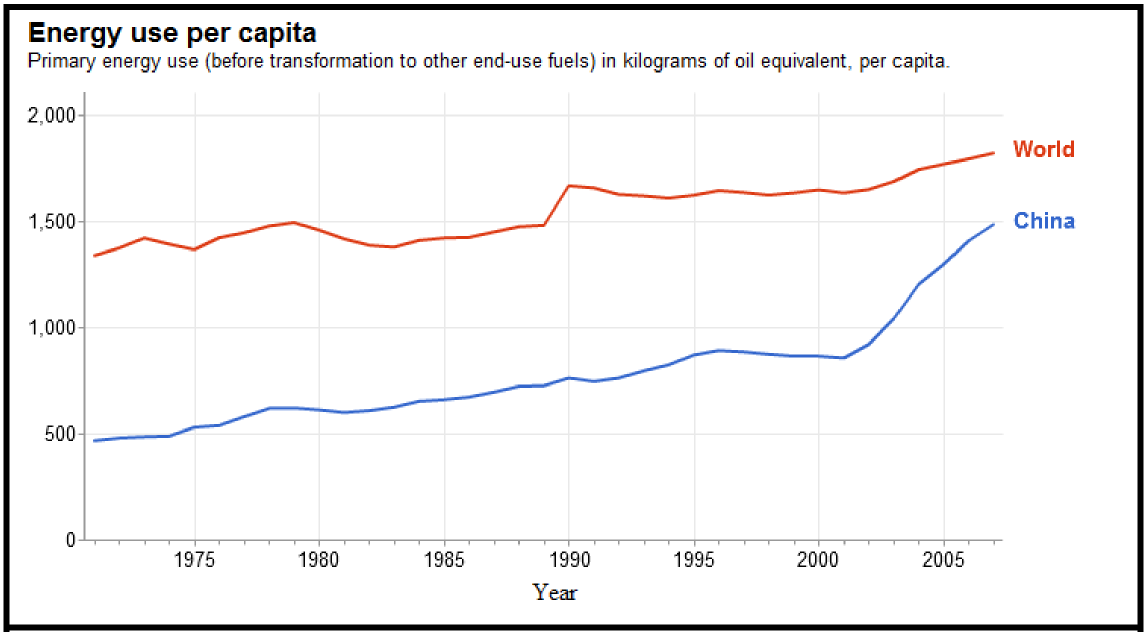


Figure 3 - Growth of Chinese Energy Use - http://www.google.com/url?q=http://data.worldbank.org/&sa=D&usg=AFQjCNE5dG2swPB0arPYbZ4dzfNh1Q3U7Q

This industrialization and modernization trend is also beginning to occur in India. The concern is that these two countries will individually reach energy consumption parity with the Unites States in the near future, forming a trio of energy gluttony. In all probability China and India's combined energy use will surpass the United States' by 2010 per information in Figure 5 gathered by the EIA.

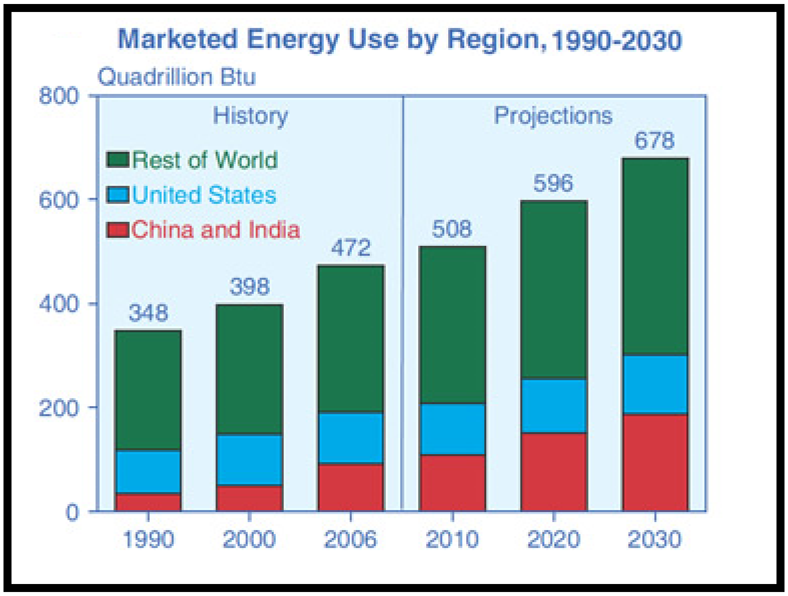


Figure 4 - Comparison of Global Energy Consumption by Region - http://www.eia.doe.gov/oiaf/ieo/world.html

1.1.4 Sources of Energy

Where the world's power comes from is as important a consideration as how much is used. If all of the world's energy was sourced from clean renewable sources then we'd be set on a sustainable course, but this is not the case. The vast majority of the world's energy is sourced from non-renewable sources that contribute significantly to carbon and other harmful emissions. Figure 6 presents the sources of Global energy consumption as proportions of the total.

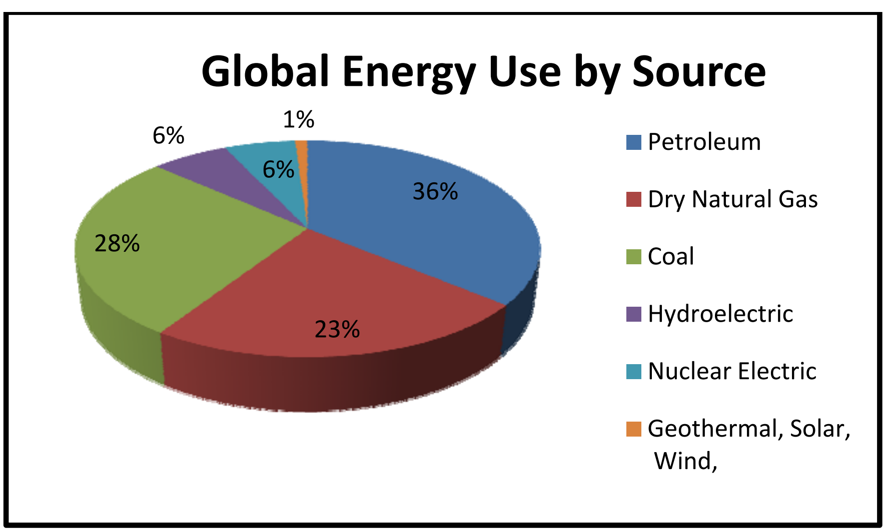


Figure 5 - Sources of Global Energy Use - http://www.eia.doe.gov/pub/international/iealf/table29.xls

Of the six most significant contributors to the total, only two, hydroelectric (6%) and the geothermal, solar, and wind combined grouping (1%), are based on renewable, non-finite resources. The remaining energy is provided by finite resources, with fossil fuels making up a combined 87% and uranium the remaining 6%.The primary concern with this situation is that the reliance on fossil fuels (petroleum, natural gas and coal) and nuclear electric power is that continued exploitation will result in resource depletion.

Petroleum is easily the most common energy source throughout the world (36% per figure 6), but may not be able to remain in that position for long. The petroleum industry has long been concerned with continued availability of crude oil for petroleum refining. The classic model, Hubbert's peak, formulated by M. King Hubbert in 1956 estimated that the global oil production would peak in 2000 [Beyond Oil]. As shown in Figure 7, this peak may have already been reached in 2003, and that the world is already experiencing a decline in production.

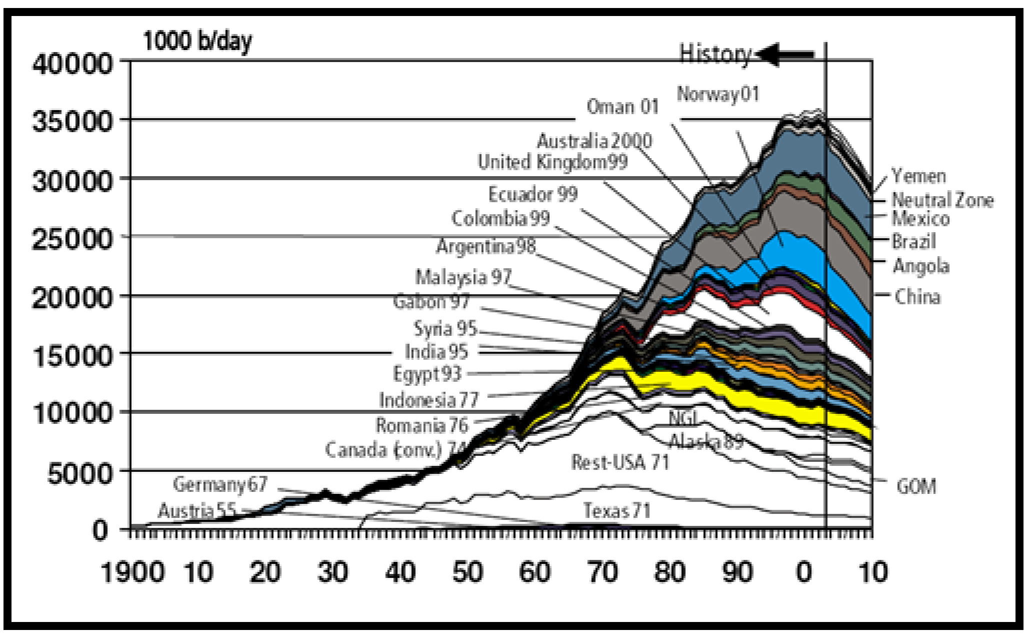


Figure 6 - Oil Production in Various Regions - http://www.fossil.energy.gov/programs/reserves/npr/publications/npr_strategic_significancev1.pdf

If this trend toward increasing global energy consumption continues unabated, there is reason for serious concern. The vast majority of global energy needs are met by non-renewable finite sources that face potential depletion to an economically unfavorable state where their exploitation is no longer economically favorable. If no action is taken to offset the consumption of finite energy resources by investing in renewable energies there stands to be a crippling global energy shortage.

1.2 US Energy Consumption

An important theme present in the continuing dialog regarding climate change and anthropogenic effects of atmospheric carbon concentrations is the inefficient energy use of The United States. At over four times the average world energy Consumption (7776 Kg of oil equivalent per capita vs. 1818 kg for the remainder of the world in 2007 (Energy Use per Capita, 2010)) the United States is an energy glutton. There are many reasons for this: transportation requirements, heavy industrialization, and high standards of living. Within the standard of living subset there is the issue of energy consumption related to the climate control of buildings, essentially the heating and cooling of businesses and residences. Accounting for 56% of residential energy consumption, heating and cooling duties are a powerful force in the U.S. energy diet (Heating and Cooling). As shown in Figure 8, regions of the US with less temperate climates, such as the North East, heating and cooling requirements are an even stronger contributor to energy consumption, and consequentially are an area of even greater promise for renewable energy offset.

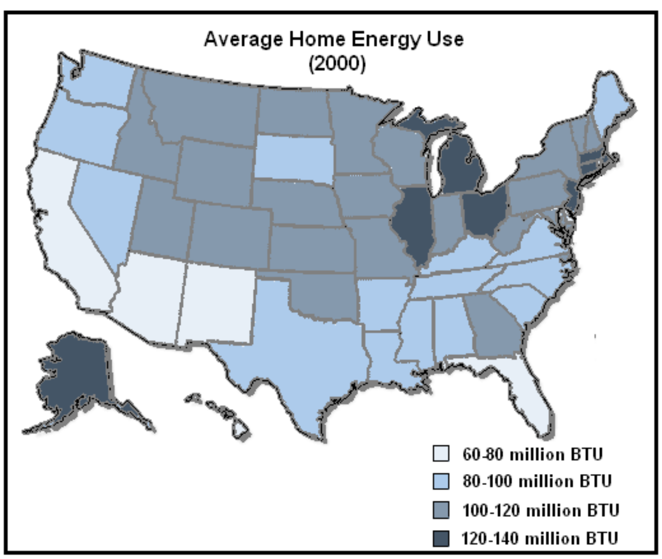


Figure 7– Heating/Cooling Duty Dependence on Region - http://knol.google.com/k/-/-/ltc02gtfr337/yj2jzw/usregions.gif

1.3 Concerns with Current Energy Consumption

The sources of the world's energy supplies carry with them many powerful consequences. The type of energy source (fossil fuel, renewable, etc.) can determine whether or not its use contributes to global climate change. Where the energy is sourced from determines what political and economic sacrifices a country must undergo in order to acquire its energy. Also how the energy is acquired and generated (localized vs. distributed) influences how effectively it can be used. All these concerns support a shift away from the traditional fossil fuel economy.

1.3.1 Climate Change

Climate change has entered the public conscience in a strong manner, because of both its immediate impacts and possible catastrophic results further in the future. The most well known aspect of anthropogenic climate change is the global warming effect caused by increased levels of greenhouse gases in the atmosphere. By trapping infrared radiation between the earth's surface and upper atmosphere, these greenhouse gases can increase the temperature of the Earth. Increased temperatures can result in a variety of issues including weather pattern disruption and ocean water level increases. The ultimate source of increased global temperatures is an oft debated topic, but clearly increased atmospheric carbon levels due to energy generation are less than desired. As of now the world rests at 375ppm CO_2, an increase from the 280 ppm CO_2 present during the pre-industrial era (Cipiti, 2007). The United States currently contributes 6 billion metric tons of CO_2 per year, and this number stands to increase to 8 billion by 2030 unless action is taken. The wisest course of action would be to offset some of the 98% of atmospheric carbon emissions produced from fossil fuels by investing in less carbon positive energy technologies (Cipiti, 2007).

1.3.2 Energy Security

Assurance that The United States energy supply will continue without interruption is another powerful driving force encouraging new sustainable energy development. By relying on other countries to provide roughly 2/3^{rds} of its crude oil The United States places itself in a difficult position (Cipiti, 2007). Greater use of domestic renewable energies would allow for less reliance on foreign countries for our energy supply, which in turn removes the US from many political situations involving less than savory nations who supply our energy. It also ensures that less money leaves the United States for foreign nations, improving the trade deficit. Clearly it is in the United States best interest to move away from foreign energy sources in favor of developing clean, self-sufficient power.

1.3.3 Energy Reliability

One of the primary concerns for an everyday citizen regarding energy is availability. Downtime due to limited energy reliability can cause catastrophic failures. Typically an electric grid operates with a combination of base load and peak generation, where the slow to operate base plants provide a constant supply of electricity, and the more dynamic peak plants can provide quick boosts in electricity generation (Cipiti, 2007). Such failures of the electrical grid as the 2003 Northeast blackout (internal failure), and December, 2008 New England Ice Storm (external failure), exhibit how powerful simple energy shortages can be on a power hungry society. A shift towards a higher number of site based energy generation systems could reduce dependence on the electricity grid.

1.4 Alternatives to Fossil Fuels

Within the field of sustainable development and alternative energies there is a spectrum of options to pursue in order to meet humanity's need for energy. While an important topic in many political and socio-economic discussions, the use of renewable energies is limited to 7% of US Energy Consumption, of which 34% is sourced from hydroelectric power (as shown in figure 9). Typically these renewable energy options fall somewhere within the following blankets of classification; solar energy, wind energy, hydroelectric energy and geothermal energy. Each technology has its own distinct advantages and disadvantages that both encourage and limit potential feasibility.

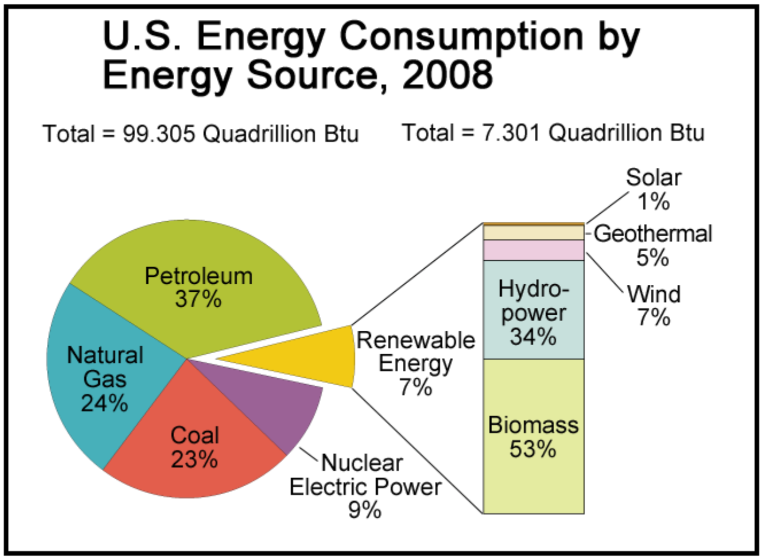


Figure 8 - US Energy Consumption Sources - http://tonto.eia.doe.gov/energyexplained/index.cfm?page=us_energy_home

1.4.1 Solar Energy

The solar energy blanket has long been considered the range of technologies that will power humanity's future in a clean renewable manner, but there are some important limitation's that must first be overcome. Solar energy encompasses a broad range of energy technologies, since it indirectly powers most other renewable energies (biomass, wind, and wave power all draw from the sun). Though, more often solar energy refers to direct extraction of energy from the sun's rays through the use of either solar photovoltaic cells, or through the use of heat collectors that use the sun's energy to either heat water for direct use, or some other heat transfer fluid for use in a heat engine. The total amount of energy received by earth from the sun has been measured at 174 petawatts (Solar, 2010)a figure so large, that it is double the amount of energy that would be yielded from using all of Earth's non-renewable resources of natural gas, coal, crude oil, and mineable uranium (Global Energy Resource Chart, 2009). There is obviously great promise in solar energy, but there are still some disadvantages that limit it's feasibility in certain regions. Primarily, solar energy's reliance on the sun for energy limits its usefulness in regions with limited solar intensity and duration. As far as simple home hot water heating the cutoff appears to be at around 40 degrees of latitude, which roughly cuts the United States in half. In figure 10 it is clear that the New England area is specifically excluded from this region of high average solar radiation. This means that, though solar energy can be used as a supplement to other renewable energy technologies, its lack of universal applicability limits its effectiveness.

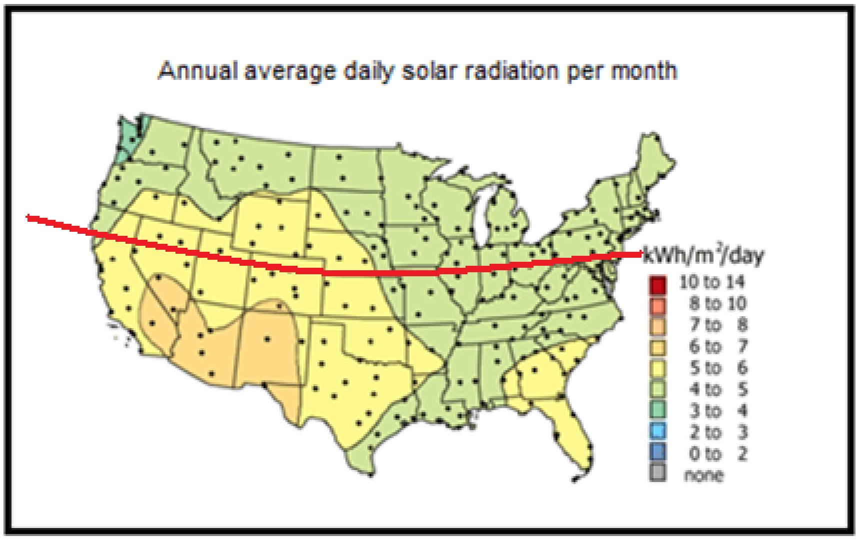


Figure 9–US Annual Average Solar Radiation per Region
http://rnp782.er.usgs.gov/atlas2/articles/people/a_energy.html#one

1.4.2 Wind Power

Wind power is an age-old technology that has been utilized in various forms to provide motivation for sailboats, to work from windmills. Currently the most important use of wind power is as a renewable alternative to fossil fuels in electricity generation. Wind powered electricity generation worldwide has reached a level of 1.5% of the total electricity usage (World Wind Energy Report, 2008). Wind power works by harnessing energy from the wind through spinning turbines. The wind drives the turbine, which in turn drives an electrical generator. The inherent problems with wind are power availability, since the wind neither blows constantly or at a constant speed depending on the area. The capacity factor is a universal term throughout the whole of the power industry, and it serves as a measure of the availability of electrical generation at a specific location. Whereas many fuel-driven power plants can operate at any level they desire, depending on fuel costs and demand, most wind plants fall within a 20%-40% range(Wind Power Capacity). This means that at any given time a group of wind turbines are only outputting twenty to forty percent of their rated power. Another concern is the availability of winds strong enough to be used to generate electricity. As shown in Figure 11 there are a few areas within the United States, pockets of New York State, the Midwest, and many coastal areas, with sufficient wind velocities and frequency for wind power electricity generation. An area specifically excluded is the landmass of New England, though the coastline of New England is a terrific wind resource. In a similar manner as solar energy, WPI's location in New England precludes it from pursuing installation of wind turbines for electricity generation due to a lack of sufficient wind resources.

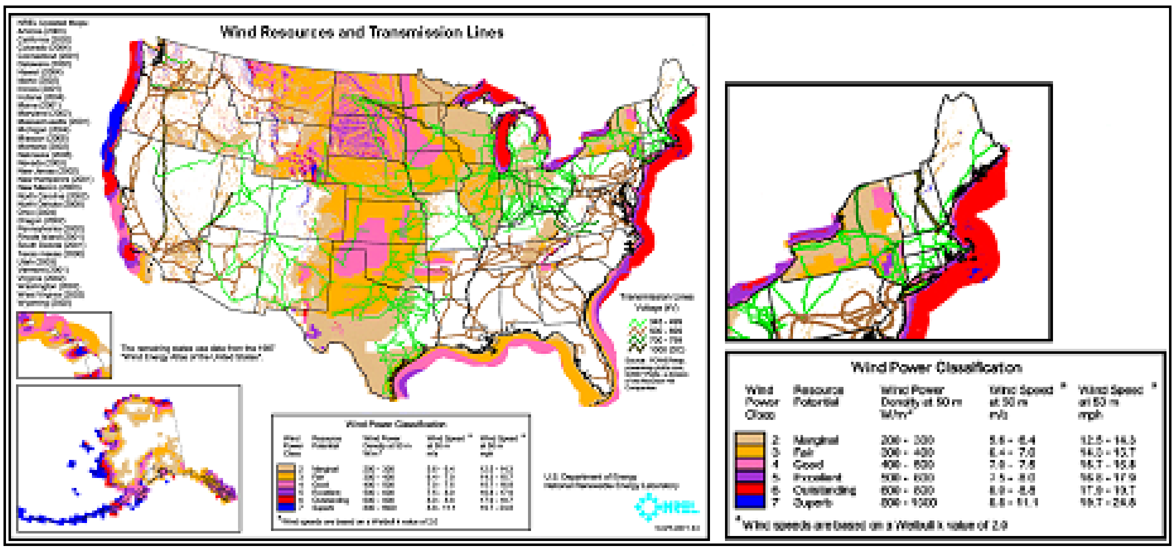


Figure 10 - US Wind Resources - http://www.nrel.gov/wind/systemsintegration/images/home_usmap.jpg

1.4.3 Hydroelectric Power

Hydroelectric power is a group of technologies related to generating electricity through the harnessing of the gravitational force exerted on falling water. Upon installation a hydroelectric facility produces nominal pollutants and greenhouse gases. Currently hydroelectric power accounts for 20% of the world's electricity production and 88% of its renewable energy production (Renewables Global Status Report, 2006). Unfortunately, hydroelectric power is not a universally applicable technology because it requires the presence of a preexisting naturally fed water source that undergoes a significant change in elevation over a short distance, or a water source that can be readily dammed. Also there is often a need to create a reservoir in order to charge the plant with sufficient water volume to ensure consistent electricity generation; often this reservoir requires the displacement of settled humans and occasionally entire towns. There is also concern with damage to the environment and natural aquatic life habitats. Some dams prevent fish from traveling upstream and reaching spawning grounds, while others increase water temperature causing changes in aquatic faunal populations. Primarily though, the dependence on naturally occurring water flow and elevation changes limits the potential regions of applicability.

1.4.4 Geothermal Power

Finally there is geothermal energy which provides a clean, consistent, readily and universally available energy source. Typically the general public relates geothermal to direct steam applications, which have limited application ranges, but there are other forms of extracting power from the Earth's crust. Deep geothermal wells use high temperature rock to generate steam; even still application ranges are limited to areas where the sub surface temperature is high. Shown in Figure 11 is a temperature profile of the United States; the desirable high temperature sub surface rock is only present in the western portion of the country.

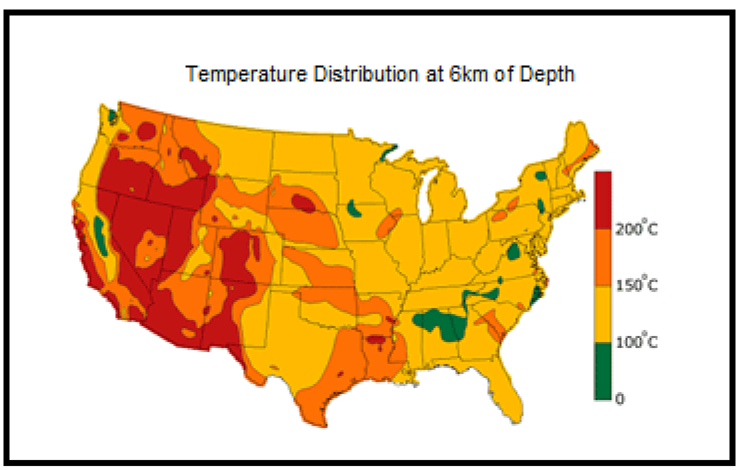


Figure 11 - US Deep Geothermal Resources - http://www.nationalatlas.gov/articles/people/IMAGES/energy_geomap.gif

Shallow geothermal power, or ground source heat pump systems, operate at depths of only 15 feet, and can be utilized in virtually any location. This is an advantage in regions such as New England where undersurface temperature distributions are not ideal for power production. By harnessing the relatively consistent near surface underground temperatures it is possible to sustainably offset heating and cooling power requirements in regions similar to New England. This offsetting of climate control duties yields reduced operating costs for businesses and residences, and a net decrease in local and national carbon emissions, making shallow geothermal power applications a particularly appropriate sustainable energy technology.

Part 2: Geothermal Energy

Geothermal energy is obtained from the ground, therefore it is available everywhere. Although is some areas in the US it can be put to use more easily than others, the development in technology and research of geothermal energy systems, which is growing rapidly as the world needs new alternative energies, allows for innovative ways to for the geothermal energy to be obtained, even in such climates as Massachusetts. This section will cover the science of geothermal energy, how it is used, and its use in heating.

2.1 Basic Science

Geothermal energy is the energy that can be obtained from the earth itself. Energy is also generated inside the earth from the decay of naturally occurring radioactive substances and friction between continental plates. The inner core of the earth is molten metal at approximately 4000 °C. At fifty to sixty miles deep, partially molten rock exists at temperatures from 650 to 1,200 °C. There are many different sources of geothermal heat it would be possible to obtain heat from, but some aren't feasible or cost too much.

2. 2 Forms of Geothermal Power

Large scale geothermal resources consist of hydrothermal, geopressured brines, hot dry rock and magma. Hydrothermal resources are mainly used commercially. They utilize water that has descended to shallow depths from a few hundred to 3,000 meters and heats. The water then escapes as steam or hot water and is used to power a binary power plant. These resources fall into three groups based on the temperature of the water that can be obtained: high (over 200 °C), medium (between 100 and 200 °C), and low (beneath 100 °C). (Berinstein) The last group is not suitable for commercial heat generation. The water-dominated resources have far lower efficiencies for converting heat to electricity than conventional steam energy plants since not all of the water can be recovered, and not all of the water heat can be converted to electricity.

Geopressured brines are hot pressurized waters at depths of 10,000 to 20,000 ft. These brines contain dissolved methane and geothermal energy and can be used to produce three types of energy: thermal energy from high-temperature fluids; hydraulic energy from the high pressure; and chemical energy from burning the dissolved methane gas. (Berinstein) Once enough fluid is removed, the pressure of the brine drops and eventually becomes unusable from an economic standpoint.

Magma is molten rock containing heat and chemical energy in the form of hydrogen gas stemming from the mantle of the earth. It is released when a volcano erupts or tectonic plates move. Magma exists at approximately 2000 °C, making it far too hot to use safely and reliably. It is an unreliable source of energy since techniques do not exist to allow for a continuous source of magma without considerable duress.
Relatively dry rocks that reside at depths of 4,000 meters and greater can be exceptionally hot. (Berinstein) These hot, dry areas are fairly common. To utilize this two wells are drilled. High pressure water is then pumped in to fracture the rock between the two wells by opening pre-existing fractures. Water is then pumped down one well to collect heat from the rock, and drawn up the other as steam, where its heat is extracted and converted to power with the use of a binary or flash power plant.

2.3. Power Plants

Commercial geothermal power plants make use of a geothermal reservoir and wells to produce energy. Water is piped from the wells into the plant on the surface. Geothermal plants operate over temperature ranges far lower than those of fossil fuel or nuclear plants: between 50 to 250 °C, as opposed to 550 °C for conventional plants. (Berinstein) This results in a loss of efficiency in converting heat to electricity. This low conversion means that for each gain in efficiency economic viability increases dramatically.

There are three types of power plants: dry, binary and flash. Dry steam plants use steam piped directly from a geothermal reservoir to turn the generator turbines.

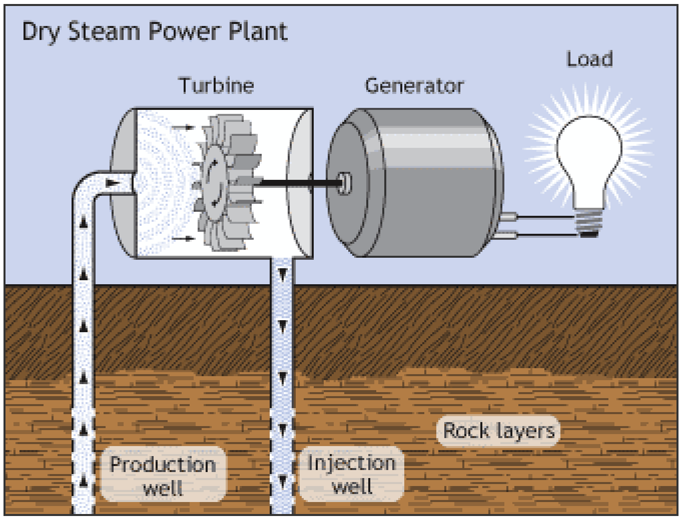


Figure 12 - A dry steam power plant - http://www1.eere.energy.gov/geothermal/powerplants.html

Flash steam plants take high-pressure hot water from deep inside the Earth and convert it to steam to drive the generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used over and over again. Most geothermal power plants are flash steam plants.

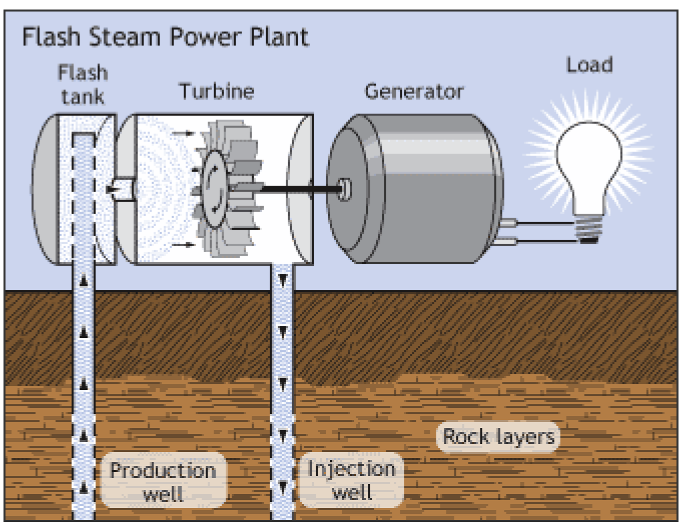


Figure 13 - A flash steam power plant - http://www1.eere.energy.gov/geothermal/powerplants.html

Binary cycle power plants transfer the heat from geothermal hot water to another liquid. The heat causes the second liquid to turn to steam which is used to drive a generator turbine.

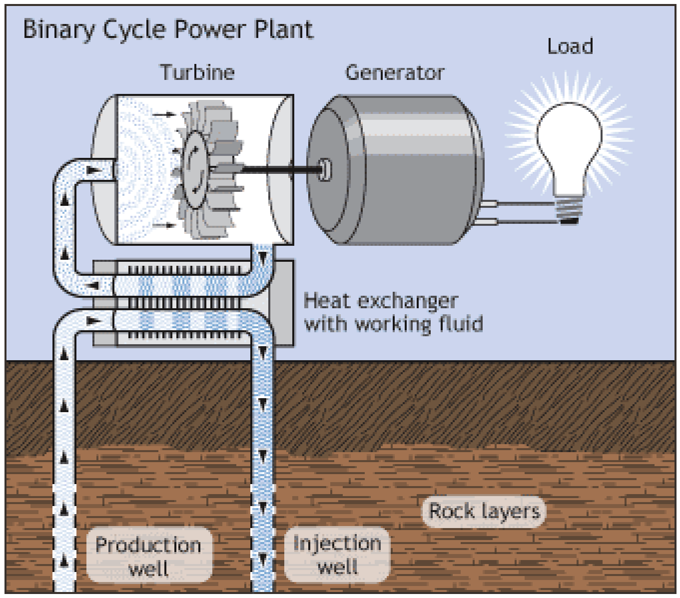


Figure 14 - A binary cycle power plant - http://www1.eere.energy.gov/geothermal/powerplants.html

The determination of which plant is best depends on the temperature of the water and the gas concentration in the water.

2.4. Ground Source Heat Pumps

There is another type of geothermal power that can be utilized. Shallow geothermal power, or ground source heat pump systems, operate at depths of only 15 feet, and can be utilized in virtually any location. This is an advantage in regions such as New England where undersurface temperature distributions are not ideal for power production. By harnessing the relatively consistent near surface underground temperatures it is possible to sustainably offset heating and cooling power requirements in regions similar to New England. This offsetting of climate control duties yields reduced operating costs for businesses and residences, and a net decrease in local and national carbon emissions, making shallow geothermal power applications a particularly appropriate sustainable energy technology.

2.4.1. Types of Geothermal Heat Pumps

Geothermal systems work off of the fact that the earth is a constant temperature about 10 feet down year round. The main components involved are loops of piping underground, a heat pump inside the house, and an air handling system. The loops of pipe are filled with a liquid antifreeze solution. When this solution passes through the loops it absorbs heat from the ground, causing it to evaporate. The antifreeze vapor is then passed through the condenser coils in the heat pump. There it gives up its heat to the surrounding air and condenses. The air handling system then moves the heated air to where it needs to go. When cooling is needed, a reversing valve allows the indoor coil to act as an evaporator and the pipes to act as the condenser. While the system is in operation, providing heat or cooling, a desuperheater can be used to heat hot water. It acts as a small refrigerant to water heat exchanger that works off of the energy given off of the heat pump’s condenser. One of the things that needs to be taken under consideration during evaluation of a site for geothermal energy is the type of soil that is present. Different types of soil have different properties for heat conduction, and affect the amount of piping that needs to be installed. Another consideration is the presence of water in the soil. Water increases the ability of the soil to transmit heat, but if it is too close to the surface, the water may freeze, which is damaging to the system. The air handling system is identical to a forced hot air system. One advantage is the ability to have a modular heating scheme, where different rooms can be heated or cooled without any trouble. This is most practical in large scale applications of geothermal heating.

2.4.2. Loop Types

There are multiple types of loops that can be used to obtain ground heat. The two main categories are open loop and closed loop systems. Open loops do not use an antifreeze solution. Instead they draw water from a surface or underground source. The most typical of these sources is a standard household well. The system will draw water from the well, pass it through, and then deposit it in a second well. Water quality plays an important part in this, for if it has impurities or is too acidic it will degrade the heat pump or otherwise damage the system.

2.4.2.1 Horizontal Loops

Closed loops also have various subsets. One of the most economic options is the horizontal loop. This is viable if there is enough land open that doesn't have any hard rock. This method uses a number of trenches. The piping is laid down at least 4 feet down and is usually run back and forth several times. Horizontal loops are nigh useless. They use up way too much space, and unless the ground is soaked in water/ the ground is actually water, they don't give up enough heat to be effective. That being said, using them exclusively for cooling, such as floating them out in a lake is very effective while not damaging the ecosystem at all.

Figure 15 - A horizontal loop - (Alliant Energy)

A variant of the horizontal loop is the slinky coil. This also utilizes a ditch, but instead of straight pipes being used, a coil of pipe is spread out in order to maximize surface area. This typically results in a trench length that is between one to two thirds shorter.

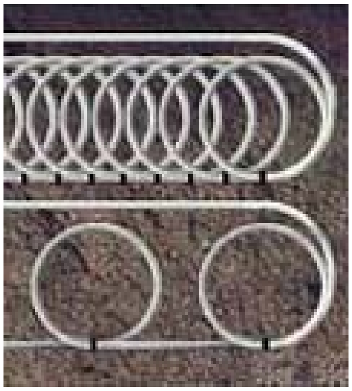


Figure 16 - A Slinky Coil - Alliant Energy

2.4.2.2. Vertical loops

The other option for a closed loop system is vertical loops. This is primarily used when land space is limited or too rocky, for preexisting structures or large facilities. When using a vertical loop, depth is not a factor, all that is needed is a certain amount of piping to be installed. Typically boreholes run between 150 to 250 feet deep. The boreholes used in this are typically much smaller than those used for wells which makes drilling simpler.

Figure 17 - A Vertical Loop - Alliant Energy

These closed loop systems can be used in different ways. Distributed systems use a central water pump and heat pumps service separate rooms and areas. Modular systems consist of dedicated heat and water pumps and loops for independent control and maintenance. Hybrid systems make use of a cooling tower to reject excess heat to reduce the size of the ground heat exchanger.

2.4.2.3. Cooling Towers

Cooling towers are a viable alternative for various commercial institutions that lack the land area needed for enough piping to heat or cool it. Typically the summer cooling load and the winter heating load are dissimilar. The ground loop then has to be sized to accommodate the larger of the two loads. Typically the ground loop will be shorter than is needed to fully meet the cooling needs. This is for a multitude of reasons. When cooling, the ground loop has to handle both the building load and power to the heat pump, while in heating only 70% comes from the ground loop, the remaining coming from power to the

heat pump. Cooling towers also have a comparably lower cost than the same amount of piping that would need to be installed to do the same duty.
There are several factors that go into choosing a loop fluid. The solution needs to have a freeze point around ten degrees colder than the minimum expected temperature. This applies to both ground temperature and the temperature of the fluid as it exits the condenser. The most typical loop fluids are alcohol and water mixtures, such as methanol, isopropanol, or ethanol, or glycols, specifically ethylene and propylene. The disadvantage of the alcohol mixtures are their flammability and toxicity (Alliant Energy).

2.5. Environmental Impact

Geothermal energy is one of the cleanest energies there is. It has virtually no emissions other than the electricity required to power the heat pump. This can be reduced by powering the heat pump through electricity garnered through solar panels. Air emissions can be controlled through standard practices so that carbon dioxide totals only 0.1 to 0.2% and sulfur dioxide less than 4% of that emitted by fossil fuel plants. No nitrogen oxides are emitted. Geothermal electricity production is so clean that in the United States it currently displaces the emission of 22 million tons of carbon dioxide, 200,000 tons of sulfur dioxide, 80,000 tons of nitrogen oxides, and 110,000 tons of particulate matter compared with emissions produced by the same amount of electricity generated by fossil fuel plants. (Berinstein)

Ground source heat pumps require electricity to operate. The source of this electricity may not be so environmentally friendly though. Most electric power plants only have a transmission efficiency of around 15%, and coupled with the fuel needed to burn to generate that electricity the heat pump would produce some emissions by proxy. However, if the heat pump were powered by a green source of energy, such as solar panels, they become practically emissions free.

One thing to be taken into consideration when operating a geothermal system is to balance the heating and cooling loads. If this is not done well, the earth will see a gradual increase or decrease in temperature and may affect the local environment.

Part 3: Economics of Operation

In order to evaluate the feasibility of the GSHP, we needed to analyze the multiple aspects of installing and maintaining the geothermal systems. In the following section the construction, time, cost and process of installation as well as savings and efficiency of the geothermal systems will be discussed.

3.1 Construction

The geothermal power systems provide space heating/cooling as well as water heating. The unit is defined as a unit with all the necessary functional components, except for installation materials (Geothermal Basics, 2008). The system is comprised of three principal components (listed below) and a device called a "desuperheater" which can be added to provide hot water when the system is providing heat or air conditioning:

- A series of pipes which are commonly called a "loop" that carry a fluid used to connect the geothermal system's heat pump to the earth near the building to be conditioned. The second important part of the geothermal system is an ???
- An electric heat pump that exchanges heat between the fluid and the air that conditions the building.
- A heat distribution subsystem, an air-delivery system that delivers the conditioned air to the building.

Of the manufacturers reporting 2008 shipments, the majority of these manufacturers sell only geothermal heat pump subsystems (geothermal heat pump units), and five manufacturers reported selling complete systems. These systems accounted for 19,043 tons, or 4.6 percent of total GHP shipped in 2008 (Geothermal Basics, 2008) (Table 1).

Shipments Information	2007	2008
Complete Systems		
Shipped	157	3,891
Rated Capacity (Tons)	623	19,043
Percent of Total Shipments	s	5
Number of Companies	2	5
Revenue of Systems (Thousand Dollars)	W	W

s = Value is less than 0.5 of the table metric, but value is included in any associated total.
W = Data withheld to avoid disclosure of proprietary company data.
Note: Complete geothermal heating/cooling system is defined as geothermal heat pump unit with all the necessary functional components, except for installation materials. These include geothermal heat pump, air handler, heat exchanger, and system kits.
Source: Energy Information Administration, Form EIA-902, "Annual Geothermal Heat Pump Manufacturers Survey."

Table 1- US Energy Information Administration- Shipments of Complete Geothermal Heating/Cooling Systems, 2007 and 2008 http://www.eia.doe.gov/cneaf/solar.renewables/page/ghpsurvey/table4_12.html

3.1.1 Cost to Install

The total revenue for shipments of geothermal thermal heat pumps was approximately $319 million in 2008 (Table). Revenue includes charges for cooperative advertising and warranties, but does not include excise taxes and the cost of freight or transportation. The average price (dollars per ton) for water-source heat pumps (ARI-320 rated) was $743.34 in 2008, and the average price for ground water-source heat pumps and ground-source heat pumps (ARI-325/330 rated) was $787.73 (Table 2).

Model Type	2007			2008		
	Quantity (Rated Capacity in Tons)	**Revenue (Thousand Dollars)**	**Average Price (Dollars per Ton)**	**Quantity (Rated Capacity in Tons)**	**Revenue (Thousand Dollars)**	**Average Price (Dollars per Ton)**
ARI-320 GHP Only	15,667	11,525	735.60	59,360	44,125	743.34
ARI-325/330	212,739	166,167	781.08	306,650	241,556	787.73
ARI-870	3,412	3,420	1,002.36	3,114	W	W
Other (Non-ARI Rated)	59,482	37,860	636.50	46,981	W	W
U.S. Total	**291,300**	**218,972**	**751.70**	**416,105**	**319,520**	**767.88**

W = Data withheld to avoid disclosure of proprietary company data.

Notes: Totals may not equal sum of components due to independent rounding. One ton of capacity is equal to 12,000 Btus per hour.

Source: Energy Information Administration, Form EIA-902, "Annual Geothermal Heat Pump Manufacturers Survey."

Table 2- US Energy Information Administration- Geothermal Heat Pump Shipments by Model Type, Quantity, Revenue, and Average Price, 2007 and 2008 http://www.eia.doe.gov/cneaf/solar.renewables/page/ghpsurvey/table4_12.html

3.1.2 Time to install

The installation time depends on soil conditions, length and depth of pipe, and equipment required. A typical installation can be completed in one or two days (Down to Earth Energy, 2006).

GSHPs are durable and highly reliable. The GSHP contains fewer mechanical components, and all components are either buried in the ground or located inside the home, which protects them from outside conditions.

3.1.3 Installation process

Almost everywhere, the upper 10 feet of Earth's surface maintains a nearly constant temperature between 50 and 60°F (10 and 16°C) (Geothermal Heat Pump Manufacturing Activities, 2009). In direct use systems, a well is drilled into a geothermal reservoir to provide a steady stream of hot water. A geothermal pump system consists of pipes buried in the shallow ground near the building, a heat exchanger, and ductwork into the building (Fig.19). In winter, heat from the relatively warmer ground goes through the heat exchanger into the house. In summer, hot air from the house is pulled through the heat exchanger into the relatively cooler ground. Heat removed during the summer can be used as no-cost energy to heat water (Fig.20). This can be used for many applications that require heat such as: heating buildings, raising plants in greenhouses, drying crops, heating water at fish farms and other industrial processes.

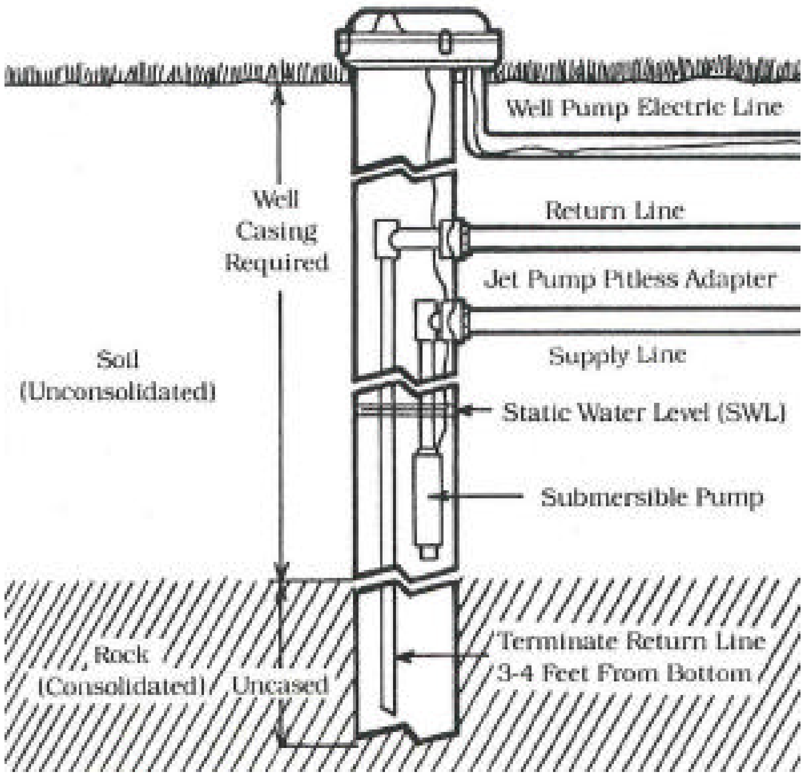
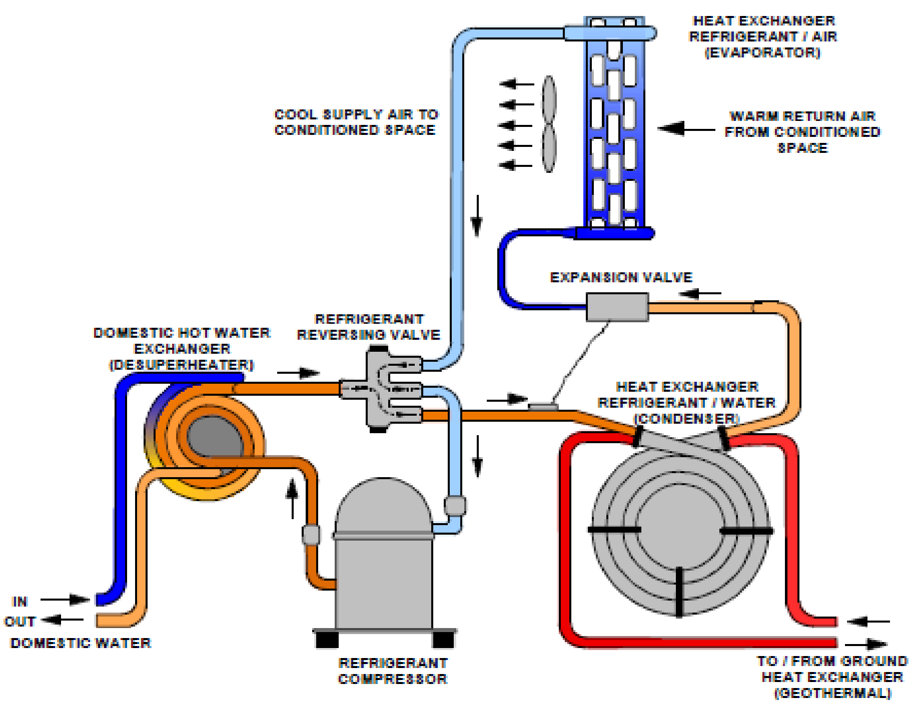
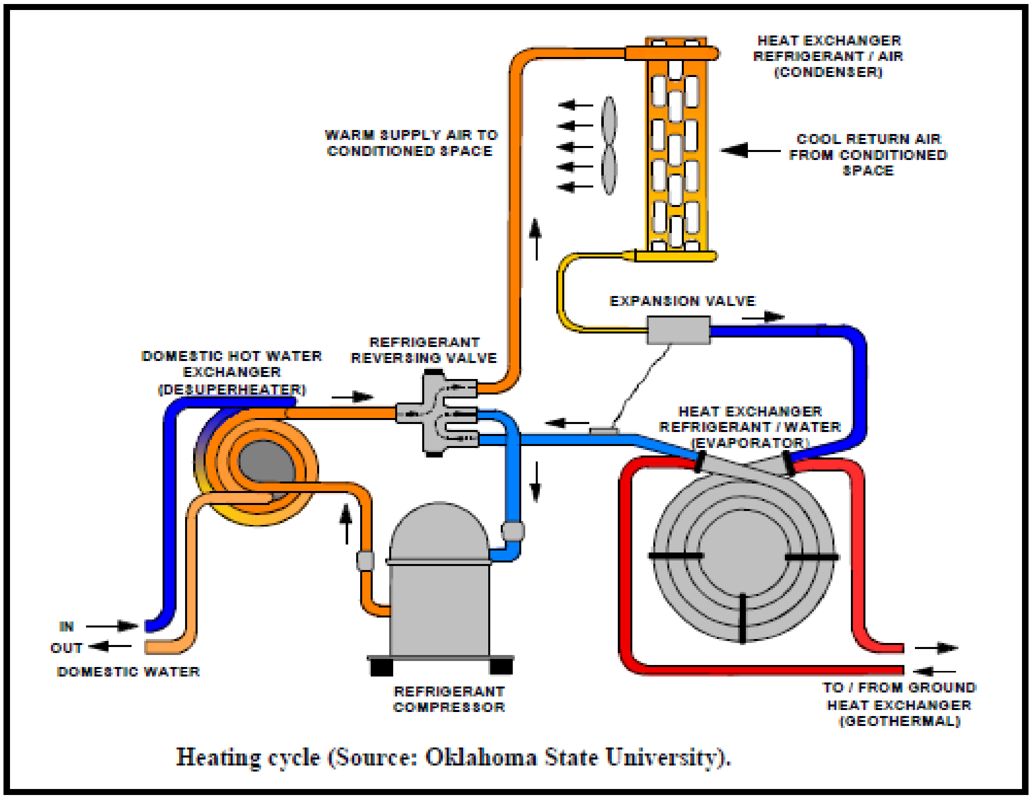


Figure 19- Cross-section view of geothermal well -Water Source Heat Pump Book



Cooling cycle (Source: Oklahoma State University).



Heating cycle (Source: Oklahoma State University).

Figure 20- Heating and cooling cycle http://geoheat.oit.edu/pdf/tp88.pdf

3.2 Savings

Savings are very important in calculating the feasibility of switching the existent heating system or installing a new one, therefore the aspect of saving was looked at from several points of view.

3.2.1 Observed efficiency

The GSHP could be called one of the most efficient residential heating and cooling systems available today because it uses the relatively constant temperature of the earth to heat and cool homes and businesses. While conventional furnaces and boilers burn a fuel to generate heat, geothermal heat pumps use electricity to simply move heat from the earth into buildings, allowing much higher efficiencies. The most efficient fuel-burning heater can reach efficiencies around 95%, but a geothermal heat pump can move up to 4 units of heat for every unit of electricity needed to power the system, resulting in a practical equivalence of over 400% efficiency (Geoexhange, 2010). On the average, GSHPs' heating efficiencies tend to be 50 to 70% higher than other heating systems and cooling efficiencies 20 to 40% higher than available air conditioners (Down to Earth Energy, 2006).

3.2.2 Savings over traditional heating/cooling

Even though water- and ground-coupled heat pumps referred to as geothermal heat pumps (GHP), have several advantages over air-source heat pumps. These are: they consume about 33% less annual energy, they tap the earth or groundwater, a more stable energy source than air, they do not require supplemental heat during extreme high or low outside temperatures (Geothermal Heat Pumps Trends and Comparisons, 1988) they use less refrigerant (freon), and they have a simpler design and consequently less maintenance. The main disadvantage is the initial capital cost. This is due to the extra expense and effort to burying heat exchangers in the earth or providing a well for the energy source. However, once installed, the annual cost is less over the life of the system, resulting in a net savings. The savings is due to the coefficient of performance (COP) averaging around 3 for GHP as compared to 2 for air-source heat pumps (Geothermal Heat Pumps Trends and Comparisons, 1988).

In a mature market, one can often have a geothermal system for about $2000 more than a new air-to-air heat pump. In other areas, it could cost $4000 more. In new construction, where a conventional furnace and air-conditioning package with ductwork would cost $5000 to $6000, a geothermal system would probably run $7000 to $8000. (Geothermal Heating, 2010)

3.2.3 Buyback time

Payback is hard to pin down nationally, due to variables of climate, ground characteristics, GSHP system type, equipment efficiency, sizing, complex utility rate structures, and a variety of economic analysis methods used in the case studies. The further the geothermal system is from the electrical plant, the more energy is lost while being transferred to the system. That is why the most powerful system is the one that combines geothermal heat pump with solar panels. In the US, Hawaii and California seem to have the most geothermal activity, which means that in those locations the drilling doesn’t have to go far down for

required hot water temperatures. Therefore the GSHP installations are less costly there and therefore more popular.
The significant factor in the payback question is the type of energy that is being replaced. Nationally, payback runs between two and six years. A short turnaround should be expected for replacing electric-resistance-heat furnaces. Oil-fired furnaces are next in line in terms of energy costs and electric heat pumps follow. The longest paybacks will come against natural gas, which is still relatively inexpensive (Geothermal Heating, 2010). But with the Geothermal heating and cooling systems providing 30%-70% energy and cost savings for homeowners in Jordan, New York (Geothermal Basics, 2008), where the geothermal activity is the same as around Worcester, MA, a payback seems to be inevitable within a few years.

A lot of support in payback comes from government tax cuts, and electric utility rebates and rate guarantees, which can save hundreds of dollars.

3.3 Governmental

The US government recognizes the GSHP as an energy saver as well as a green energy, because it has no carbon footprint. It provides individuals as well as businesses and other organizations with tax rebates and funds.

3.3.1 Tax rebates

According to the U.S. Environmental Protection Agency (EPA), geothermal heat pumps are the most energy efficient, environmentally clean, and cost effective systems for temperature control. Although most homes still use traditional furnaces and air conditioners, geothermal heat pumps are becoming more popular. In recent years, the U.S. Department of Energy and the EPA have partnered with industry to promote the use of geothermal heat pumps.

As part of the Emergency Economic Stabilization Act of 2008, new energy credits for installed qualified geothermal heat pump systems include a 10% investment tax credit to a business and a 30% investment credit, capped at $2,000, to a residential consumer. The criteria are: for a closed-loop system, 14.1 energy efficiency ratio (EER) and a coefficient of performance (COP) of at least 3.3. For an open-loop system, 16.2 EER and 3.6 COP. For a direct expansion system, 15 EER and 3.5 COP In addition, the geothermal heat pumps must include a desuperheater, which helps heat water, or an integrated water heating system (Emergency Stabilization Act of 2008, 2008).

The Stimulus Bill signed into law by President Obama in February, 2009 recognizes the importance of geothermal energy usages by industries as well as homes, and school buildings, by providing the facilities that install the geothermal heat pumps with tax credits and grants. According the bill geothermal heat pump systems for residential applications will receive 30% tax credit starting January 1, 2009 through December 31, 2016, schools will receive billions for modernizing and improving energy efficiency, all commercial and private buildings are eligible for a 10% grant in lieu of tax credit for the total cost of installing geothermal systems, federal facilities and military installations will receive billions for energy upgrades, and geothermal heat pumps will be an important component of those upgrades, each state will receive an average of $100 million to upgrade energy efficiency in the state, the uses for that money to be determined by each state, and geothermal rebates and loans are a good use of those funds (Earth Source, 2006). Many high schools and universities across US is switching to geothermal energy. Ball State University in Muncie, IN plans on replacing the coal-fired stoker boilers with a geothermal system to provide energy to more than 40 buildings on campus. The project would take 5-10 years to complete with a total cost estimated to be $70 million (American School and University, 2010).

3.3.2 Other funding

On December 4, 2009 Department of Energy (DOE) issued a final rule amending regulations for its Loan Guarantee Program. The revised rule will allow for increased participation in the program by financial institutions and other investors, and it will enable the support of more innovative energy technologies in the United States. Under the rule change, the Loan Guarantee Program will be able to consider financing projects together with other lenders and will be able to provide loan guarantees to projects with multiple participants. As an example, export credit agencies and other financial institutions will now be able to provide financing to complement the loans guaranteed by DOE. This approach will result in lowered risk, while minimizing potential costs to taxpayers (US Dept of Energy, 2009). DOE's Loan Guarantee Program paves the way for federal support of clean energy projects that use innovative technologies, and is aimed at spurring further investment in these advanced technologies. The department incorporated feedback from industry and other interested parties in order to maximize the reach and success of the program.

On October 29, 2009 the US Department of Energy Secretary Steven Chu announced up to $338 million in Recovery Act funding for the exploration and development of new geothermal fields and research into advanced geothermal technologies (Geothermal Basics, 2008). These grants will support 123 projects in 39 states, with recipients including private industry, academic institutions, tribal entities, local governments, and DOE's National Laboratories. The grants will be matched more than one-for-one with an additional $353 million in private and non-Federal cost-share funds. Collectively, these projects will represent a dramatic expansion of the U.S. geothermal industry and will create or save thousands of jobs in drilling, exploration, construction, and operation of geothermal power facilities and manufacturing of ground source heat pump equipment.

Part 4: Existing Installations

There are a number of installations in place already that use geothermal energy as a source of heating and cooling. A few examples are the Doyle Conservation Center in Northeast Massachusetts and Allegheny College.

4.1 Doyle Conservation Center

The Doyle Conservation Center, a 22,000 square foot facility in Northeast Massachusetts, meets standards set by the US Green Building Council's Leadership in Energy and Environmental Design (LEED) program for the Gold level certification. The data from the Doyle Conservation Research Paper presents that the building is 60 percent more energy efficient than a modern building with the same square footage (Benny Lee, 2005). Its design incorporates a host of sustainable features, including: minimal land disturbance, photovoltaic panels that provide 25 percent of the building's electricity, ground source heat pumps for heating and cooling, maximized day lighting, composting toilets and waterless urinals, ecological landscaping and green furnishings (Benny Lee, 2005).

Two GSHPs are in 1500ft deep wells, and the two 5-horsepower Gould pumps are 200ft below ground. They move the water to and from the 18 heat pumps distributed thought the new building and one in the Garage, with a cooling load of 45 tons and the heating load of 42tons (Benny Lee, 2005). The heat pumps operate an "open loop" system, meaning that the water is returned back to the well after it is used. The water comes from the ground at a constant temperature of 50 ^{0}F, and gets either cooled or heated up by 8 ^{0}F, before it goes back down. The facility uses an estimated annual 200,000 kWh of electricity. Because the new construction is heated and cooled with its geothermal wells, no natural gas or oil is used in the new building. The 3,568 square feet of the two pre-existing structures use approximately 155 mmBtus of fuel oil per year (Benny Lee, 2005).

Since the project presented itself with some issues, the system was not fully operating until spring of 2005, eight months after the opening of the building. According to the DCC records the initial test for hydrology and expected performance was never done, also the original pump was not powerful enough to draw the water up to the second floor. Later it was discovered that the water was being drawn out from the wells faster than it could be replenished, therefore the city water had to be used until the proper adjustments were complete.

The DCC began with a vision and a $5 million donation. The soft costs totaled $900,000, and the hard costs were $4,300,000, for a total investment of $5,200,000, that is $236 per square foot (Benny Lee, 2005). The Trustees of Reservations estimates that incorporating green features in their headquarters resulted in a 15 percent cost premium. With a Massachusetts Technology Collaborative grant of $361,515 that offset the costs of the photovoltaic panels. Additionally, rebates of $2,009 from National Grid were secured through the "Cool Choice Application," for the HVAC system and $6,405 was procured through efficient lighting incentives from Mass Electric.

4.2 Allegheny College

Allegheny College is located in Northwest Pennsylvania with a 540-acre campus and a student body of 2,100. In planning to provide on-campus housing for 85-90 percent of its students, the administration also considered sustainability, by using geothermal power source in the future dormitories.

The 5-acre area bordered by East John Street on the south, North Main Street on the west, Highland Avenue on the east, and Limber Street on the north is collectively known as the North Quad. Phase I of the construction was finished in August 2006, with enough available space for 105 students and a total cost of $9.7 million. The 3 buildings received Leadership in Energy and Environmental Design certification for energy efficiency, indoor environmental quality, materials selection, sustainable site development and water savings. Plans call for Phase II to qualify for LEED Silver Certification. The 4-story residential complex is to house 232 students; in single, double, and quadruple, one- and two-story apartments with kitchens (only the quadruple apartments have an oven). (The Campus, 2009) The second phase construction started in April 2009, and is on schedule to finish it in time for the 2010-11 school year. Allegheny found an innovating way of distributing heat to all the apartments, by connecting each apartment to its own well. The complex will feature 45 wells, each going down 200ft, with an average of 1 well being completed per day. (The Campus, 2009) The cost of construction is estimated at $14 million (North Village Gets Green Light, 2009). Both Phase I and II create a U-shape “green space” that will be used for recreation.

Part 5: Proposed Installations

There are several buildings that are going to be built or could be retrofitted so that geothermal energy will benefit them. A few examples are the new Recreational Center that WPI is building, the existing Stoddard Complex Dormitory, and a typical student apartment in the vicinity of WPI.

5.1 WPI Recreational Center

WPI is building a new recreational center to replace the facilities we currently have. This new 114,000 square-foot facility will provide 11,000 square feet of fitness space, a four-court gym, a competition length pool, and new squash and racquetball courts. The new facility will require heating needs as well as sufficient energy to heat the pool.

5.1.1 Solar Panel Usage

The current design of the athletic facility mainly utilizes solar thermal panels and a steam line to provide heating. One of the main focuses in designing the facility is maintaining a green profile. Since the energy gained from the power plant is not as green as we would like, we propose keeping the solar thermal panels to deal with the majority of heating needs. A majority of power plants use fuel that is not very efficient or gives off harmful emissions. This is compounded by the fact that energy is lost through transmission to the heat pump. We can cut down on the energy required from the plant by transmitting directly from the solar panel. By providing enough energy to fuel the pumps we would be able to reduce the load needed from the power plant, eliminating the need for the steam tunnels to be extended.

5.1.2 Sizing the System

If we're able to supplement the geothermal system with a gas boiler we can base the size of the ground loop off of the cooling load rather than the heating load. This is because the cooling load is typically larger than the heating load. We'd also be able to use the boiler during the summer to heat the pool and provide domestic hot water.

By working with geothermal heating, we'll be able to save money from having to extend the steam line 300 ft and having to produce more steam. We'll be able to replace the cooling tower and chillers currently included on the plan with eight fifty ton modules used for cooling without using any more room. Since WPI shuts down the power plant during the summer, the athletic center would still need to receive supplemental heating for the pool and water. If the supplemental gas boiler is installed it can be used for such a purpose.

The square footage of the athletic center is 140,000 square feet. To heat that amount of square footage, we'll need approximately 270 400-foot wells assuming 1.5 tons per well and a 20 foot grid. The main con with this is if something goes wrong, we'd have to figure out where the problem occurred and if we can't we'd be out of luck. Digging up an entire field to find what went wrong is problematic. Installing a monitoring system may incur extra initial costs, but would be useful in preventing costs in the future. Routine maintenance would be needed to be done once or twice a year to ensure that all systems are still functioning correctly and to switch over from summer cooling to winter heating.

5.1.3 Placement of Wells

We would have to use some ground space for the wells for this to be feasible. The three main options we have in the vicinity of the new athletic center are the football field, the area near the baseball field and the quad. We would need a 20 square foot grid of wells to be installed. Using a large area of the football field limits the use of the entire field for a while and also presents problems if something goes wrong and maintenance needs to take place. The area near the baseball field is eventually going to be turned into a parking garage which disqualifies it. The quad is left. The main problem would be dealing with the existing infrastructure present: sprinkler lines, water lines, etc.. Finding a suitable spot for the wells would be necessary for this to be a feasible project.

If digging in the quad is possible, we may be able to extend our geothermal energy reach to the residence halls or apartments. Geothermal would be able to provide heat during the winter, which we already have, but it would also be able to provide cooling during the summer for next to no expense. By enabling this option, we would save money on steam production/transportation as well as providing necessary cooling during the warm parts of the year. One of the problems that was encountered when a similar project was installed at Delphi was unexpected pressure drops in the field. This was most likely caused by detritus getting in the pipes during assembly due to not enough quality control. Steps could be taken to reduce the risk of this occurring with extra precautions taking place during installation.

5.1.4 Cost

The addition of geothermal energy to this project would cost approximately $1 million. It would take around 15 years to make this back through savings. Money would be saved on certain aspects such as not having to extend the steam line to the athletic center and provide additional heat. It is very green and it would make up for its initial cost eventually while continuously providing heat and cooling. WPI is clearly interested in green energy as evidenced by East Hall's gold LEED rating. East Hall has a green roof, which has no payback at all; it's only an educational tool. The geothermal system would also be a valuable teaching tool. The economy collapse put a lot of projects and unnecessary spending on hold, but geothermal energy is a long term investment that will pay itself off. The initial cost may seem daunting, but compared to the money that will be saved in the long run it is worth it. According to John Swift a payback time of 15 years, will exist, we will be saving approximately $66.7 thousand a year on heating and cooling. One thing to think about is whether or not the cost of the heating/cooling that we are currently using will increase during the next 15 years or so. Geothermal is a constant source of heating and cooling, and the only outside factor is a bit of electricity to drive the heating process. The general rule of thumb regarding that is that for every unit of energy you put in, you get four out.

This plan will save us approximately 800,000 kbtus a year in energy compared to extending the steam tunnels and the solar thermal panels will cost around $150,000. Since WPI is a nonprofit organization we are not eligible for any tax deductions. We are able to receive utility rebates from the utility companies themselves for letting them use our energy if they need to. Grants are somewhat available; there is just a large amount of time involved in applying for grants.

No formal study has been done for WPI recently. Most of the contractors are experienced enough that they just go by rule of thumb. A formal study now may reveal different results regarding the feasibility of geothermal energy. (John Swift)

We recommend geothermal energy for heating and cooling the new athletic center. The initial cost is high, but there are many long term benefits. The initial cost is high, estimated to be approximately $1 million by John Swift, the lead engineer in charge of project design for the center. This would be in comparison to the cost of $150,000 for the solar thermal panels in addition to the cost of extending the steam line 300 ft to the facility, estimated at around $200-300,000. There would also be the cost of producing enough steam to heat the facility. The $1 million cost would most likely have a buyback time of around 15 years. This is a while before returns are seen, but the long term gains are worth it.

In addition to providing efficient heating in the winter, the system would provide ample cooling in the summer. A supplemental gas boiler would need to be installed to provide heat to the pool in the summer for either option since the WPI power plant closes down for the summer. This gas boiler could also be used to supplement the heating in winter for the geothermal system.

A geothermal heat pump operates at 400% efficiency, meaning that for every unit of energy put in, four are received. The only fuel that is required is electricity, making this option very environmentally friendly in addition to efficient. This plan will save WPI approximately 800,000 kbtus a year in energy, resulting in a net savings of approximately $66,000 a year, that would otherwise be spent on heating the center. Past the initial installation cost, operating a geothermal system would be comparatively inexpensive in relation to other typical heating methods. WPI would not be able to receive any tax deductions for installing this system because as a nonprofit organization, we do not pay taxes.

5.2 Stoddard Complex

The Stoddard Complex is a preexisting complex of dormitory buildings. Using geothermal energy to heat the complex is an alternative that may save WPI money.

5.2.1 Design

Stoddard is a residential complex at Worcester Polytechnic Institute in Worcester, MA. It's a compilation of three three-story buildings arranged in U-shape, with 9 single and 24 double rooms, 3 bathrooms, and a game room. It provides housing for 57 students per building. One of the buildings also has a Health Services Office. The area in the center of the 3 buildings is just a lawn, which students often use for recreation. Since the structure is very similar to the Allegheny College North Quad, for which the installation of GSHP seems to be efficient and save money, we would propose a similar project to be done with the Stoddard Complex at WPI.

5.2.2 Installation

Before installation the composition and properties of the soil and rock at the construction site should be analyzed. Different soils can affect the heat transfer rate, and therefore the soil with good heat transfer properties requires less piping, reducing the overall cost of installation. Assuming the soil properties and the amount of soil available are similar to those of Allegheny Project, it would be safe to base our conclusions on that construction. At Allegheny Project each apartment consisted of two floors and every one of them had their own well, then each of the 33 rooms in the Stoddard Complex should share the well with another room. That would make 17 wells in total per each building. All the wells would be centrally located in the courtyard in the middle of the complex, since there are no underground constructions like steam pipes or sprinkler system. Each well would be about 200ft deep, and the geothermal system used would be the vertical, closed loop system. Vertical, closed loop installations minimize the disturbance to the landscape, and by circulating an antifreeze fluid, they are also environmentally safe (Energysavers, 2008). The Ground source heat pump and the compressor would have to be located in the washing-machine-size sealed, insulated cabinet inside the buildings, but the pump runs very quietly since it doesn't need a fan like the one of air to air pumps, therefore it wouldn't interfere with the life of residents in the building (Geothermal Heating, 2010), and the sealed environment can even improve on the efficiency of the system in comparison to the outdoor one. The Stoddard geothermal system would also include a desuperheater, which should provide up to 60% of the residence's hot water, as well as cut down on underground piping required to dissipate the extra heat.

5.2.3 Cost

Each well will needs to be 200ft deep, which based on $20/linear ft of pipe would make it $4000 per well, that is $68000 per building. Each building would also require one ARI-325/330 GSHP which costs $787 and a desuperheater, which is about $500. Since the buildings already have the heat distribution subsystem that would lessen the total cost. Therefore the total cost per building would be $69 287, and for all buildings the total cost would come to $207 861. Even though the system seems to be very costly, factoring in the savings of 60% on heating the water, 20-40% savings on GSHP operation over the conventional heat pump, infrequent maintenance issues, and the long lasting efficiency of the geothermal system related to the indoor location of the pump, the 2-speed compressor, and the durability of the mechanical parts, and possible EnergyStar discounts from the electric company, the system payback could take as little as 5 years.

5.2.4 Time

In the Allegheny project, it took one day to drill each well 200ft deep. It is safe to assume that a similar installation at Stoddard could be completed in a similar amount of time (17 days per building). Accounting for possible bad weather and other complications for instance the lack of experience of the crew related to geothermal systems being a relatively new technology, as well as the inconsistency of the different conditions and factors that can affect the installation, it should be possible for the construction crews to complete each building's installation in a month, totaling 3 months for the entire Stoddard Complex project.

5.2.5 Issues

Major issues in geothermal heat system originate in faulty installation process, and are usually evident very early in the system usage. To avoid issues related to aquifer depletion or groundwater contamination a detailed analysis should be conducted before the start of the construction. Included in this analysis should be tests for hydrology and expected performance. The maintenance of the system should be made easy by control units, that sequence the startup so that less stress is put on equipment, and also have a built-in fault sensor which can identify both minor problems that can be corrected right away, as well as the serious ones, that can be diagnosed before the service technician arrives (Geothermal Heating, 2010) Since the pump and compressor are inside, the debris that usually ends up in the air-to-air heat pumps located outside, making them very inefficient overtime, is no longer a problem, making the system efficient for a much longer time. The 2-speed compressor also saves on energy used, by cutting down on heat supplied on mild days and increasing it during extremely cold days.

Overall a well-installed geothermal system should not have any major problems and be very easy to maintain.

5.3 Typical student apartment

Many WPI students reside in apartments with the traditional triple-decker setup. These buildings could be a terrific starting point for expanding the installed base of ground source heat pumps. Of course there are limitations that restrict where ground source heat pump systems can be installed.

5.3.1 Design Considerations

The typical student apartment which was model consisted of a number of bedrooms, a kitchen, a living room and a bathroom. For this model the apartments were assumed to contain 4 bedrooms each.

Typically subsurface soils have a consistent year round constant temperature of 10 ^{o}C, whereas the air temperatures in Worcester, Massachusetts average 0 ^{o}C and from November through April, and 16.3 ^{o}C from May through October (Worcester Weather, 2008). Clearly, in order to take advantage of the heat sink properties of the Earth, it is necessary to adjust the GSHP system's operation. In winter the earth would serve as a source of heat which could be extracted with a GSHP system in order to heat the apartment. Contrarily in the summer the process would have to be reversed, so that the earth's cooler subsurface temperatures could be used as a heat sink to store undesired heat.

Location of the building is very important to the net efficiency of the GSHP system, since ground source heat pump systems require the input of a small amount of electricity to operate the pumps. If within a close proximity of a power plant, then the losses from transmission are reduced and the total amount of energy used to create the electricity needed to run the GSHP decreases. This makes it economically and environmentally viable to run the GSHP off the grid. On the other hand if the distance is significant from the power plant is large then a significant amount of energy is lost prior to it reaching the GSHP system. This makes the system less efficient and less economically favorable. An option is to supplement the GSHP system with a solar electric system that can generate the electricity needed to operate the pumps.

Another consideration is the available physical space surrounding the residence. In more rural locations it is possible to select from a variety of installation types, whereas more constrained city locals have limited options.

5.3.2 Installation

The model installation was based on a standard apartment available in the WPI vicinity consisting of a three floor building with four people living per floor. Typically one residence requires a 3 ton unit to serve all the residents (Selecting and Installing a Geothermal Heat Pump System, 2008). Included within this total unit is the well network. Since many of the triple-decker residences located near WPI have limited open space for the installation of a horizontal system, a vertical well is the best option. In order to provide the required service duty a 400 foot well is typically necessary (Selecting and Installing a Geothermal Heat Pump System, 2008). Also of importance is the heat distribution system within the residence, since most GSHP systems operate using an air-liquid heat exchanger there needs to be a distribution network to effectively use the extracted energy.

5.3.3 Cost

Since one 400ft deep well will be able to provide the heating and cooling duty for each residence, this will be the only required drilling. At $20/linear ft of pipe (a linear foot is a measure of total depth of the well, not the length of the piping), a 400ft well would cost roughly $8000 to drill and install piping. In addition each building would also require one ARI-325/330 ground source heat pump system in order to process the heat transfer fluid and extract heating or cooling duty; this unit costs $787 (Table 1). Since many of these residences already have the required heat distribution subsystem, there is a minimal additional cost to integrate the GSHP system into the building, lessening the total cost. The addition of the duct work will add roughly $4000 to the price (Adding Central Air, 2007). The predicted costs would result in a final price of $8787 for equipment and well drilling, as well as $7000-8000 for the installation and integration of the GSHP system. (Geothermal Heating, 2010)

5.3.4 Time

Based on contractor estimates it would be possible to drill the well and lay the pipe in a single day. If the building already contains ductwork for forced hot air and central air conditioning then the installer can integrate the unit into this network rather quickly, typically while the well is being drilled. On the other hand if the building uses another form of climate control and does not contain ductwork, then the total installation time will stagnate while the ductwork is implemented in the building. Typically the period of time required to add the ductwork is three days (Adding Central Air, 2007).

5.3.5 Issues

The most limiting issue associated with a ground source heat pump system in a city apartment is the availability of space for the well installation. This can be mitigated by using a vertical well network. Also of concern is the style of heating in each apartment. If there is a preexisting forced hot air network, then the system can be installed inexpensively and quickly, otherwise the costs increase as there is a need to install ductwork.

Part 6: Conclusions

6.1 Summary of key points

Geothermal energy is an alternative energy that utilizes the earth's latent heat to provide efficient heating and cooling. Energy is obtained by harnessing the heat differential between the earth's surface and the ground, which is at a steady temperature year round. Ground source heat pumps make use of piping laid.

6.2 Feasibility of Ground Source Heat Pumps

Compared to other renewable energy options geothermal energy presents some clear advantage, especially in a region like Worcester. While solar, wind and hydroelectric power require specific resources in order to be harnessed, geothermal power is universally applicable. This allows for greater feasibility, with the main hindrance being available land for the wells.

From a design standpoint, geothermal energy is recommended if enough land space is available for wells. The initial cost is high, but geothermal energy is so efficient that in the long term money will be saved. For larger facilities the amount of land and initial cost are dramatically higher, but the eventual savings will also be greater. A geothermal system for a house would be recommended if the resident had plans on staying long enough to benefit from the savings.

We recommend geothermal energy for heating and cooling the new athletic center. The initial cost is high, but there are many long term benefits. The initial cost is high, estimated to be approximately $1 million by John Swift, the lead engineer in charge of project design for the center. This would be in comparison to the cost of $150,000 for the solar thermal panels in addition to the cost of extending the steam line 300 ft to the facility, estimated at around $200-300,000. There would also be the cost of producing enough steam to heat the facility. The $1 million cost would most likely have a buyback time of around 15 years. This is a while before returns are seen, but the long term gains are worth it.

In addition to providing efficient heating in the winter, the system would provide ample cooling in the summer. A supplemental gas boiler would need to be installed to provide heat to the pool in the summer for either option since the WPI power plant closes down for the summer. This gas boiler could also be used to supplement the heating in winter for the geothermal system.

A geothermal heat pump operates at 400% efficiency, meaning that for every unit of energy put in, four are received. The only fuel that is required is electricity, making this option very environmentally friendly in addition to efficient. This plan will save WPI approximately 800,000 kbtus a year in energy, resulting in a net savings of approximately $66,000 a year, that would otherwise be spent on heating the center. Past the initial installation cost, operating a geothermal system would be comparatively inexpensive in relation to other typical heating methods. WPI would not be able to receive any tax deductions for installing this system because as a nonprofit organization, we do not pay taxes.

6.3 How environmentally friendly are GSHPs

Ground source heat pumps are very environmentally friendly. They operate at an efficiency of 400% and do not require any fuel burning past the electricity generation needed to power the pump. If this electricity is obtained through solar panels or other similar green energy sources, GSHPs have virtually no impact on the environment.

6.4 Is it a worthy technology to pursue further?

In this group's opinion geothermal energy is a technology that is worth being pursued. With each increase in efficiency, the cost decreases, making it more affordable. If society became more knowledgeable, more people may take advantage of the savings and energy inherent in the design.

Part 7: References

1. Adding Central Air, 2007 http://www.thisoldhouse.com/toh/article/0,,194722,00.html
2. Alliant Energy, http://www.alliantenergygeothermal.com/index.htm, "A website focusing on design of geothermal systems", 2010
3. American School and University, http://asumag.com/searchresults/?ord=r&terms=geothermal+energy&x=0&y=0, "An educational website with articles related to college research, and geothermal energy topics and up to date information", 2010
4. Benny Lee, "The Doyle Conservation Center research paper about their techniques on saving the energy", 2005
5. Down to Earth Energy, http://www.igshpa.okstate.edu/geothermal/faq.htm, "International Ground Source Heat Pump Association website answering frequently asked questions about GSHPs and geothermal energy",2006
6. Earth Source, http://www.earthsource-energy.com, "A Geo Direct company website explaining the workings of GSHPs", 2006
7. Emergency Economic Stabilization Act of 2008, http://financialservices.house.gov/eesa.html
8. Energysavers, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12670, "Government website, explaining multiple aspects of installing Geothermal systems", 2008
9. Geoexchange, www.geoexchange.org, "A company website with information about GSHP heating and cooling", 2010
10. Geothermal Basics, http://www1.eere.energy.gov/geothermal/geothermal_basics.html, "US Department of Energy website explaining the basics of Geothermal Power" 2008
11. Geothermal Heating, http://www.popularmechanics.com/home/improvement/energy-efficient/1274631, "Popular Mechanics article explaining the advantages and the general idea of the GSHP installation for individuals", 2010

12. Geothermal Heat Pumps Trends and Comparisons, John W. Lund http://geoheat.oit.edu/pdf/tp88.pdf, "Research Paper with information about GSHP design", 1988

13. Geothermal Heat Pump Manufacturing Activities, http://www.eia.doe.gov/cneaf/solar.renewables/page/ghpsurvey/ghpssurvey.html "US Energy Information Administration website overview of renewable energy", 2009

14. Hydrothermal Systems, http://www1.eere.energy.gov/geothermal/powerplants.html, "US Department of Energy website explaining the basics of Geothermal Power Plants" 2008

15. Insulation Materials And Their Uses, http://www.house-energy.com/Insulation/Insulation-Materials.htm, "A website explaining different ways of saving energy at home", 2010

16. Interview with John Swift, "An interview with John Swift in regards to the planned Athletic Center", February 23, 2010

17. North Village Gets Green Light, (http://www.allbusiness.com/education-training/students-student-life/11927279-1.html), "An Allbusiness website with all types of articles, one of which was in regard to the new dormitory construction project at Allegheny College", 2009

18. Paula Berinstein, Alternative Energy: Facts, Statistics, and Issues, "A book detailing alternative energies",

19. Selecting and Installing a Geothermal Heat Pump System, 2008 http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12670

20. Tables, http://www.eia.doe.gov/cneaf/solar.renewables/page/ghpsurvey/table4_12.html "US Energy Information Administration website with charts of with information related to geothermal energy usage in the US", 2009

21. The Campus, www.webtool.allegheny.edu, "The Allegheny college website, informing about the new dormitory construction project", 2009

22. US Department of Energy, http://www.energy.gov/news2009/8369.htm, "The article about the department's Final Rule on Loan Guarantees", 2009

23. Worcester Weather, http://countrystudies.us/united-states/weather/massachusetts/worcester.htm, "A website with temperature information for different cities", 2008