A Carbon Emissions Analysis of the New Haverford Recreational Center

Bethany Giblin

Teresa Palasits

Jenny Sichel

& Amy Veprauskas

Department of Mathematics

Bryn Mawr College

May 8, 2010

Contents

1. Introduction

The Haverford Township is in the process of finalizing plans for a new recreational center they will be constructing. This building is part of a project that is turning the land from a former hospital into a park area rather than allowing the land to be developed. Included in the plans for the building is an area related to environmental learning.

They are considering three different heating and cooling systems. One of these systems is a geothermal heat pump which is an alternative form of energy. It is far more efficient than the other two systems but has a much larger installation cost. They are also considering installing solar panels to provide some of the electricity for the building.

Since the costs of these different systems have already been calculated, our goal is to determine the environmental impact of the systems. The Haverford Township recently created a carbon plan and their goal is to reduce the total carbon emissions from 2005 Township Operations by 30% by the year 2020. Therefore, we will examine the environmental impact the new building with these different systems will have and how this will affect the overall goal of reducing emissions.

2. The Carbon Cycle

Carbon is one of the building blocks of life on Earth. The movement of carbon in all of its forms between the atmosphere, oceans, biosphere, and geosphere is called the Carbon Cycle. The cycle consists of several storage pools of carbon and processes which exchange carbon. The storage pools are where carbon is naturally found in the Earth: the atmosphere, vegetation, in soil as fossil fuel, rivers surface ocean, deep ocean, and sediment below the ocean. If more carbon enters a pool than leaves it, the pool is called a **net carbon sink**. Conversely, if more carbon leaves a pool than enters it, the pool is called a **net carbon source**. The carbon cycle can be broken down into two sectors; the geological carbon cycle, and the biological carbon cycle. For the purposes of this project, we will focus on the biological carbon cycle. The following discussion information was obtained from [5].

The biological carbon cycle moves carbon between land, ocean, and atmosphere through photosynthesis and respiration. Almost all multi-cellular life on Earth depends on sugars from sunlight, carbon dioxide, and the metabolic breakdown of those sugars to produce the energy needed for movement, growth, and reproduction. During sunlight hours, leaves absorb sunlight and take in CO2 from the atmosphere by the process of photosynthesis. Of course at night, this process cannot occur, but respiration, when that CO2 is released back into the atmosphere by other plants and animals, continues. Thus there exists an imbalance between the two systems which is reflected in seasonal changes in atmospheric CO2 concentrations. These two complementary reactions are described below:

Respiration: C6H12O6 (organic matter) + 6O2 6CO2 + 6 H2O + energy

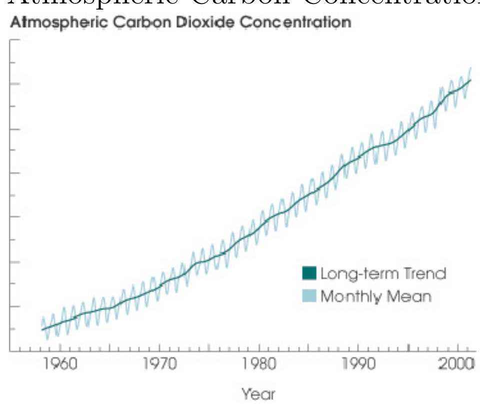
Photosynthesis: energy (sunlight) + 6CO2 + H2O C6H12O6 + 6O2

Plants use the sun to turn CO2 into sugars, and then other plants and animals use these sugars in respiration. Respiration releases the energy contained in sugars to use in metabolism and changes the sugars back to CO2, which is then released into the atmosphere.

In the oceans, phytoplankton use carbon to make shells which then settles to the bottom of the ocean when phytoplankton die and thus become buried in the sediments. These shells, made of calcium carbonate, become compressed, and eventually turn into limestone. At the same time, under certain geological conditions, organic matter can be buried, and over time form deposits of coal and oil. These non-calcium deposits are what humans use as fossil fuel to burn in order to create energy, and in this burning, create CO2e emissions.

Consequently, since the beginning of the industrial revolution about 150 years ago, the burning of fossil fuels along with deforestation have greatly contributed to the rising CO2 level in the atmosphere. The CO2e emissions from these activities create an imbalance between absorption of CO2 by plants, and release of CO2 by a multitude of natural processes. In addition, deforestation reduces the number of plants which can remove the CO2 from the atmosphere, thus swinging the cycle even more out of balance. Figure 1 shows the atmospheric carbon concentration since 1960.

FIGURE 1. Atmospheric Carbon Concentration since 1960



The problem with having so much CO2 in the atmosphere is that CO2 is a heat trapping gas, commonly referred to as a "greenhouse gas". "Many attribute the observed 0.6 degree C increase in global average temperature over the past century mainly to increases in atmospheric CO2" (vision learning). Therefore, in this project we explore technologies which will help compensate for this imbalance by being more "energy efficient", meaning they produce less carbon emissions than their more commonly operated counterparts.

3. The Haverford Township Carbon Plan

Haverford Township has created a plan to help them stay on target in their efforts to control carbon emissions. Before discussing that plan, one must see where it originates. Here we highlight the important aspects of this plan [1]. In July 2007, Haverford Township joined the Local Governments for Sustainability (the ICLEI), which is an organization interested in protection of the climate through prevention. Through joining the ICLEI, Haverford Township recognizes the effect of greenhouse gases on global warming and climate change and promises to be an active participant in creating change and a greener future. In order to progress forward, Haverford Township has a five-milestone plan to reduce their carbon footprint. Below is an outline of that plan:

> **Milestone 1:** Conduct a baseline greenhouse gas emissions inventory and forecast.
>
> **Milestone 2:** Adopt an emissions reduction target.
>
> **Milestone 3:** Develop a Climate Action Plan for reducing emissions.
>
> **Milestone 4:** Implement policies and measures identified in your Climate Action Plan.
>
> **Milestone 5:** Monitor, re-evaluate, and verify results.

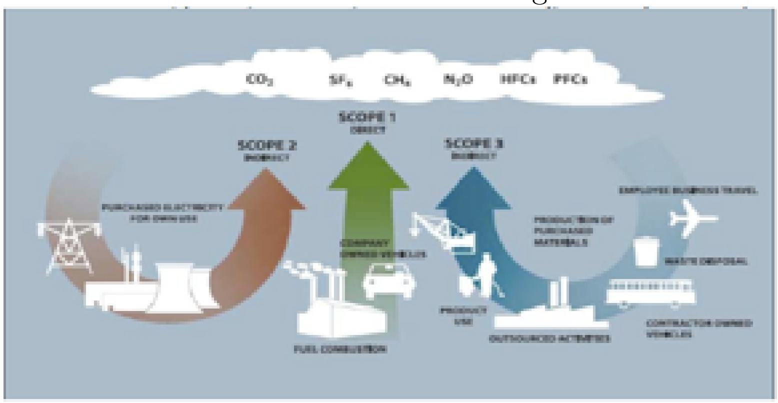
The baseline greenhouse gas inventory was completed in March 2008, cataloging 388,906 metric tons of carbon dioxide (CO2e) emitted by the community annually. A subset of this inventory was the Government Operations, including vehicles, street lights, water sewage pumping, and the school district, which totaled 15,313 metric tons CO2e annually. However because the school district provided about 10,279 metric tons CO2e to the total Government Ops. emissions annually, without the school district, Haverford Townships Operations emissions totaled about 5,037 metric tons CO2e annually.

The ICLEIs greenhouse gas inventory emissions are split into two categories, Key and Secondary. The Key emissions sources are those sources essential in the local greenhouse gas inventory. All Key emissions were included in the calculation of the data. Secondary emissions are those that are generally challenging to gather reliable data for at a local level, and/or which are usually minimal in magnitude [1, p. 19].

The ICLEI also categorized community emission sources depending on where they occur with relation to geographic boundaries and the time of the inventory. These three categories labeled as Scope 1, Scope 2, and Scope 3 are seen in Figure 2. Scope one is defined as being the direct greenhouse gas emissions, i.e. natural gas and oil used for heat and vehicles. Scope two is defined as the greenhouse gas emissions, which are indirect, that are in relation to the purchase of electricity, steam, heating, or cooling. This category includes emissions that are produced by power plants while the production of energy is completed. Scope 3 emissions are all other indirect emissions, which are more difficult to calculate. These emissions may include the electricity usage at a factor where a vehicle is created, or the energy used to transport the fuel oil. Haverford inventory contains Key emissions sources that fall in Scope 1 and Scope 2.

In Figure 3, we see estimations of emissions for the Township Operations if no climate action plan were enacted, ie- The Business as Usual trajectory. By 2020,

Figure 2. Emission Categories



there is expected to be a 2.19% increase in emissions resulting in 372 metric tons CO2e more.

Figure 3. The Business as Usual trajectory

Table 3.2: Township Operations Forecast Comparison – 2005 and 2020			
Sector	CO_2e (metric tons): 2005	CO_2e (metric tons): 2020	Percent Change
Buildings	2,028	2,090	3.06%
Vehicle fleet	1,692	1,691	-0.11%
Streetlights	1,223	1,268	3.77%
Water/Sewage	83	86	4.40%
Total	**5,037**	**5,148**	**2.19%**

Considering this increase and increases in other sectors of the community, the Township opted for a reduction target of 30% below 2005 levels for Township Operations by 2020 which in metric tons is a reduction of 1,510 CO2e.

The creation of the Haverford Township Climate Action Plan represented the completion of Milestone 3. The plan includes eighteen measures, which will help to reduce CO2e in buildings, vehicles, and street lighting. When implemented, all eighteen measures together will not only achieve the reduction of 1,510 metric tons CO2e, but also surpass that goal by 1040 metric tons CO2e. While this plan is very aggressive it can be accomplished. To help with savings in this plan the installation of geothermal and solar panel in the new recreation center will contribute immensely.

4. An Introduction to the Different Systems

The Haverford Township is considering three different systems for heating and cooling the recreational center. They are:

(1) a gas heater with DX air cool,

(2) a gas boiler with a water source heat pump,

(3) and a geothermal heat pump.

In this section we will give a brief overview of the different systems.

4.1. System 1: Gas Heater and DX Air Cool.

A gas heater works very simply by allowing a gas valve to open, which permits a certain amount of gas, which fuels a flame, to heat the air around it. This air is then pumped through the building as heat. For the cooling, the DX (direct exchange) air cool has refrigerant flowing through coils, which cools the air around them. Then a fan pushes the cold air through the air ducts and into the house. The DX air-cooled system is generally called your basic air conditioner [10].

4.2. System 2: Gas Boiler and Water Source Heat Pump.

For heating, a gas boiler burns natural gas, oil, or wood pellet to heat water that goes through hot water tubes of cylinders, radiators, or under floors systems. The boiler works by allowing gas to be released into a combustion chamber where it is then ignited. This heats up the water, which is then circulated through the area wanted [12]. In this system, much of the CO2e emissions come from the combustion process, but it is important to keep in mind the CO2e emissions which are attributed to the actually obtaining of these materials which the boiler burns. As we know from recent events, drilling for oil not only creates a lot of CO2e emissions, but can also cause ecological catastrophe such as the current BP oil spill in the Gulf coast of Mexico.

For cooling, the water-source heat pumps use an evaporative cooling tower to reject heat in the summer. The temperature of the water in the loop is between 60F and 90F. The cooling tower blows air through the water so that it evaporates. This cools the stream of water and because some of the water is lost through evaporation, the cooling tower replaces the water as needed [6].

4.3. **System 3: Geothermal Heat Pump.** Although the geothermal heat pump has the greatest initial cost of all the systems, it has the cheapest annual usage costs, and is clearly the most energy efficient out of the three systems. It is an electrically powered system that uses the Earth's constant temperature to provide heating and cooling. Since the system is moving heat rather than generating it and then moving it, the system only produces CO2e emissions in the process of moving the heat as opposed to the other two systems which produce CO2e emissions in the processes of moving and generating the heat [2]. There are a few different options for geothermal systems, which depend on the surroundings, geological makeup of the ground, weather conditions, and other factors surrounding the potential geothermal pump site.

There are two types of ground source heat pump, closed loop systems, which are most common, and open loop systems. Closed loop systems involve water, or antifreeze, which is circulated through pipes, which are placed beneath the surface of the Earth. For heating a home, the fluid flows through the pipes, collecting heat as it goes. This heat is then carried into the building and pumped out into the house usually through air ducts. For cooling, the system reverses itself and pulls heat from the building and pushes it into the ground. Open loop systems are quite similar to closed loop systems except that they can be installed where there is an aquifer or some other body of water. It works the same way as the closed loop system though ground water is pumped from the well to the building where the heat is transferred into the heat pump. When it leaves the building, the warm/cool water is discharged via a second well [4].

These wells can be installed in three different ways. The first way is the horizontal closed loop system. This is especially helpful if you have a large area of space and wish to install geothermal because it is so much less expensive. Trenches are dug three to six feet below the ground and then a series of parallel plastic pipes are laid down. A horizontal loop system is about 400-600 feet long per ton of heating and cooling capacity. These loops can even be installed under existing buildings or driveways as well [4].

The second way the wells can be installed is through a vertical closed loop system. This type of installation is best for a building that does not have enough space to entertain a horizontal well. Holes are bored into the ground about 150 to 450 feet deep depending on the area. Laid into each hole is a single pipe with a u-bend at the bottom. The pipe is then connected to all of the other ones via two common pipes. One of these common pipes allows the flow of warm liquid into the house and the other removes the cooled down liquid and recirculates it through the ground. The opposite is true again for cooling. This system is not as cost efficient as the horizontal, but still produces the same results [4].

The final way to get geothermal heating and cooling is through a pond-closed loop. When a home or building is near a body of surface water such as a pond or lake, a system like that of the horizontal ground loops, is sunk into the water to lay at the bottom of the pond. The heating and cooling for this system is the same as the two previous examples [4].

5. Calculating the Carbon Emissions from the Heating and Cooling Systems

To calculate the emissions from the heating and cooling systems we use two methods based on material that was provided to us.

> **Method 1:** We calculate the carbon emissions using the yearly heating and cooling loads for the building.
>
> **Method 2:** We calculate the carbon emissions using the yearly heating and cooling costs for the building with the three different systems.

In what follows we provide these two different calculations. We include both of these because the values for geothermal give very different results depending on which method is used.

5.1. **Method 1: Calculating the Carbon Emissions Using the Heating and Cooling Loads.** We were given estimates for the yearly heating and cooling loads of the building. These values were not calculated using the degree day method. Rather, they were calculated using a very sophisticated computer program that takes into account heat sources such as solar heat gain and heat gain from interior objects.

We are given that the yearly heating load is $3,200,000$ MBTU and that the yearly cooling load is $213,700$ ton-hours which is equal to $2,564,400$ MBTU yearly.

Before we begin our calculations we introduce the Coefficient of Performance and the Energy Efficiency Ratio.

Definition 1 (Coefficient of Performance (COP))**.** [3] The coefficient of performance is the ratio of the energy transferred for heating or cooling to the input energy, or work, used in the process.

(i) The heating coefficient of performance is given by

$$COP_{heating} = \frac{\Delta Q_{heat}}{\Delta W}$$

where ΔQ_{heat} is the amount of heat delivered and ΔW is the work done to accomplish this.

(ii) The cooling coefficient of performance is given by

$$COP_{cooling} = \frac{\Delta Q_{cool}}{\Delta W}$$

where ΔQ_{cool} is the amount of heat extracted and ΔW is the work done to accomplish this.

Note that this ratio has the same units in both the numerator and denominator and, hence, is dimensionless.

The coefficient of performance is needed to determine the amount of energy that is required to heat or cool a home. Any heating system that creates heat, as opposed to moving heat from one place to another, cannot have a coefficient of performance greater than one. This follows from the Laws of Thermodynamics.

Definition 2 (Energy Efficiency Ratio (EER))**.** [3] The efficiency for cooling systems is often given by the Energy Efficiency Ratio. This ratio is the output cooling in BTU/hr over the input power in watts W.

We can easily convert between EER and COP using the conversion

$$1 \quad \text{EER} = 3.413 \quad \text{COP}.$$

For our cooling calculations we will be using the coefficient of performance.

We approximate the coefficients of performance of the different heating and cooling systems. We choose to use the following values, using the Department of Energy website as a source for reliable coefficients of performance [9].

Table 1. Coefficients of Performance

Heating System	**COP**	**Cooling System**	**COP**
Gas Heater	0.8	DX Air Cool	2.9
Gas Boiler	1.1	Water Source	3.8
Geothermal	3.5	Geothermal	7.9

We use the equation:

$$\text{Heating/Cooling Load} \quad \times \quad \text{COP} \quad = \quad \text{Yearly Energy Use}$$

to obtain the following yearly energy use for the different systems.

Table 2. Yearly Energy Use for Heating

System	**MBTU**	**Cubic Ft Natural Gas**	**kWh**
Gas Heater	4,000,000	3,891,051	-
Gas Boiler	2,909,091	2,829,855	-
Geothermal	914,286	-	267,962

Table 3. Yearly Energy Use for Cooling

System	MBTU	kWh
DX Air Cool	875,222	256,513
Water Source	683,767	200,401
Geothermal	324,156	95,005

To convert from MBTU to cubic feet of natural gas and to kWh of electricity we used the conversions:

$$1 \quad \text{Cubic foot of natural gas} = 1028 \quad \text{BTU}$$

$$1 \quad \text{kWh} = 3.412 \quad \text{MBTU}.$$

Finally, to obtain the emissions for the different systems we use the conversions:

$$1 \quad \text{Cubic foot of natural gas} = .12 \quad \text{lbs of CO2}$$

$$1 \quad \text{kWh of electricity} = 1.216 \quad \text{lbs of CO2}$$

$$1 \quad \text{Metric ton of CO2} = 2204 \quad \text{lbs of CO2}.$$

We obtain the following heating emissions.

Table 4. CO2 Emissions for Heating Systems

System	CO2 Emissions (lbs)	CO2 Emissions (tons)	Difference (tons)
Gas Heater	466,926	212	64
Gas Boiler	339,583	154	6
Geothermal	325,842	148	-

The following are the cooling emissions.

TABLE 5. CO2 Emissions for Cooling Systems

System	**CO2 Emissions** (lbs)	**CO2 Emissions** (tons)	**Difference** (tons)
DX Air Cool	311,920	142	89
Water Source	243,687	111v	58
Geothermal	115,526	52	-

Finally, we provide the total emissions for the different systems.

TABLE 6. Total CO2 Emissions for Heating and Cooling

System	**CO2 Emissions** (tons)	**Difference** (tons)
System 1	353	153
System 2	265	64
System 3	200	-

From this analysis we see that geothermal produces less emissions for both heating and cooling.

Additionally, we compare the amount of electricity the three different systems use. Here we see that geothermal uses significantly more electricity than the other two systems. Since we have been told that the geothermal system should use less electricity, these values do not seem very reasonable.

TABLE 7. Total Electricity Use Yearly

System	**kWh**	**Difference from Geothermal**
System 1	256,513	-106,454
System 2	200,401	-162,566
System 3	362,967	-

5.2. **Method 2: Calculating Emissions Using the Yearly Cost.** We are given the total costs for operating each of the heating and cooling systems. We are also given that the cost of one therm of natural gas is $1.35 and that the cost of one kWh of electricity is $0.12. Using these values we determine the amount of natural gas and electricity each of the systems will use in one year. Recall that geothermal and the other two cooling systems run on electricity and that the gas heater and boiler run on natural gas.

TABLE 8. Energy Use for Heating Systems

System	**Cost Per Year**	**Therms**	**Cubic Ft**	**kWh**
Gas Heater	$43,190	31,993	3,199,259	-
Gas Boiler	$29,34	21,734	2,173,407	-
Geothermal	$12,188	-	-	101,567

TABLE 9. Electricity Use for Cooling Systems

System	**Cost Per Year**	**kWh**
DX Air Cool	$28,212	235,100
Water Source	$22,570	188,083
Geothermal	$10,156	102,914

Next, we once again calculate the carbon emissions for the three different systems.

We obtain the following heating emissions.

TABLE 10. CO2 Emissions for Heating Systems

System	**CO2 Emissions** (lbs)	**CO2 Emissions** (tons)	**Difference** (tons)
Gas Heater	383,911	174	118
Gas Boiler	260,809	118	62
Geothermal	123,505	56	-

The following are the cooling emissions.

Table 11. CO2 Emissions for Cooling Systems

System	**CO2 Emissions** (lbs)	**CO2 Emissions** (tons)	**Difference** (tons)
DX Air Cool	285,882	130	83
Water Source	228,709	104	57
Geothermal	102,914	47	-

Finally, we provide the total emissions for the different systems.

Table 12. Total CO2 Emissions for Heating and Cooling

System	**CO2 Emissions** (tons)	**Difference** (tons)
System 1	304	201
System 2	222	119
System 3	103	-

From this analysis we see that geothermal produces less emissions for both heating and cooling. We also note that geothermal produces less emissions based on this method compared to the previous method.

Additionally, we compare the amount of electricity the three different systems use. Here we see that geothermal uses less electricity than the other two systems.

Table 13. Total Electricity Use Yearly

System	**kWh**	**Difference from Geothermal**
System 1	235,100	+48,900
System 2	188,083	+1,883
System 3	186,200	-

From the analysis of the emissions using the two different methods we see that there is a large discrepancy between the numbers related the heating the building with geothermal. In order to make the amount of electricity used by the geothermal system found using our first method agree with the amount of electricity used by the geothermal system found using our second method, we would need a coefficient of performance of about 8. While it is possible that the coefficient of performance for the geothermal heating system is greater than 3.5, a coefficient of performance of 8 is not very reasonable.

Since this second method did not require any guess-work on our part, in the remainder of this paper we use the values found using this method.

6. Calculating the Total Emissions for the Recreational Center

The total electricity use for Recreational Center, including heating and cooling, if System 1 is chosen is expected to be around 500,000 kWh.

From our previous calculations using Method 2, we found that Systems 2 and 3 will use around 50,000 kWh of electricity less each year. Therefore, the Recreational Center with System 2 or 3, is expected to use 450,000 kWh annually.

We use these results to calculate the total carbon emissions for the Recreational center.

Table 14. Annual totals of energy use (kWh) and CO2 emissions (tons)

System	**Electricity Use Annually** (kWh)	**CO2 from Electricity** (tons)	**CO2 from Heat** (tons)	**Total CO2** (tons)	**Difference** (tons)
System 1	500,000	276	174	450	+202
System 2	450,000	248	118	367	+118
System 3	450,000	248	0	248	-

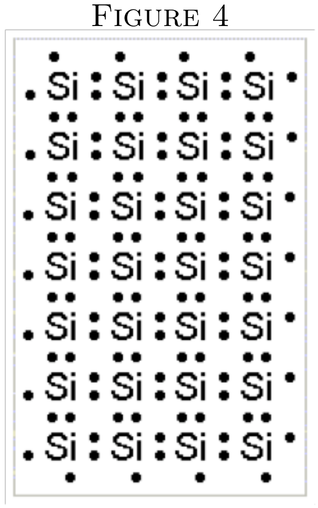
We see that using System 1 the building can produce as much as 450 tons of CO2 annually and that using System 3 the building can produce as little as 248 tons of CO2 annually.

7. Using Solar Panels on the Recreational Center

7.1. **The Mechanics Behind Solar Panels.** Most solar energy is created through what are commonly referred to as solar panels, but are more specifically known as photovoltaic (PV) cells. In simply looking at the derivation of the word photovoltaic, we can get an extremely simple sense of how they work. "Photo" means light and "voltaic" means electricity; thus converting light energy into electrical energy that we can use [8]. The process behind converting light into usable energy is fairly complex and requires a basic knowledge of the properties electrons and how atoms bond.

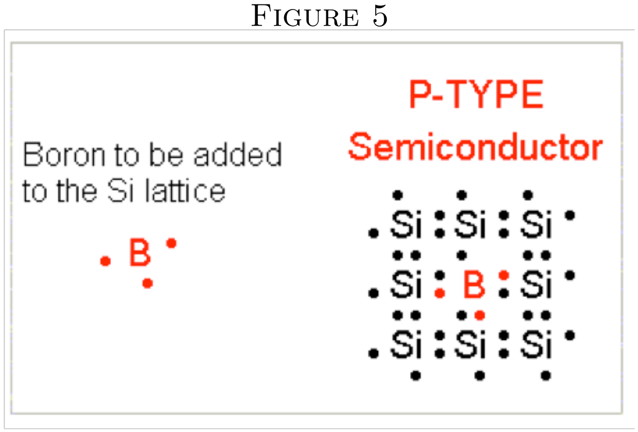
Many solar panels are made out of semiconductors, primarily silicon. Semiconductors are good materials because they can lose "grip" of their electrons (i.e. conduct energy) when either exposed to heat or a magnetic field [7]. Silicon, only having four out of a possible eight electrons in its outer orbital, easily makes bonds with four other silicon atoms, creating a lattice of atoms, as shown in Figure 4.

Figure 4



However, in this silicon lattice, all the atoms are “happy” as they have full outer orbits. Thus we need to modify this lattice so as to encourage electrons to move throughout the lattice, thus conducting energy. By inserting an element like boron with only three out of eight electrons in its outer orbit into the lattice, it creates a “hole”, making the lattice electron-needy and more inclined to take an electron when agitated by heat [7]. Because it is short an electron, the lattice is therefore more positive; we call this a “P-type” [7]. This is illustrated in Figure 5.

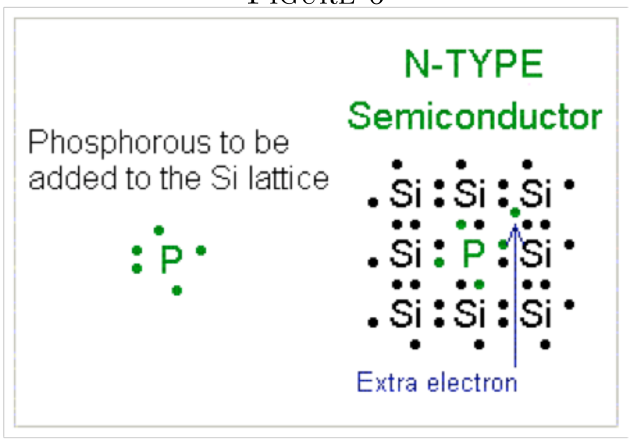
FIGURE 5



However, for conduction to work, the cell also needs a lattice that is opposite of the P-type; one that has more electrons than needed. Manufacturers use elements like phosphorus, which have five out of eight electrons in its outer shell, to create a bond with one electron to spare. Since this lattice has more negative charge, we call it an “N-type” [7]. This is illustrated in Figure 6

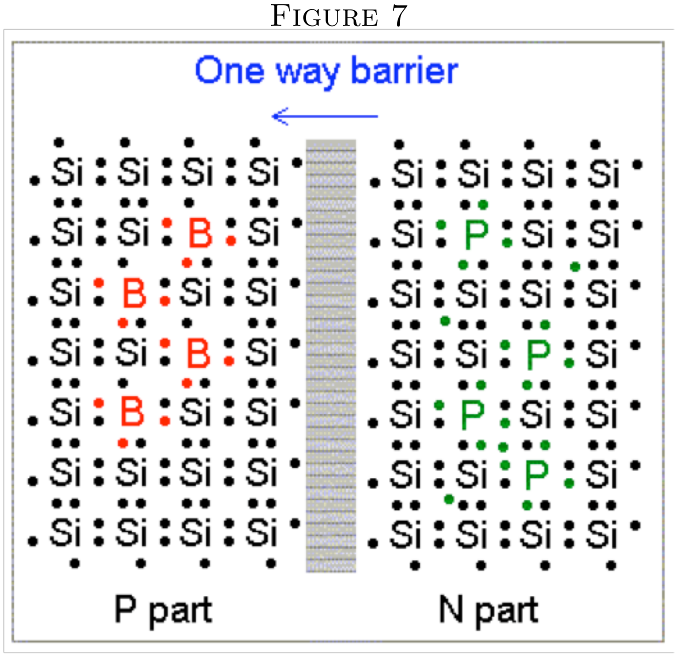
When we put the N-type lattice next to the P-type lattice, we create an electric field. The N-type lattice loses its extra electron, which it passes to the P-type, filling the hole in the P-type lattice. This process occurs on its own without light; the attraction of the positive to the negative is all it takes [8].

FIGURE 6



Light comes into play with the newly filled P-type lattice. Boron only has a loose grip on its newly acquired atom; when heat from light is applied, the charged electron breaks free and is transmitted to a wire conductor attached to the P part of the cell [7]. It cannot go back to the N part because of the one way barrier, as shown in Figure 7.

FIGURE 7



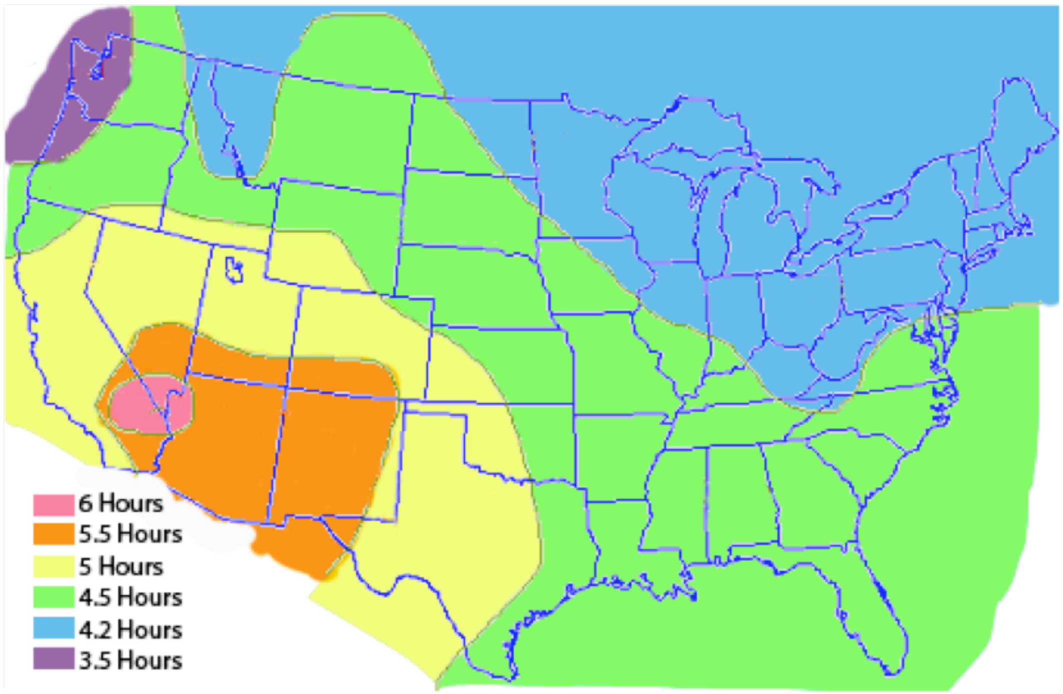
Once again we are left with the P-type short an electron, and the cycle begins again. The arrangement of the cells with negative and positive lattices, as well as the barrier, helps ensure the proper flow of electrons. The current of electrons, plus the voltage from the electric field creates power [8].

Because silicon is such a shiny material, many solar panels also put an antireflective coat so as to reduce premature loss of photons. Further, a glass covering is also put on the cells to protect them from the outdoor elements. Solar panels should be installed at an angle of inclination close to the areas latitude to ensure that they get the most sunlight possible [8].

7.2. **The Emissions Payback Period for Solar Panels.** When choosing to install a green technology for the purpose of reducing carbon emissions, it is important to consider the amount of emissions produced in the manufacturing of the technology. While sources disagree about how much time exactly it takes to reach a level of payback, the range seemed to be within 1 to 10 years. The most energy-intensive part of production is the purification and crystallization of the silicon. Payback partially depends on the specific type of photovoltaic cell purchased, since different manufacturers may use slightly different materials, but is also heavily reliant on location [11]. Solar panels installed closer to the equator which get a lot of sunlight will naturally reach their payback period faster. Likewise, areas that receive less sunlight will take longer to reach payback. This concept is demonstrated in Figure 8.

However, the general guarantee for solar panels is 25 years, so even if a system does take 10 years to reach payback, there will be a good 15 years where the installation of solar panels is purely beneficial. Thus while it is good to consider payback when contemplating installing PV cells, this factor is somewhat negligible since all

Figure 8. Hours of Sunlight per Day



systems should make up for the emissions used in its production and the continued use of PV cells is highly beneficial for the environment as using PV cells adds no emissions to the atmosphere.

7.3. **Calculating the Emissions for the Recreational Center if Solar Panels are Used.** Solare estimates that solar panels on the Recreational Center would be able to produce as much as 309,000 kWh of electricity annually. This amounts to reducing the carbon emissions for electricity by 170 tons annually.

We continue with the assumption that the building will use 500,000 kWh of electricity annually with System 1 and that it will use 450,000 kWh with Systems 2 and 3. We calculate the total emissions for the building with the addition of these solar panels. Note however, that the solar panels reduce the amount of emissions for each system by the same amount.

Table 15. Annual totals of energy use (kWh) and CO2 emissions (tons) with Solar Panels

System	**Electricity Use Annually** (kWh)	**CO2 from Electricity** (tons)	**CO2 from Heat** (tons)	**Total CO2** (tons)	**Difference** (tons)
System 1	191,000	105	174	280	+202
System 2	141,000	78	118	196	+118
System 3	141,000	78	0	78	-

Thus we see that with the addition of solar panels it is possible for the building to produce as little are 78 tons of CO2 annually.

8. Conclusions

We first summarize the total emissions for the building given the different systems below.

Table 16. Total Emissions for the Recreational Center Given the Different Systems

System	**CO2 Emissions without Solar**	**CO2 Emissions with Solar**
System 1	450	280
System 2	367	196
System 3	248	78

We see that the worse case scenario is if the building has System 1 installed and solar panels are not installed. Meanwhile the best case scenario is of the building has geothermal and solar panels installed. In fact, the worst case scenario produces about 5.5 times more CO2 emissions than the best case scenario.

We add these CO2 emissions to the total CO2 emissions for Township Operations in 2005 and determine what percent of these new totals the building contributes. We obtain the following values.

Table 17. Percent the Recreational Center Contributes to the 2005 Township Operations

System	**Percent of Emissions without Solar**	**Percent of Emissions with Solar**
System 1	9%	6%
System 2	7%	4%
System 3	5%	2%

Using these percents we see that, with the addition of the Recreational Center, the township would need to reduce its new 2005 emissions by 39% if System 1 is chosen without solar panels to reach its original 30% reduction goal. Meanwhile, if geothermal is chosen with solar panels the township would only need to reduce the new 2005 emissions by 32%.

From our analysis we see that geothermal is clearly the best choice environmentally. The main downside to the geothermal system is that it costs about twice as much to install as System 1. However its operational costs are lower and the system will eventually pay for itself. Additionally, there are various grants available at the moment that could help make geothermal a more affordable option.

When conducting a cost analysis of the systems, one should also consider the expected increase in the cost of electricity due to the deregulation of electricity in Pennsylvania. We saw using Method 2 to calculate the building's emissions that geothermal uses less energy to heat and cool the building than the other two system use to just cool the building. Additionally, the other two system require natural gas to heat the building. Therefore, it is possible that the geothermal system could become a more economical choice in the future.

While the geothermal heat pump must be installed in the building during its construction, the solar panels could be install on the building at a later date. Therefore, it is our hope that the Haverford Township will choose to install a geothermal heat pump in the new recreational center and, perhaps in the future, also consider the addition of solar panels.

References

[1] "Township of Haverford Climate Action Change Plan (CACP)." *Local Governments for Sustainability.* Web. 12 April 2010. http://www.havefordtownship.com/egov/docs/1239295902_125946.pdf.

[2] "Energy Savers: Geothermal Heat Pumps." EERE: Energy Savers Home Page. Web. 7 May 2010. http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640.

[3] Georgia State Univerisity, *HyperPhysics*. Web. 21 March 2010. http://hyperphysics.phy-astr.gsu.edu/hbase/HFrame.html.

[4] "Geothermal Heat Pumps." *Geothermal Heat Pump Heating and Cooling Systems.* Web. 7 May 2010. http://www.geoexchange.org/index.php?option=com_content&view=article&id=48:geothermal-heat-pumps.

[5] Harrison, John Arthur. "The Carbon Cycle: What Goes Around Comes Around," Visionlearning Vol. EAS-2 (3), 2003. Web. 8 May 2010. http://www.visionlearning.com/library/module_viewer.php?mid=95.

[6] "Heat Pumps". GHP Technology. Web. 7 May 2010. http://www.geo4va.vt.edu/A3/A3.htm.

[7] "The Solar Energy Cell: What It Is Made of and How It Works." *Solar Power Facts: A Brighter, Cleaner Future*. Green-Planet-Solar-Energy.com, 5 May 2010. Web. 07 May 2010. http://www.green-planet-solar-energy.com/solar-energy-cell.html.

[8] Toothman, Jessika, and Scott Aldous. "How Solar Cells Work" *Howstuffworks* Web. 07 May 2010. http://science.howstuffworks.com/solar-cell.htm.

[9] "Procuring Energy-Efficient Products." U.S. Department of Energy. Web. 15 April 2010. http://www1.eere.energy.gov/femp/technologies/procuring_eeproducts.html.

[10] "Split-system AC Units". *Howstuffworks "Home and Garden"*. Web. 7 May 2010. http://home.howstuffworks.com/ac3.htm.

[11] "What Is the Energy Payback for PV?" *PV FAQs*. U.S. Department of Energy: Energy Efficiency and Renewable Energy. Web. 7 May 2010. http://www.nrel.gov/docs/fy04osti/35489.pdf.

[12] Woodford, Chris. "How gas central heating boilers work: Explain that Stuff!" *Explain that Stuff*. Web. 7 May 2010. http://www.explainthatstuff.com/gasboilers.html.