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Renewable Energy with Photovoltaic Systems

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RENEWABLE ENERGY WITH PHOTOVOLTAIC SYSTMES

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by

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1 Abstract

In view of the perceived depletion of energy sources from fossil fuels, this project undertook a comprehensive evaluation of various alternative energy technologies. Special emphasis was placed on the potential of solar energy and its future development. In particular, we determined when and under what circumstances it will be economically feasible to install solar arrays on a house in Worcester, MA as the primary source of electrical energy.

2 Executive Summary

This report offered an analysis of the current fossil fuel situation and focuses on one primary source of renewable energy. Our dependence on oil (petroleum), natural gas, and coal was examined and evaluated, including the political and environmental ramifications of such dependencies.

We then proceeded to analyze solar energy. A comprehensive quantitative breakdown of semiconductor physics and its influence upon the *pn*-junction was performed. We considered lattice structures, intrinsic and extrinsic semiconductors, depletion regions, bandgap energy, and the energy carried by photons of light. We also explored the frequency and wavelength of light as well as what effect they have on photovoltaic devices.

Next, we analyzed the different photovoltaic materials that compose solar cells. During this analysis, we discussed the progression and projection of the both the efficiency for each type of photovoltaic material. On average, efficiencies have increased from approximately 8 % in 1975 to about 20 % in 2007. We also performed an extrapolation of the cost of solar panels, showing that the cost per Watt of power has gone from $30 in 1975 to around $2.50 in 2007.

A few local implementations of solar technology for home power was shown and discussed. These models showed the setup and statistics of the installations of photovoltaic systems on a couple of residential houses. Also, we presented a few estimates of local photovoltaic installation companies for an example house in Worcester, Massachusetts. We demonstrated what factors lead to the costs of the systems as well as how these installation companies use these factors to develop an estimate. Using these factors, we then used risk analysis to determine the return on investment of installing solar arrays on a house in Worcester, Massachusetts.

Using the estimates, the extrapolation of the photovoltaic efficiencies, and the extrapolation of the cost of a photovoltaic system, we performed a comprehensive return on investment (ROI) analysis. Under current conditions we estimated that, on average, the return on investment will occur after 19.5 years. However, with favorable tax treatment and an increase in efficiencies by a factor of two, this time span reduces to 4.3 years.

Future predictions were made, accounting for many of the influencing factors, such as government subsidization, doubled efficiency, lower costs, etc. These predictions were part of a thorough risk analysis.

We then presented and explored a few technologies that implement solar power. These technologies presented a couple of theories (viruses used in photovoltaics and quantum dots) that have the potential to increase photovoltaic efficiency. Theoretical estimates have shown that efficiencies as high as 60% may be possible through the utilization of quantum dots. There was also consideration given to the storage solar energy in the form of hydrogen. In addition, we considered solar efficiency improving technology such as the use of quantum dots and viruses in photovoltaic devices. We then provided an analysis of the political and environmental benefits to implementing solar technology, including its economic benefits as well as the effects it would have on global warming. Without the advancement of new technology to increase photovoltaic efficiencies, solar energy through photovoltaic systems in the residential sector will not be feasible in the foreseeable future (by 2025).

3 Introduction

3.1 Shane Larson

My motivation for taking the renewable energy IQP is simple. I believe that in today's world there are many problems that face us- not just as a nation, but as a people. One of these problems is the use of fossil fuels to run our everyday lives. This creates havoc on the environment, and may end up creating havoc on humankind. Although the developments of new technology for renewable energy and alternative fuels are available today, they have not been given the attention they deserve. Sadly, a country like the US- a supposed leader in the world for development- refuses to change and adapt to a different lifestyle to accompany the need to save the world we live in. However, it is not just the government's problem to deal with. The American people not only have to deal with this problem, but through their consumer choices have to take control of the market and aggressively change it. So it is my motivation to study renewable energy sources and bring the reality of their uses and benefits to the community.

Although there is only a limited connection between my studies and that of renewable solar energy, it is still something I deeply believe in. As a biotechnology major I study the molecular side of life rather than the ecological side. The difference is that ecology deals with how people are interacting and changing the environment while molecular biology studies life on an extremely small level. However, there may be a new breakthrough on the use of viruses as a way to transfer solar energy and harness it. As a molecular biologist, this would most certainly be something closely related to my major field of study. The broad spectrum of renewable energy also includes various other alternatives that are made or processed with technological breakthroughs in biotechnology- like the use of biomass. In spite of these possible connections between biotechnology and solar energy, it is unlikely I will be able to apply a great amount of my previous education here at WPI. I have also taken an environmental philosophy course which has given me the initial stages of research and knowledge in the areas of alternative living and renewable energy.

If using viruses as a major key in harnessing solar energy receives a major breakthrough, I would plan on making it my career to research and develop it further. If not, there will be little impact from this IQP on my plan in becoming a molecular biologist. It will, however, help me become more educated in the area of alternative living and renewable energies and give me the means in educating others in this generation defining issue.

The reasons that this IQP in renewable energy qualifies as a project here at WPI are clear. Research and development in solar energy would reduce consumption of oil, natural gas, and electrical consumption in the house. This would mean huge savings to businesses and homeowners, especially in our region of the country. It would reduce a large amount of the oil imports in this country within this decade, which would correlate to a decrease in reliance on the troubled regions where oil is produced. This in turn would also mean more money to be used on important domestic issues and a higher public confidence in alternative energies. Combine this with the use of alternative fuels in transportation, and the US is heading towards a bright future free of the petroleum shackles of today.

With this project alone, I would like to accomplish a deeper understanding of the mechanics of solar energy and its use specifically in the home. I would then like to look at the reality of having solar panels installed in more homes and the cost effectiveness of that choice. Lastly, I would like to make all of our findings readily available to the community so they can also see how beneficial solar energy is to our environment and more importantly to their economic well-being. Therefore, the best way I believe to disseminate the results of this project would be in community places, possibly pamphlets at local business, on town web sites, and possibly somewhere down the line brought before congress to have more funding for the development of solar energy and education for the people of the Northeast.

3.2 Garabed Hagopian

The one notion that every generation, whether reluctant or not, must consider is that they are responsible for the shape of the world, both physical and societal. Unfortunately, no generation has the chance to start completely from scratch. That is, they inherit the shape of the world from the generations that have preceded them. Many people may consider this a disadvantage, but I believe our generation should use this to our advantage. I believe that the vast majority of my generation may be a bit pessimistic. They see all the problems that await them as members of one of the future generations and back. I see this as an opportunity, an opportunity to make an impact.

We are at a critical crossroads. With exponential growth in the world's population, any problem in the world will begin to globalize and increase exponentially. This is especially applicable in the realm of energy. For a society with such great technological advancements within the last 100 years, I believe that the realm of energy has remained relatively stagnate. We can no longer afford this. Any changes that are made will not yield results overnight. Therefore, it is imperative that we do not put off addressing this issue.

I want to help address this issue. This is a topic that people often talk about, but I do not hear a lot of meaningful words . Most people seem to be repeating the fact that it is a problem and how we can confirm it. As an engineer, I believe we should not be asking whether or not there is a problem, but rather what can we do to solve it. I believe that an IQP on Renewable Energy Resources will help give me a different perspective on this issue.

My other motivation for this project involves my overall curiosity. For a high school physics project, I was a member of a five person team that designed and built a solar panel. Knowing what I know now about physics and electromagnetic radiation, I have realized that the solar panel was not nearly as efficient as it could have been. Still, the solar panel was able to notably increase the temperature of the air that entered it. I have since wondered why it is not used more abundantly if it is effective. I am interested in learning about many of the limiting factors behind renewable energy resources.

As an Electrical/Computer Engineering (ECE), I have learned a lot about energy and power. I have taken classes on how energy is sent from one place to another in the form of signals as well as courses on how energy propagates through spaces as waves with varying frequency and wavelength. I feel that I am very much suited to excel at understanding the limitations of solar energy, whether the limitations involve the sun or transmitting/receiving the power.

When I enter the work field, I would like to have a job in research and development, mainly because I want to be on the cutting edge of new technology and I want to be able to see how, even if slowly, a new product benefits society. I believe that this will give me a great background in working on a team trying to understand what means of attacking a problem would best suit society. If I were to develop a new project as an ECE in the workplace, I would need to understand the need for the project. Plus, I believe that knowledge in such an important issue would be a great asset to any company for which I might work.

This project deals with one of the most important issues on which our generation must focus. I believe that the IQP should, in some way, make an attempt to benefit society. I cannot think of a better position from which I can better society than as a member of this IQP group. There really is no other issue more real and more frightening than the problem that exists with energy. The problem does not merely lie in a lack of fossil fuels in the future, but also in the rate in which we are hurting the physical condition of the world with the emissions created by burning fossil fuels. No aspect of the energy problem is going away in the foreseeable future.

I think this project will help me learn about many limiting factors that exist in the world today, such as money, means, supply, and resistance towards change. I would like to examine the efficiency of solar power and how easy it is to exploit the power and heat of the sun. This will help me become a better rounded individual. Since this topic is not going away, there will be discussions on it for a while to come. Not only will I be able to save money should I choose to apply what I know in the near future, but I will also be keen on entering such discussions.

This IQP will probably not change the world. To think as such is idealistic, and a quintessential representation of all that is wrong with the current books on the energy problem. Human beings are creatures of habit. People resist change. People fear the unknown, even if the unknown leads to a much better lifestyle. Asking people to change the way they live overnight is just not a possibility. That said, it would be most beneficial to at least try to reach people. There would be no need to give people painstaking details, since most people do not care for them. When figures are put into a number to which a person can relate, he or she will become more interested and pay much more attention. Often times this involves putting a number into dollars and cents. If that is this extra effort that is needed to truly make a difference, I would be most happy to undergo such a task.

3.3 Nicholas Bebel

This IQP is incredibly important for numerous reasons, the biggest being that this project is taking an active interest in the future of our country and the globe. Oil is in the news almost every day for having an extremely detrimental effect to our environment, political process and economy. Taking up a project that attempts to help alleviate our dependence on this resource is incredibly rewarding and could potentially be very influential in the coming years. The research and recommendations from this report could eventually help our country to be able to allocate more resources towards other issues that could help improve the lives of the general population.

I chose this report because I have always had an interest in the energy policy of the country, since it has had one of the biggest influences over our government and our economy. I feel that by being able to switch over to an energy source that is unlimited and unaffected by the whims of other countries, our country's economy would become more stable and could be more predictable towards the fluctuations that are inherent with having an economy based off of an unstable resource like petroleum.

I feel that this project is good for me since it relates very heavily to both my major, Industrial Engineering, and minor, Political Science. It relates to Industrial Engineering since this project requires a quantitative analysis of the aspects of the solar energy economy. This is precisely what my major entails- analysis of major investments and business practices. This project will require an analysis of the practicality of the potential investment into a solar cell system and the analysis of the major business and manufacturing processes of the biggest solar production companies in existence currently.

My Political Science background can come into play since the petroleum economy and potential renewable energy economy would have a major influence over the federal and state governments, as I had mentioned earlier. Knowing the influence that petroleum has over our political process currently, it would allow for a more accurate analysis of what would happen if the country started to move over to a renewable energy economy. This background would also allow for a better estimation of what our government needs to do in order to make the prospect of solar energy a possibility to replace petroleum as a major energy resource.

4 Literature Reviews

4.1 Oil Dependence

The first chapter of Winning the Oil Endgame is a summary of the major points that follow in this book. The authors reveal the strikingly obvious, but well hidden problems that underlie the dependence on oil. Not only are billions of dollars spent on gas at the pumps, but billions more are spent protecting the pipelines and cleaning up the environmental messes left behind. Surprisingly, the amount of energy we burn in oil "could be more cheaply provided by wringing more work from the oil we use and substituting non-oil sources for the rest" (Lovins et al 3). Since alternatives to oil usually cost less and are more efficient for the consumer, the author argues that they would be able to change the market faster.

Lurking behind the current price of oil is the amount spent each year by the US protecting oil interests in foreign lands. The reason why this is mostly unknown to the public is that the costs are usually shouldered by the military and other governmental organizations. These costs are not cheap as they quite frequently are reasons why taxes are raised each year to spend on a grossly inflated military budget. "The worlds key oil terminals, shipping lanes, ports, pipelines, refineries, and other facilities could be devastated by plausible small-group attacks" (Lovins et al 10) and are routinely attacked in countries such as Iraq and Columbia. Even though intelligence helps thwart these attacks, many still happen and each time causes an increase in the price. Furthermore, we are held hostage as a nation each time a country in the Middle East or South America want to increase prices by holding up production because of our limited oil supplies at home. An example of this was the embargo on oil in the late 1970's and early 1980's when gas was at its most expensive because of the limited supply Saudi Arabia was granting the US. Although this led to an establishment of rules and regulations, not all oil exporting nations abide by these laws.

The hidden costs of oil are not always in dollars. Americans have to give up fundamental foreign policy interests anytime oil is involved, "engaging vital national interests in far-off and unfamiliar places where intervention causes entanglement in ancient feuds and grievances, and even in oil wars" (Lovins et al 22). Sadly, this puts American traditions of prosperity and freedom into symbolic targets worldwide where all issues are oil concerned. This in turn creates more and more anti-American rampage worldwide. By supporting governments in northern Africa and the Middle East that have oil, we also support their unjust and inhumane methods that keep the money, food and sanitary equipment from the people. This creates a double-standard in our foreign policy, further weakening our ability to be a beacon of democratic freedom that does not stand for corrupt governments that inflict pain on their people.

However, the author argues that all is not lost and hopeless and America still has a chance to win this oil game. Even in the 1970's when OPEC limited production and drove up the cost of oil, the American industry was able to increase "GDP...3% a year, yet oil use fell 2% a year" leading to "net imports from the Persian Gulf" to fall "by 87%" (Lovins et al 7). This showed the world that even in limited petroleum times, America's creativity and hard work paid off by actually have an economy that grew instead of crumbled. This was the last time the Americans took control of the oil market and it was by becoming more efficient that the country actually grew- economically and technologically. If only the US was able to sharpen its focus today like it did back then, with even better technology now, we could most certainly rid ourselves of oil dependence.

So what do we do about ridding ourselves of oil dependence? First we can start realizing that the alternative technology is just as good if not better than oil technology. It is this central dogma of thinking that oil companies and those associated in the business would not like the public to believe. They say that if "smarter technologies could save energy more cheaply than buying it, they'd already have been adopted" (Lovins et al 26). Although oil technology is where both the public and private sector have comfort, stability and infrastructure, there was a day when petroleum was the alternative energy source to whale oil. Large companies like IBM and DuPont are cutting their energy costs 6% a year and at the same time receiving 1-3 year paybacks (Lovins et al 27) by using alternative energy sources. Even American consumers are starting to finally realize that huge paybacks from using alternative energy resources do not have to come with dramatic compromise. Toyota offers new energy efficient cars that have twice the gas mileage but for the same costs and while giving up no luxuries. Not only were they awarded North American Car of the Year, but they have been the fastest selling car in the world staying on the lot an average of 5 to 6 days (Lovins et al 29). This has been surprising; especially to the American car audience considering the overwhelming consensus was that an alternative energy car meant losing out to the power and luxury that many Americans have been accustomed to.

Toyota is just one example of a company being competitive in the global marketplace with an alternative energy source. The reasons Toyota has been on top and will continue to do so are its "self-interested melding of advanced technology with bold business strategies" (Lovins et al 32). As described before, America is not a stranger to saving oil and becoming more efficient. However, in this day and age it will take a lot more from a lot more different facets of American culture. "It takes attention; leadership at all levels and in many sectors of society; a comprehensive and systematic but diversified and flexible approach" (Lovins et al 32). This time, the people in this country shouldn't wait for the government to make a change, but instead make the changes themselves by becoming more educated and researching about the benefits that alternative energy sources bring. We need to aggressively bring about the change through openness to unusual and unorthodox substitutes to energy.

Not only does ridding ourselves of strong oil dependence bring promise back to a stumbling American economy, but it will ensure the future generations a cleaner and healthier environment. Winning the oil endgame will help restore Americas role as a world leader and through the money saved by investing less in foreign turmoil over oil we will be able to better educate and supply the necessities for all back home. The USA can win the oil endgame for "our prosperity, and our quest for common goals of substance and spirit, applying the problem-solving prowess that for two centuries has helped to make the nation and the world better and safer" (Lovins et al 32).

4.2 *Substituting for Oil*

4.2.1 Available Possibilities

There are certainly a plethora of alternatives to fossil fuels from which we can produce energy. Some of the problems with these alternatives are that they are not nearly as convenient as oil. Solar panels can be bulky. Thermal energy cannot easily be harnessed to power an automobile. This makes oil a lot more attractive.

New developments in biofuels and biomaterials, such as cellulose and lignin, have made the switch from burning oil to burning a more abundant and less harmful substance quite a possibility. Most of these substances are available from a multitude of feedstocks, at some of which bacteria are engineered to efficiently produce these biofuels from ethanol. Still, this is not a set science. The efficiency is continually increased by rapid development of new technology.

4.2.2 Feasibility

A transition from burning oil to burning biofuels is not easy. It will take a lot of effort from the government as well as the general public. It is very possible though. From1975 to 1989, Brazil undertook a project that would consume plenty of money and attention. This endeavor involved finding an economically sound method of producing and utilizing ethanol as a source of energy. As of 2002, this ultimately created 700,000 jobs and returned a profit over 10 times the original fiscal commitment. Also, VW has created cars that can run on any mix of gasoline and ethanol, including a mix of 100 percent of either one.

4.2.3 Location

The main plants used for biofuels include, but are not limited to swtichgrass, hybrid willow, and poplar. A notable benefit to such crops is the flexibility they provide in terms of the location in which they must be grown and harvested. They do not require any special climate; most of the climate regions in America are suitable for such growth. They are also very resistant to flooding, droughts and can be harvested twice during a year. Even more remarkable is the cleanliness of these plants and what they can do for the environment around them before they are even burned: “Properly grown feedstocks can even *reverse* CO_2 emissions by taking carbon out of the air and sequestering it in enriched topsoil whose improved tilth can boost agronomic yields.” (Lovins et al 108)

4.2.4 Saved Natural Gas

There is a critical shortage of natural gas that will only continue to worsen as time progresses. An improvement in electrical efficiency will result in abundance in natural gas. This abundance can also be substituted for oil, especially in the realm of residential heating.

4.2.5 Creating an Abundance

Before any natural gas is used in the stead of oil, methods of saving natural gas must also be considered and successfully implemented. There are three primary end uses that should therefore be considered: electrical power generation, residential/commercial buildings use, and industrial gas use. (Lovins et al 113)

The most obvious method for saving natural gas via electrical power generation is to use less. A widespread cross-country attempt to save electricity would certainly assist with the natural gas shortage. Another option would be to switch to a power generator that does use not use gas, rather than turbines that consume large amounts of gas. The biggest way in which residential and/or commercial buildings could improve upon natural gas is heat entrapment, with a common manner of improving such as having proficient insulation. Industrial uses for natural gas are often tougher to reduce in quantity.

4.2.6 Substitution

Recent demands have driven up the cost of natural gas, which was at one time competitive with residual oil, making the key to save enough natural gas. Assuming that is realistic, natural gas can be substituted in the place of oil uses such as industrial fuel, feedstocks, inner-city buses, lubricants, and the heating of residential and commercial buildings. This substitution has plenty of potential considering the fact that natural gas is not currently available for residential heating in many rural areas. A switch from oil to gas in those places alone would create noticeable effect in the effort to reduce oil consumption.

4.3 Saving Oil

The biggest key to saving oil will be by reducing our dependence on oil for our major transportation needs. This can be accomplished by making vehicles that can achieve the same performance, size and other comforts that people have come to expect, but with the added advantage of being more fuel efficient. By doing this, it will make fuel efficient vehicles more acceptable to the general public.

The biggest step that has been taken was done through the initiative of producing lighter weight vehicles. The next major breakthrough in this field may prove to be an ultra-light weight steel that can be utilized in mass market vehicles, where hopefully this technology can soon enter the general market.

There have been numerous arguments against making lighter weight vehicles; including that it would make the cars unsafe or unaffordable. However, thanks to recent technology, neither of these issues should be a major problem. The biggest steps towards making this technology safe and affordable have been taken by Toyota. The company has been testing and advancing lighter weight steel for nearly a decade and has begun to install it in their prototype cars. Toyota states that that the technology should be ready for mass use in their main models of cars.

Another major breakthrough in the technology has been developed by BMW, which they have dubbed Z22, which is a carbon fiber based concept car. While this car is not quite ready for the mass market, in theory this car could nearly halve the weight of the current comparable model of BMW automobile.

These technological advances have shown a great deal of promise to save both gas and lives in the tests that have been performed upon it. When this is combined with the advancement in hybrid technology, the fuel efficiency of most vehicles will be drastically improved and can move them into the forefront of the automotive industry.

However, these are not the only two areas of vehicle technology that are being improved in order to make an attempt to improve the fuel efficiency of the vehicles. The major areas of improvement have been seen in the tires, engines, and wind drag. These advancements have been made to reduce the weight and drag of all of these components of the automobile. Many of these improvements are planned to be utilized in bigger trucks and SUV's in order to boost their efficiencies.

There are also being improvements being made in the highway system that are improving the highway fuel efficiency of vehicles and saving time and money for drivers and the government. The major improvements that are being made on the highways are to lessen the drag on the wheels by utilizing new varieties of roads. The government has been working on different types of road that move away from the traditional concrete based roadways that will increase the durability of the road and thus improve the general efficiency of the transportation system.

There are also improvements being made to the fuel efficiency of major outlets of public transportation, like trains, buses and airplanes- and to military vehicles. These new types of vehicles include clean air buses, concept hydrogen cars and the increased use of biomass. The improvements being made to these vehicles are helping save a great deal of oil and are helping to preserve the limited supply that is left. This will not only help preserve oil but it will help save the government billions of dollars.

4.4 Progress and Prospects

Since the oil embargo of the mid 1970s, a lot of effort has been made to effectively utilize renewable energy resources. Recent developments in the efficiencies of renewable energy resources has allowed for quite a jump in such energy production. In 2000 alone, the global generating capacity of wind turbines increased by 4500 MW (Baldwin). In the same year, photovoltaic generation capacity increased by 109 MW (Baldwin). There is still plenty of room for improvement. Out of a total 98.5 quads (one quad is approximately equal to 10^{18} joules) of energy used in the United States of America in 2000, only 6.6 quads were produced from renewable energy resources (Baldwin). There were 23 quads produced by both coal and natural gas, while oil accounted for 38 quads of energy, nearly half of all energy consumed (Baldwin).

Photovoltaics have improved drastically in recent years, but they still have a long way to go before they become a completely lucrative solution in the search for alternate means of energy production. As of 2000 most efficiencies were peaking at around 24.7%, while the average was around 12-15% (Baldwin).These efficiencies have been limited by factors such as optical losses due to mismatched reflection coefficients, recombination of electron hole pairs (which prevents the electrical current from being generated), bandgap size of the materials being used, and the resistance of the metal contacts on the semiconductor. Recent developments have been made to improve some of these inefficiencies.

As of 2000, the most popular photovoltaic cell was made from single-crystal or polycrystalline silicon (c-Si), accounts for around 86% of all commercially produced solar cells (Baldwin). While c-Si solar cells are certainly the most popular and are among the most efficient, there is an anticipated problem with the availability of the materials. It is suspected that a mass production of photovoltaic cells will dry up the supply of silicon used in semiconductors.

There is a feasible substitute to the c-Si solar cell: thin-film photovoltaic devices. The primary advantage to the thin film solar cell is the fact that they have a direct bandgap, which allows for a very high optical absorption of the photons incident upon the *pn*-junction. The three main types of thin-film photovoltaic devices are amorphous-silicon thin films, thin films composed of $Cu[_{1-x}Ga_x][Se_{1-y}S_y]_2/CdS$, and CdTe thin-film cells.

There are still other high-efficiency thin-film cells available, such as those composed of InGaAsN/GaAs, which have adjustable bandgaps.

With the increased efficiency and popularity of solar cells, wind energy is often times overlooked. With an increase from the average wind power generating unit from 50 kW to 900 kW (1800%) in the last 20 years, wind power has demonstrated its ability to produce mass amounts of energy (Baldwin). However, the biggest limiting factor on wind energy is the fact that it is subject to such great structural stress. One important cause of this could be the fact that wind varies as a cube with power. Also, many of the first primary designs did not allow for fluctuations in the turbine blades. It is estimated that a single turbine blade can go through hundreds of millions of such fluctuations in a period of 30 years.

Another means of renewable energy is biomass. Biomass includes wood, landfill gas, as well as ethanol made from various plants. In 2000, it accounted for around 3.4% of the United States energy supply (Baldwin). The harnessing of biomass helps to keep CO_2 levels down, helps remove plant and animal wastes, and reduces the need for America's oil imports, yet it is still not competitive. At a price of $2.60 per million Btu, it cannot compete with coal's cheap $1.05 per million Btu (Baldwin). Until the cost of biomass and biofeuls reduces, there is not much of a chance that it will be competitive on the energy market.

5 Analysis of the Current Fossil Fuel Situation

5.1 Petroleum Limitations

America's dependence on fossil fuels reaches upwards of 85%, including the need to power almost the entire transportation in the country plus two-thirds of the electricity (DOE). Not only does the department of energy estimate that this dependence will remain high, they believe it could even increase despite advances in renewable energy. A troubling development is the possibility of peak oil- the expiring of oil production.

5.1.1 Peak Oil

Peak oil, also known as the Hubbert peak theory, is the term most experts use to describe the finite source of petroleum that is in the ground. Some experts believe that we are currently peaking in oil production right now and that we should expect to run out of oil in the next few decades. The evidence of this peak comes from the fact that 33 out of the 48 largest oil producing nations have already seen a peak in production (Chevron). Along with this, 2 out of the 3 largest oil producing fields have also experienced a peak. The Mexican Cantarell field, the third largest, has produced another low this past year (2005) of 1.74 million barrels per day, a decline of 13% from the year before, a trend that has been seen for the past 4 years (Arai). The Kuwaiti Burgan field, the second largest, will produce 1.7 millions barrels per day this year (2006), down from roughly 2 million (Critchlow). The Burgan oil field was supposed to output 2 million barrels per day for another 30 or 40 years, but has declined production citing an exhaustion of the oil field (Critchlow). The largest oil field, Saudi Arabia's Gharwar field, is currently under research over whether its declining production numbers are the result of its peak oil as well.

This is troubling for the world's largest oil users, namely the United States which uses 1 out of every 4 barrels produced. Once oil has peaked, there will be political battles for control over strategic oil fields and transporting lanes in hopes to secure their countries share of what is left over. Unless there is global cooperation, there will be a world wide panic over the shortage of oil. This could end up creating a wide array of problems, taking into account that mostly everything that is accomplished on a day to day basis in developed nations is powered by fossil fuels. Therefore under peak oil stress it is extremely critical for countries to effectively manage their stock reserves and depreciating production. If effectively prepared for and executed, the transition to alternative energies will be less harmful to the global economy.

There are still key global reserves and oil fields along with new types of technologies that will allow a smoother conversion to alternative fuels. The United States key petroleum reserves, and the oil fields in Russia, the Gulf of Mexico, and the coast of Africa exemplify sites that will become increasingly important in maintaining economic stability in the world.

5.1.2 United States Petroleum Reserves

An important option for the United States during a time of duress is its extensive reserve system. As America's dependence grows and global availability diminishes, the U.S. Strategic Petroleum Reserve (SPR) and the Northeast Home Heating Oil Reserve are two powerful options to alleviate the pressure on the domestic market.

The SPR is the largest government-owned oil stocks in the world, roughly 730 million barrels strong (DOE). However, only about 730 million at this point, the Energy and Conservation Act signed by President Ford states that reserve should be at least 1 billion barrels. These are mostly stored in the salt flats in the Gulf of Mexico. The Northeast Home Heating Oil Reserve also stocks oil, but is restricted just for home-heating. There are 7.7 million households that are dependent on home-heating oil in the United States, 5.3 million of which reside in the Northeast (DOE). These are stored in two locations in New Haven, CT (750,000 barrels), one in Providence, RI (250,000) and the largest residing in Woodbridge, NJ (1 million barrels).

The United States' oil consumption is by far the largest in the world. In 2002, the United States demand was 18.5 million barrels per day; by 2004 it rose to 20 million barrels per day and by the same time last year in 2005 it was already up to nearly 22 million barrels per day topping oil consumption in one year to nearly 8.03 billion barrels (GC). Most of this oil has been imported, with 13.2 billion barrels used per day in 2005 (GC). This not only shows that oil stocks are decreasing, but also that oil consumption in the United States is *increasing*. If oil wells dried up today and usage remained constant, the oil in the United States reserve would last us little more than a month (about 33 days).

The United States, however, is not the only country to depend significantly on oil. Countries such as China and India are also increasing their usage at a rate similar to the United States. With the world's population currently just over 6.5 billion people, the fact that China and India compose over one-third of it is becoming a sizeable problem to the world's oil reserves. In 2003, the world oil reserves were estimated at about 1.27 trillion barrels of oil (SPE). At this time it was also estimated that the worlds oil supply would last about 44 years, however with usage increasing worldwide that number has probably decreased significantly. The countries that do contain large amounts of reserve oil also lay in the most troubled regions such as Saudi Arabia, Iraq and Venezuela. With the cost of oil increasing on a fairly regular basis, this is only adding to the turmoil in these unsettled areas, making the future of these reserves unpredictable.

The horizon does not look very bright for countries relying heavily on oil consumption in the next century and even in the next decades. Even though there has been a significant deep oil well breakthrough in the recent weeks for the United States, this only prolongs the situation. Eventually the United States, with the world following, will need to adapt and switch to alternative energy technologies.

5.1.3 Russia-Caspian Sea

Russia contains only 3% of the global population, yet control 13% of global territory and 13% of the known global oil reserves (Energy). Through the next decade, Russia is slated to produce roughly 10.67 million barrels per day, 6.24 million barrels per day of which will be exported (Energy). Transneft, Russia's state-owned pipeline company built a major oil field and pipeline in Siberia named the Eastern Siberia-Pacific pipeline that extends from Siberia to the Pacific Ocean and is expected to pump out 588 million barrels per year (Energy). This pipeline however will be mainly used by Russia as economic growth through sale to the European Union (93% of these exports are expected to go to Europe alone) and the growing market of the Asia-Pacific region. However, this oil field has great potential as 92 oil fields have been developed with another 19 on the way, while another oil district close by has 26 fields that have only been explored (Oil). Even though this pipeline is not meant for import in the US, it will significantly help to take the load off of oil consumption in the Asia-Pacific Region- which consumes roughly 28% of the world's oil (Oil).

Another pipeline, called the Western Siberia-Barents Sea pipeline system, is expected to be able to match the capacity of 588 million barrels per year by 2020 (Energy). This pipeline will also alleviate the stress of imports to the United States and Europe as well as account for a large percent of domestic use.

A pipeline of smaller capacity, the Baltic Pipeline System, is currently in the initial stages of expanding. The current figures suggest that as of 2002 12 million tons of oil were transferred; as of 2003 30 million tons of oil was transferred; as of 2004 42 million tons of oil were transferred (Five). The target capacity should increase at least another 10 million tons to 50 million tons of oil per year within the next few years (Five).

A pipeline in the Caspian Sea area, named the Caspian Pipeline Consortium, expects to transfer close to 1.35 million barrels per day (Energy). 2014 should signal the final completion of this project headed by Russia and Kazakhstan and already has made an impact on the region in terms of oil production. Between 2004 and 2014, the pipeline should increase its capacity and be transporting close to 67 metric tons per year (roughly 1.4 million barrels per day) (General, U.S.). This number is up from the 22.5 metric tons per year in 2004 (roughly 500,000 barrels per day) (General, U.S.). The combination of these four happening pipeline projects expect to increase capacity and efficiency in the next decade raising Russia's ability to export oil to about 6 million barrels per day (Energy).

Russia will prove to be a huge asset in maintaining and delivering energy demands in Asia. Although it will not have the capacity to supply a large amount of it, it will alleviate the economic stress of the countries having to buy inflated oil prices from OPEC in times of oil shortages.

5.1.4 Cuba-Gulf of Mexico

The estimates by the CIA's World Fact book say that as of 2003 Cuba consumes roughly 205,000 barrels per day and as of 2005 were producing roughly 72,000 barrels per day (Economy). Cuba's proved oil reserves are also estimated- at approximately 552 million barrels (Economy). Lately however, Cuba has been receiving a lot of attention with its potential oil production off its coasts. According to a BBC article, Cuban oil and natural gas production has grown about 10% a year with domestic oil production at 4.1 metric tons per year, meeting most of its domestic needs and relying less on imports that have crippled the economy in the past 15 years (Fawthrop). The BBC also reported that a survey done by the U.S. Geological Survey estimated that in the North Cuba Basin there is a possibility of 4.6 billion barrels of oil (Smith-Spark). Cuba has taken hold of this powerful resource to jumpstart the Cuban economy by selling off lots to foreign countries and private companies. However, since the trade embargo with Cuba was established 44 years ago by the United States, they have essentially eliminated themselves from getting in on the bidding competition. This may prove to be a tough political situation for the US to lose out on such a vital energy source. Once again however, the need for oil may over come the moral standards of which the embargo was established (lack of human rights by Cuban President Fidel Castro) compromising the foreign policy set forward by the US.

By using state of the art rigs in the Gulf of Mexico, drills have the ability to go twice as deep as before. This development set up Chevron to drill in a new location in the Gulf to see if their theoretical hypothesis was correct. Using modern 3-D seismic gear, Chevron proved victorious finding that the rig, termed Jack-2, in its initial stages was producing 6,000 barrels per day (Morrison). Chevron also estimated that the area has a huge commercial potential, possibly being able to produce as little as 3 billion barrels of oil or as much as 15 billion barrels of oil (Morrison). A deep oil reservoir could also mean pushing US oil reserves up by 50% (Morrison). Of course these are preliminary estimates that could completely over estimate the potential of this new site, not including the time it takes (about five years) to get into full production. However, with the new rigs and new drilling technologies, it is hopefully that one successful well will lead to more.

If this rig proves to be successful in the Gulf, analysts are arguing that there are potential areas all over the world with deep oil deposits. "Areas believed to have oil deposits extremely deep beneath the ocean floor, which could now become commercially recoverable, include the North Sea off the coast of Britain, the Nile River Delta off the coast of Egypt, and possibly coastal Brazil" (Morrison). This opens up a whole new area of exploration for oil companies wishing to expand their operation. However, these rigs aren't cheap; BP is slated to pay $525,000 per day of use when they start digging late next year (Morrison).

5.1.5 African Coast Reserves

The coast of Africa has proved to be as large of a site as the Gulf of Mexico and recently countries such as Angola are selling off blocks to private companies and countries to be mined.

5.2 Coal Energy

Coal is a carbon based fossil fuel whose use was popularized during the Industrial Revolution. It found a great deal of use during that time because it can be used straight out of the ground as an energy source. Since the Industrial Revolution it has only gained popularity as it is the most utilized source of electricity in the world. While it was popularized during the Industrial Revolution, its use has been traced back to the Bronze Age in Britain where it was used in house heating. While the use of coal can be traced back in history; it was not used heavily or valued as an asset until the Industrial Revolution, when it became crucial in industry and manufacturing.

5.2.1 Composition

While coal is carbon based, it is not entirely composed of carbon. The highest purity of coal is only 95% carbon and contains trace amounts of hydrogen, oxygen and nitrogen. A very common element found in all types of coal is sulfur, but is most often present in the lower purity coals. There are numerous varieties of coal, with the most pure being Anthracite and Lignite being one of the lower grade coals available. A constant with all of these varieties of coals, is the fact that they all contain certain amounts of incidental moisture; which is the water trapped between the coal molecules. Because of this, most coal is mined and stored wet in order to prevent spontaneous combustion.

5.2.2 Coal Uses

Coal is currently being utilized in numerous processes; however the most common use is for heating and electricity through combustion. Currently the world is using 5800 million short tons of coal and 75% of which is for electricity. The process of using coal to generate electricity is to pulverize the coal and then put it into a furnace attached to a boiler. The burning coal heats the water to a boiling point, converts it into steam which is sent to a turbine, where the steam pressure generates electricity ready for usage.

The turbines that are currently in use can generate about 40% efficiency out of the coal burned. New turbines, however, are being created that can withstand high temperatures and pressures that will allow for better efficiencies to be gained reaching upwards of 46%.

However there are other alternatives to improve the efficiency of the coal powered turbines. The best ideas currently available are the fuel cells created from solid-oxide or molten carbonate. Theoretically, experts hope that the efficiency derived from these fuel cells can reach up to 85%. Downsides for the use of these newer technologies include the poisoning of the cells from the sulfur and the ability to only use gaseous fuels. One idea to battle the limited use of gases is to gasify coal with water, creating a lower fuel cell voltage, but simplifying the ability to sequester the carbon dioxide released.

One of the other major uses for coal is in the production of coke, which is a “solid carbonaceous residue derived from low-ash, low-sulfur bituminous coal from which the volatile constituents are driven off by baking in an oven without oxygen at temperatures as high as 1,000 °C (1,832 °F) so that the fixed carbon and residual ash are fused together” (Friedman). The main use for coke is as a fuel and reducing agent in the smelting of iron ore in blast furnaces. The biggest problems associated with coke are the bi-products, which are coal tar, ammonia and coal gas.

5.2.3 Problems with Coal

While coal has been a long standing source of energy and electricity for much of the world, it does have numerous serious problems. The largest being the damage to the environment, since the combustion of coal produces various dangerous gases including carbon dioxide, nitrogen oxide and sulfur dioxide. Sulfur dioxide is one of the more dangerous gases since it reacts with oxygen to create sulfur trioxide which can react with water to create sulfuric acid. Sulfuric acid is one of the more dangerously potent chemicals for the environment.

Carbon dioxide has also become an escalating problem since coal burning plants have begun producing increasingly dangerous levels of CO_2. This increase in emissions from power plants has been linked to the increasing problem of global warming. Coal also contributes to the global warming problem since coal mines produce high levels of methane, another extremely harmful gas to the atmosphere. The waste products of coal burning also contribute to the deterioration of the environment by releasing a variety of dangerous heavy metals into the ground, some that are even radioactive. In fact, coal burning power plants are now responsible for more radioactive waste than nuclear power plants.

Another major problem with coal is the fact that it is a finite resource and will become scarcer. While the coal industry estimates that there is enough of a supply worldwide to last another 300 years, this does not take into account that the demand for coal is expected to rise at a level of 25% over the next decade because of the increase in the demand from India and China. It is also expected that mining production will hit its peak within the next 25 years. The following are representations of the current supply of coal:

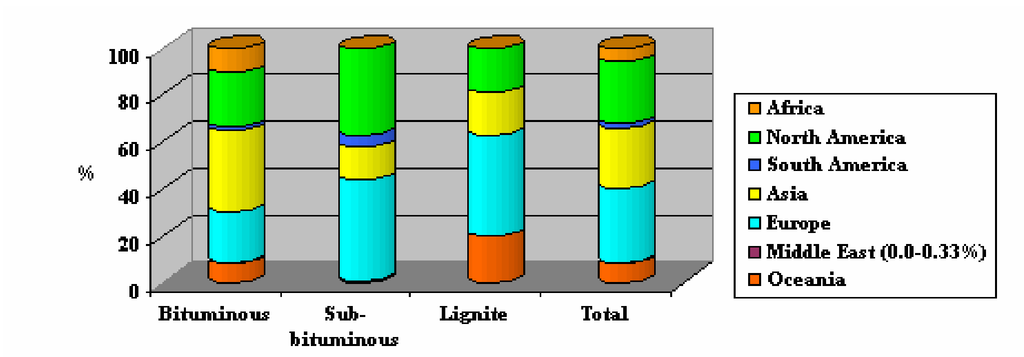

Figure 5.1: Regoinal Distribution of Proved Coal Reserves - 1999

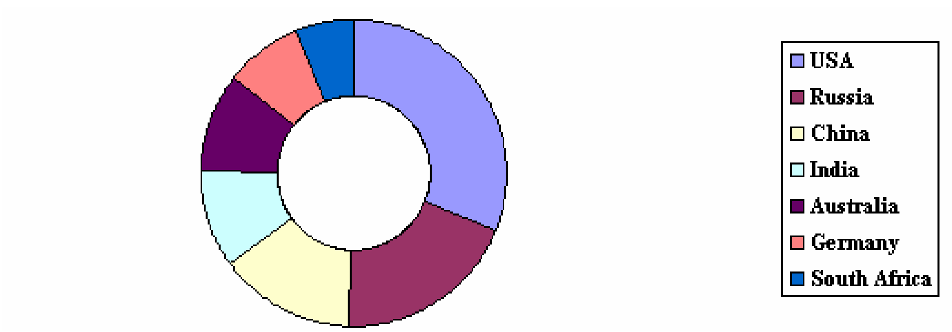

Figure 5.2: Leading Countries of Proved Coal Reserves - 1999

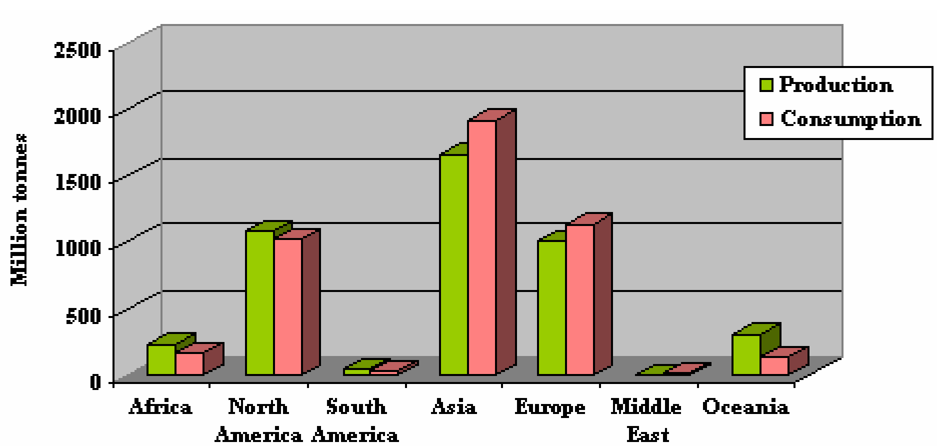

Figure 5.3: Regional Distribution of Regional Coal Production and Consumption - 1999

While coal has provided an excellent source of easily accessible energy for decades, it is time to move towards more efficient and less harmful energy sources. Even though carbon dioxide levels have increased exponentially though the use of coal, a great deal of the damage that has done can be reversed through renewable energy processes.

5.3 Natural Gas

Natural gas is a fossil fuel that has been heavily advocated since it is one of the cleanest burning fuels. It is mostly composed of methane, with small amounts of ethane, butane or propane depending on how pure the natural gas is that is being utilized. Since this gas is based off of a different hydrocarbon, it burns cleaner and is a great deal safer than other gases based on hydrocarbon backbones (i.e. propane). The combustibility of natural gas has lead to its production for heating and energy purposes and is currently being used residentially, commercially and industrially.

5.3.1 Natural Gas Formation

Since natural gas is a fossil fuel, it is formed in a process related to that which forms petroleum. It is formed from organic matter being compressed by incredibly high pressures in the earths crust. It is commonly found in deposits with petroleum, but is more commonly found in deeper composites of the earth's crust where the pressure is higher enough to compress the material into pure methane.

Through technology, there have also been new methods of creating natural gas that, the main method being the transformation of organic material into methane by microorganisms. The major problem with this process is the fact that the methane is extremely difficult to harness since much of the methane produced is lost into the atmosphere during transfer.

A third method of methane production is known as an abiogenic process, which is when

> "extremely deep under the earth's crust, there exist hydrogen-rich gases and carbon molecules. As these gases gradually rise towards the surface of the earth, they may interact with minerals that also exist underground, in the absence of oxygen. This interaction may result in a reaction, forming elements and compounds that are found in the atmosphere (including nitrogen, oxygen, carbon dioxide, argon, and water). If these gases are under very high pressure as they move towards the surface of the earth, they are likely to form methane deposits, similar to thermogenic methane."(Naturalgas.org)

5.3.2 Natural Gas Resources

Being that natural gas is a fossil fuel, and a finite source of energy it is incredibly important to know how much is available for use. While this is a guessing process, and a difficult one at that, new technologies have shed some light that can make this process more reliable. Determining natural gas accessibility has become more important since there is a feeling among the public that there is a shortage of natural gas resources. However, this is one of the more plentiful fossil fuel resources available for current use. Major concerns come from the periodic price spikes in the market yet these have come from major differences in supply and demand, which can generally cause major price fluctuations.

The federal agency that is in charge of formulating these estimations of natural gas resources is the Energy Information Administration or the EIA. The last estimation was made in 2000 and the next expected test is scheduled to occur in 2008. The major difference in years between tests is the fact that it is not the top priority of the EIA. Since the estimates of how much natural gas is remaining is much larger than most other finite sources of energy currently available. The data that was released by the EIA can be seen in the tables and graphs below:

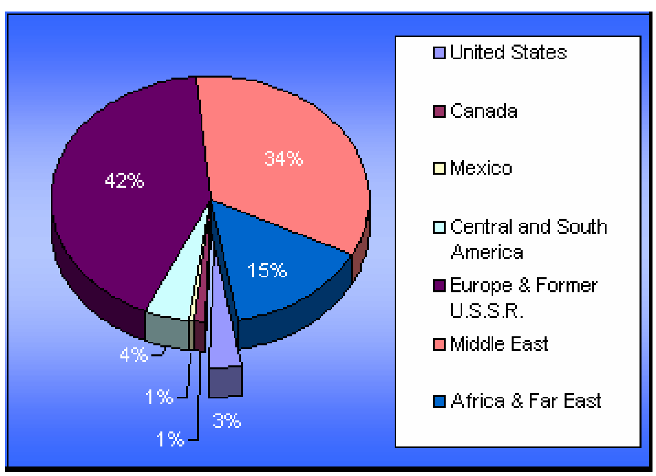

Figure 5.4: Percentage of Natural Gas Around the World

Natural Gas Resource Category	(Trillion Cubic Feet) As of January 1, 2000
Nonassociated Gas	
Undiscovered	**247.71**
Onshore	121.61
Offshore	126.1
Deep	81.56
Shallow	44.52
Inferred Reserves	**232.7**
Onshore	183.03
Offshore	47.68
Deep	7.72
Shallow	39.96
Unconventional Gas Recovery	**369.59**
Tight Gas	253.83
Shale Gas	55.42
Coalbed Methane	60.35
Associated-Dissolved Gas	**140.89**
Total Lower	**48**
Unproved	**990.89**
Alaska	**32.32**
Total U.S. Unproved	**1023.21**
Proved Reserves	**167.41**
Total Natural Gas	**1190.62**

Table 5.1: Natural Gas Technically Recoverable Resources

5.3.3 Problems with Natural Gas

Though natural gas is a positive alternative to more common petroleum based energy resources; it does have numerous problems that need to be addressed. The biggest issue deals with the problems of supply. Texas, which has the majority of America's natural gas resources, has to drill more and more wells just to keep up with the energy demand of the country. This stems very greatly from the fact that natural gas is now being used heavily in the summer, which is depleting our extra supply which was always held for the winter to be used to heat homes.

This is leading to more and more dependence on other countries for our energy needs, including an even higher dependence on the Middle East for our energy needs. By once again relying on an unstable region of the world for something we desperately need, it will lead to natural gas being as unstable a commodity as petroleum currently is.

The other solution to our natural gas supply problems is to start drilling in the Arctic and Alaska regions. While there is a supply of natural gas present in those areas, it is harder to obtain than in any other part of the world because of climate conditions. It would also have extreme consequences for the area since it would be heavily disrupting the environment of the area.

While natural gas is one of the cleanest burning and most plentiful fossil fuels available currently, it is still a fossil fuel and that does have several negative connotations to it. While it is clean burning, it does produce a significant amount of indoor pollution, which can be extremely dangerous to a homeowner who would over-utilize it. The pollution that is produced also has major adverse affects on the environment, and while the levels of damage are less than the ones produced by more common fossil fuels, they are still present. The other inherent fact that accompanies natural gas being a fossil fuel is that it is a finite resource and becoming more reliant on it is only a temporary solution. Eventually, like all other fossil fuels, it is likely to dry up forcing us to find another energy source.

While natural gas is a nice alternative to more common petroleum based energy resources, there are still dangers and risks involved with using it. However, it will play a major part in easing the possible transition to renewable energy resources, like solar and wind.

6 Societal Impacts of Fossil Fuels

6.1 Environmental Issues

One of the issues besides energy prices and fossil fuel availability that have focused the world's attention on finding alternative energy sources is the environment. Since the Industrial Revolution began in the late 18^{th} and early 19^{th} centuries, the Earth has been bombarded with millions and millions of particulates of toxins. The environment has experienced the likes of CFC's (chlorofluorocarbons), CFH's (chlorinated hydrocarbons), PFA's (perfluoroalkoxy polymer resin), PCB's (polychlorinated biphenyls), MTBE (methyl t-butyl ether), CO_2, CH_4, SO2, bisphenols, benzene, and dangerous metals in inappropriate places like lead and mercury. All of these compounds have hazardous or even fatal toxicity reports. They are all closely related to our growing problem with the health of our surrounding environment due to fossil fuels.

So what does this mean? How have these chemicals changed our everyday lives? More importantly, how have they changed the environment?

6.1.1 Chemicals

On one hand, these chemicals have given developed countries the luxuries most are unable to afford. They are used for stain and scratch resistant materials (PFA's), coolants and insulators for our highly technological world (PCB's), and the wide array of plastics our society relies on (bisphenols) (Duncan). For many years they have enabled technology to develop at amazing rates because of the extensive amount of untested chemicals that are used. The United States, however, does not have a strict testing plan as "only a quarter of the 82,000 chemicals in use in the U.S. have ever been tested for toxicity" (Duncan). This method of using before testing has turned out to be detrimental for everyone and everything involved. This means that not only are chemicals leaking into our surrounding environment, but they are also leaking into us. Many of these toxins have been banned or in limited use for many years, but they keep showing up in toxicology tests in humans, animals and the environment (Duncan).

These chemicals have led to an increase in respiratory problems, cancers, neurodegenerative conditions, and damage to other sensitive organs. The World Health Organization estimates that 3 million people die each year breathing in the pollutants from sources such as vehicles and industrial plants (Kirby). They also estimate that an additional 1.6 million people die each year breathing in solid fuels from indoor pollution (Kirby). Water is also a deadly carrier of disease killing roughly 2.1 million people each year; most specifically where in third world countries where it is responsible for 80% of the deaths (Kirby). Lastly, soil is an often overlooked environmental risk factor with chemicals. Out of date factories and power stations are likely to leave their grounds riddled with heavy metals and other dangerous substances for decades that end up as run-off into nearby cities and neighborhoods.

Some may wonder what these chemicals have to do with fossil fuels. It so happens to be the case that many chemicals are in fact associated with petroleum. Many are created in a process that needs to use extreme amounts of heat or energy to be created, the rest are direct pollutants, such as carbon dioxide, of burning fossil fuels. Like every thing else in our culture, energy can almost always be ultimately equated back to oil and fossil fuel use.

6.1.2 Global Warming

Even though the extent of chemical damage may be high, the major crisis of the environment is still global warming. It has been the most heated issue for over a decade and will continue to be a pressing subject for governments and citizens alike for a long time. The basic definition of global warming is that the climate of the earth has seen an accelerated change due to greenhouse gases (GHG) and that "evidence suggests a discernible human influence on global climate" (Summary). Most of the evidence has pointed to the increasing amounts of harmful gases that reach the protective layer of our atmosphere- the ozone. Sadly,

> "our [United States] energy-related activities account for three-quarters of our human-generated greenhouse gas emissions, mostly in the form of carbon dioxide emissions from burning fossil fuels. More than half the energy-related emissions come from large stationary sources such as

> power plants, while about a third comes from transportation. Industrial processes (such as the production of cement, steel, and aluminum), agriculture, forestry, other land use, and waste management are also important sources of greenhouse gas emissions in the United States" (Greenhouse).

As the United States has grown to become the most industrialized nation in the world, it has also significantly damaged the Earth as well.

Most scientists believe the evidence of an accelerated change is the average surface temperature increasing by 1˚F (0.6˚C), decreases in the polar ice caps and other world reservoirs of natural water (ex. glaciers), and the rising of the sea level by 4 to 8 inches (10 to 20 mm) (Scientific). These are the major climatic and environmental changes that have been seen, but global warming also encompasses many other subtle changes to our surroundings. Included in this category is the increase in precipitation, cloud cover, tropical storm formations such as El Nino, and more extreme temperatures both low and high leading to a slight increase in drought in some areas and severe wetness in others (Scientific).

The recent tragic hurricane that destroyed New Orleans has also been controversially blamed on global warming, with many scientists citing a trend of an increase in weather activity leading to more dangerous natural disasters. This is not to say that global warming causes *more* hurricanes, but that global warming increases the *intensity* of each hurricane. Two independent studies preformed by Kerry Emanuel of MIT and Greg Holland of the National Center for Atmospheric Research have shown that "the frequency of intense category 4 or 5 storms has nearly doubled" (Kunzig). Using wind speed and the life of the hurricanes, researches have compared and analyzed hurricanes for the past 50 years in the Atlantic and Pacific to obtain this data. Critics who believe that this is just part of a trend also have acknowledged the increasing force behind these natural disasters.

Even if critics are able to diffuse the argument against global warming increasing the danger of natural disasters, it is harder to argue the effect that climate change is having on animals and ecosystems. The increased temperatures, less snow and ice cover, sea level and temperature changes, and acid rain have documented negative effects in flora and fauna. Polar bears, which rely on the Arctic ice shelf for shelter, have been found to "swim up to 60 miles across open sea to find food" (Iredale). Leading to the first evidence ever of polar bears, who are naturally strong swimmers, drowning. Similar effects have been felt across the world where animals are being forced out of their habitats, and sometimes into extinction. Annual migration and other timing of life patterns may influence and shift the predator-prey balance so intricate and vital in any ecosystem. The ocean pH, which has lowered as a result of CO_2 absorption, has had a direct correlation to coral reef deaths. Lastly, ecosystems have been enduring negative feedback loops where the warming trend is accelerated through its own means. For example in the frozen tundra the rapid thawing of the ice is releasing large amounts of methane into the atmosphere that may in fact worsen the situation (Pearce).

The environment has had to undergo the brunt of the negative effects of climate change. Although ecosystems are in fact always evolving and changing, this delicate process that has withstood life for millions of years is being thrown off by the abrupt changes of global warming. Most critics that argue against global warming cite that the Earth has always had these annual warming and cooling periods in which the climate changes. The problem, however, is not that it *is* changing; the problem is *how quickly* it is changing. If the effects of global warming continue, the negative changes will not be shouldered by the environment, but by the people of the world.

6.2 Economic Problems

If the changing of the climate continues on an accelerated pace, governments and citizens around the world will be dealing with the problems financially. Although it is easier to ignore the problem of global warming now, it will continue to grow harder to do so once the effects become more apparent. Insurance companies alone are starting to feel the heat as the UNEP Finance Initiative report concluded that the "worldwide economic losses due to natural disasters appear to be doubling every 10 years and, on current trends, annual losses will reach almost $150 billion in the next decade" (UNEP). These costs, which would be related to relieving those experiencing disaster will likely be put on the shoulders of the governments and taxpayers. According to the Stern Review of BBC News, 1% of global GDP could be spent in order to stabilize the environment now and for preparation for a cleaner future (Stern). If that money is not spent now, it is likely to rise to 20% of global GDP to alleviate the stress on the environment and those in the third world countries (Stern).

Hopefully the governments of the world realize the risk of not investing heavily in alternative energies for a cleaner future. Although much of the global warming issue has been caught in a fierce political debate, it is hard to ignore the present climatic trends. The different toxins that have been polluting the environment have had an increasing effect on the livelihood of ecosystems across the plant. Toxins, like carbon dioxide, are tough to get rid of as they last in the atmosphere for up to 200 years (EPA). This compounds the problem, making it harder to deal with as the current carbon dioxide production levels are expected to increase with time, not decrease. It is tough to say what should be done, when, and how. However, if world leaders can begin to collaborate and act now to preserve what is left for the future, the ecological troubles may be able to be reversed in time.

6.3 Political Impact of an Oil Based Economy

One of the biggest players in the United States political scene now and for the past 50 years has been the oil industry. This has stemmed completely from the fact that for that period of time our energy needs have been almost completely based off of our petroleum and petroleum derivates. With our dependence being so great and our country's ever growing usage of petroleum, our country's foreign and domestic policies are being more and more influenced by the machinations of the petroleum industry.

While this problem could very easily be traced back to the highly paid lobbyists that are hired by the oil industry in order to protect interests, this problem does delve much deeper than that simple cause. Since our country accounts for more than 25% of the world's petroleum usage and we only have only approximately 3% of the world's oil resources, it causes us to become entangled in the affairs of other countries in order to ensure our petroleum supplies. Unfortunately for the country, many of the countries that are major oil producers are incredibly unstable and vehemently anti-American. Countries like Iran, Iraq, Saudi Arabia, Venezuela and Nicaragua are having major impacts on what our country is involved in on the global front.

With these countries having the constant threat of being able to cut off exportation of oil to our country, numerous political actions have had to be taken for numerous years in order to maintain our constant supply of oil reserves. These actions range from economic aid, to international sanctions, to the most extreme being military intervention. These interactions with dangerous and unpredictable countries often cause a great deal of controversy among our government and the public in general. This stems from the fact that because of the extreme dependency of our economy on petroleum resources, these interactions with the countries is very expensive; in the monetary sense, the reputation sense and the cost of American lives. This influence was stated extremely well by United States Senator Richard Lugar,

> "Energy is vital to a country's security and material well-being. A state unable to provide its people with adequate energy supplies or desiring added leverage over other people often resorts to force. Consider Saddam Hussein's 1990 invasion of Kuwait, driven by his desire to control more of the world's oil reserves, and the international response to this threat. The underlying goal of the U.N. force, which included 500,000 American troops, was to ensure continued and unfettered access to petroleum."

However, possibly one of the biggest controversies regarding our involvement in these countries and our dependence on an economy based off of petroleum is that most of our petroleum resources come from countries that are notorious for supporting Islamic Fundamentalist terrorism against America and the rest of the western world. With the attacks in London, Spain, American embassies across the world and of course the World Trade Center attack on September 11, 2001; terrorism has become one of the issues in the American governmental spotlight. Our dependence on oil can be traced back as one of the biggest influences on these terrorists; both their inspiration for attack and hypothetically their financial backing to carry out the attacks.

While the oil industry can not be traced back as the major cause of the political problem of our dependence on petroleum, they are a major contributor to the problem. The biggest influence has been through the act of lobbying, paying representatives to go to Congress and influence legislation that hits the floor. The oil industry has poured over 1 billion dollars in to their lobbying in the past 8 years and this has had a tremendous effect on the energy based legislation that has gone through our federal government. It has ensured that their assets are protected, being able to receive incredible amounts of federal subsidies that should be placed in other possible energy sources.

Another way that the energy industry has been able to influence the government is to actually have people elected into office that have been major players in the oil industry. These men range from Presidents George Bush Sr. and George W. Bush to numerous senators and congressmen like Joseph Lieberman and Joe Barton. Having these people in places of high power has allowed for even more control over energy based legislation as it goes through the halls of Congress.

7 Solar Energy

Photovoltaic cells, otherwise known as solar cells, convert light into electricity by making use of semiconductor principles. At the heart of many solar cells, is something known as the *pn*-junction. When a photon of light collides with this junction, a negatively charged electron and a positively charged "hole" is produced through a process known as photogeneration. Once apart, the two charges move to opposite sides of the device and produce a current. To fully understand the operation of a photovoltaic solar cell, we must first understand the semiconductor physics behind it.

7.1 Semiconductor Physics

Semiconductors fall into one of three main categories: *n*-type, *p*-type, or intrinsic. An intrinsic semiconductor is a composed purely of the one element, usually a metalloid with four valence electrons, such as silicon or germanium. The lattice structure of an intrinsic silicon based semiconductor is depicted in Figure 7.1[*]:

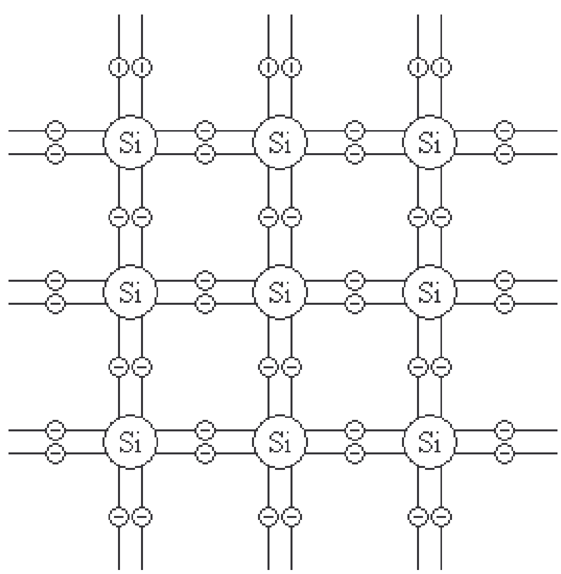

Figure 7.1: Lattice Structure for Silicon Based intrinsic Semiconductor

[*] Lattice structure images based on similar images found in RF Circuit Design: Principles and Applications. Ludwig, Reinhold and Bretchko, Pavel.

The four valence electrons will form covalent bonds to produce a structurally sound lattice. For ideal conditions (0˚K), there is a complete lack of thermal energy and the electrons will not move around, causing the semiconductor to behave as an insulator. As the temperature increases, the electrons will amass a critical amount of energy, known as the bandgap energy (E_g). The expression for bandgap energy is given by Equation 7.1, where E_C is the lowest energy level of the conduction band and E_V is the highest energy level of the valence band.

$$E_g = E_C - E_V$$

Equation 7.1

Once this occurs, the electron will break free from its covalent bond and move from the valence band into the conduction band. The excess electrons are called donors. This also creates an open spot for an electron. This positively charged open spot is called a "hole". This occurrence creates something that is referred to as an Electron Hole Pair (EHP).

For *n*-type and *p*-type semiconductors, the generation of positive and negative charges happens a little differently. Silicon or germanium is doped (mixed) with elements containing either three or five valence electrons. If the intrinsic silicon is doped with an atom containing three valence electrons, such as boron, one of the covalent bonds will not be filled, resulting in the creation of a "hole". Due to the existence of this "positive charge", the semiconductor is labeled as *p*-type. The lattice structure of a silicon based *p*-type semiconductor is shown in Figure 7.2:

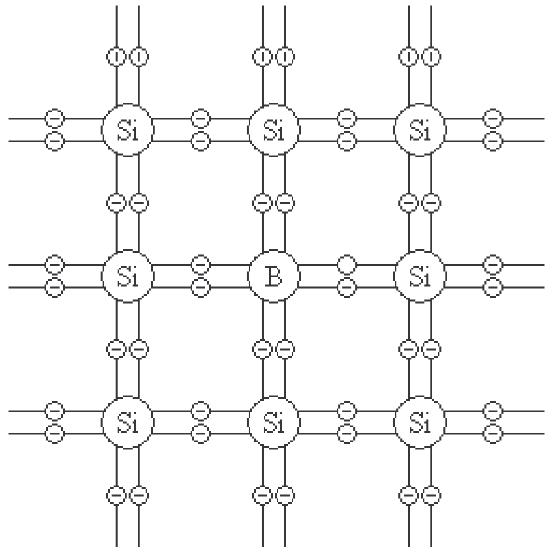

Figure 7.2: Lattice Structure for Silicon Based p-type Semiconductor

If the intrinsic silicon is doped with an atom containing five valence electrons, there will be an extra electron. Subsequently, this negative charge provokes the naming of this semiconductor as *n*-type. The lattice structure of a silicon based *n*-type semiconductor is shown in Figure 7.3:

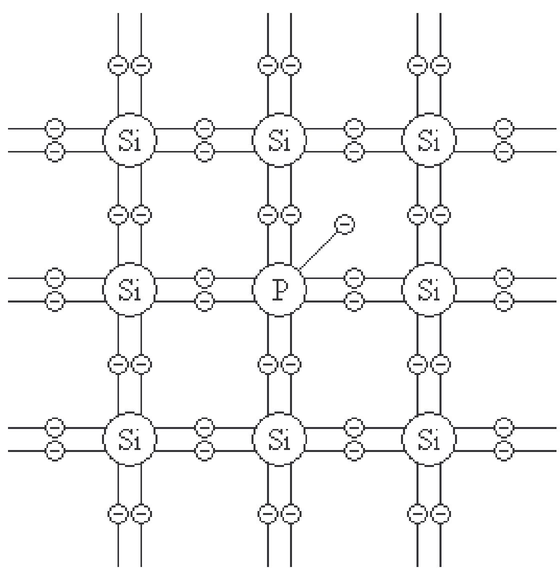

Figure 7.3: Lattice Structure for Silicon Based n-type Semiconductor

7.2 The pn-Junction

As previously stated, sufficient amounts of thermal energy will cause the creation of more EHPs. The thermal energy can also come from absorbed photons. Since, it is not possible to keep the *pn*-unction at absolute zero, and since it is hard to keep a device in perfectly dark storage, there will be fluctuations in the thermal energy. These fluctuations will cause acceptor and donor concentrations to spread out, forming diffusion current, I_{diff}. The diffusion current is not significant until both the *p*-type and the *n*-type placed adjacent to one another.

When *p*-type material is placed adjacent to *n*-type material, a typical *pn*-junction is created, as shown in Figure 7.4:

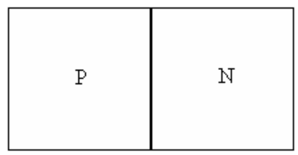

Figure 7.4: Layout of the pn-Junction

Before the *pn*-junction is formed, there is a build up of donors (negative charge) in the *n*-type material. However, there is still a small concentration of acceptors (positive charge). The reversed condition exists in the *p*-type material, with a build up of acceptors and a small concentration of donors. When the *pn*-junction is formed, the acceptors in the in the *n*-type material diffuse towards the *p*-type material, and the donors in the *p*-type material diffuse towards the *n*-type material. They cannot, however, pass through the barrier into the other respective regions, so they collect at the middle edge of the junction. This diffusion creates an area referred to as the depletion region, *W*, depicted in Figure 7.5:

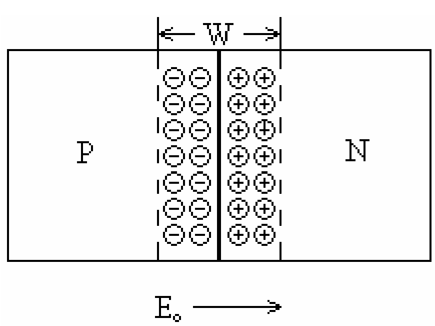

Figure 7.5: pn-Junction with Depletion Region and Built in Potential

The width of the depletion region can be represented as the sum of the width of the depletion region located in the *p*-type material and the width of the depletion region located in the *n*-type material:

$$W = W_n + W_p$$

Equation 7.2

The movement of the negative charge in one direction and the movement of positive charge in the opposite direction create a built-in electric field, E_o, for the *pn*-junction. The following expression defines the built-in electric field for *pn*-junctions with overall neutral charge:

$$E_o = -\frac{eN_d W_n}{\varepsilon} = -\frac{eN_a W_p}{\varepsilon}$$

Equation 7.3

In Equation 7.3, *e* represents the charge of an electron (1.60218 • 10^{-19}), N_d and N_a is the concentration of donor and acceptor atoms (respectively), and ε is the electric permittivity of the material. The electric permittivity of the material is equal to the relative permittivity, ε_r (often called the dielectric constant), multiplied by the permittivity of free space:

$$\varepsilon = \varepsilon_r \varepsilon_o = \varepsilon_r \cdot 8.85 \cdot 10^{-12}$$

Equation 7.4

The diffusion of the positive and negative charges within the built-in electric field will generate a potential difference (voltage). As we know from electrostatics, negative charges always move in opposition to the electric field. This is shown in Figure 7.6:

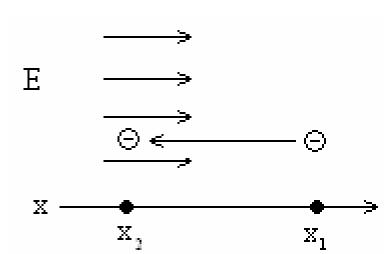

Figure 7.6: Movement of Charge against an Electric Field

The voltage created by the movement of the charge from point x_1 to x_2 is given in Equation 7.5:

$$V_{21} = -\int_{x_1}^{x_2} E \cdot dx$$

Equation 7.5

If we substitute Equation 7.3 into Equation 7.5, we arrive at an expression for the built-in potential, V_o:

$$V_o = -\int E_o = \int \frac{eN_d W_n}{\varepsilon} = \int \frac{eN_a W_p}{\varepsilon}$$

Equation 7.6

7.2.1 Biasing the pn-junction

Previous discussions of the *pn*-junction have not taken into consideration the biasing effects. We will now examine the effects caused by a voltage applied across the *pn*-junction.

7.2.1.1 Forward Bias

A *pn*-junction is forward biased when a greater voltage is applied to the side of junction containing *p*-type material side and while a lesser voltage is applied to the side of the junction containing *n*-type material side. Such a configuration is pictured in Figure 7.7:

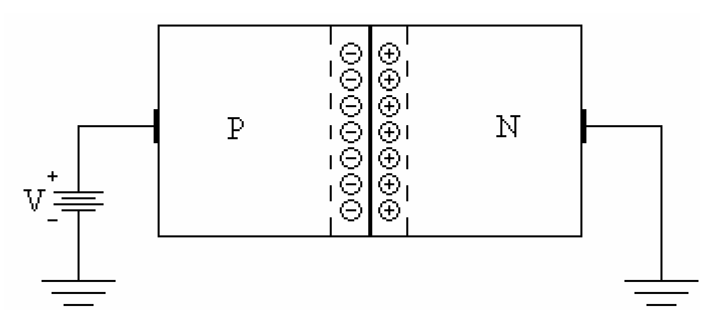

Figure 7.7: Circuit Representation of a Forward Biased pn-Junction

The applied voltage, V, causes a build up of positive charges the depletion region to shrink as the built-in electric field, E_o, is reduced. The barrier at the center of the junction diminishes and the positively charged holes in the p-type material, becoming minority carriers. The same effect occurs with the majority carriers (electrons) in the n-type material diffusing into the p-type material and becoming minority carriers. After crossing over into the p-type material, the holes in the n-type material diffuse away from the depletion region and begin to combine with the electrons. Also, they begin to attract some of the negative charge away from the connection to ground (which is connected to the negative terminal of the battery). The same effect transpires with the electrons passing into the p-type material attracting holes from the positive terminal of the battery. This produces a current, I. The expression for the current across the junction is given in Equation 7.7:

$$I = I_s(e^{\frac{V}{nV_T}} - 1)$$

Equation 7.7

I_s is defined as the saturation current, which is a limiting factor of the junction. It is also known as the leakage current. n is known as the emission coefficient, which is equal to 1, for most applications. V_T is the referred to as the thermal voltage:

$$V_T = \frac{kT}{q}$$

Equation 7.8

In Equation 7.8, q refers to the charge in Coulombs (the charge of an electron in this case), T defines the Kelvin temperature, and k represents a quantity known as the Boltzmann constant ($1.38066 \bullet 10^{-23}$ J/K). For room temperature (298 K) analysis, we arrive at the following thermal voltage:

$$V_T = \frac{(1.3806505 \cdot 10^{-23}) \cdot (298)}{1.60217653 \cdot 10^{-19}} = 25.68mV$$

Equation 7.9

Generally, an approximation of 26 mV is used as a substitute for the thermal voltage. If we substitute our result from Equation 7.9 into Equation 7.7, we ascertain the following expression:

$$I = I_s\left(e^{\frac{V}{25.68 \cdot 10^{-3}}} - 1\right) = I_s\left(e^{38.94V} - 1\right)$$

Equation 7.10

7.2.1.2 Reverse Bias

A *pn*-junction is reverse biased when a greater voltage is applied to the side of junction containing *n*-type material side and while a lesser voltage is applied to the side of the junction containing *p*-type material side. Such a configuration is pictured in Equation 7.8:

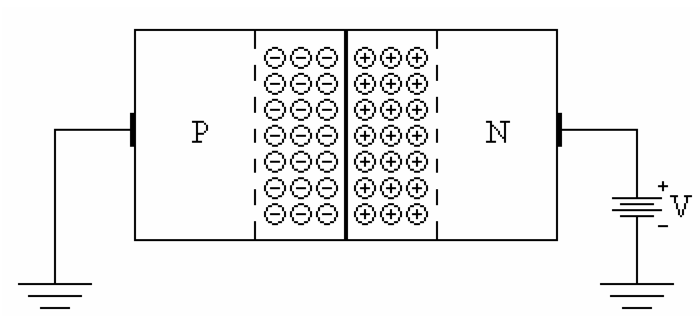

Figure 7.8: Circuit Representation of a Reverse Biased pn-Junction

When the *pn*-junction is reverse biased, the applied voltage increases the magnitude of the built-in electric field, causing the depletion region to increase. Since only a minute amount of minority carriers are able to cross the junction barrier, the overall current across the *pn*-junction is minimal.

As the reverse biasing voltage increases in magnitude, the width of the depletion region increases. This causes the majority carriers to be pushed further away from the minority carriers in the opposite depletion region. As the depletion region increases, the holes in the *p*-type material are forced away from the holes located in the depletion region of the *n*-type material. A separation and build up of charge constitutes a capacitive effect. The capacitance will increase as long as the reverse bias voltage and depletion region area increase. The depletion capacitance, C_d is given as follows (Hambley 176):

$$C_d = \frac{C_{do}}{[1-(V/V_o)]^m}$$

Equation 7.11

In Equation 7.11, C_{do} is equal to the depletion capacitance at zero bias and *m* is known as the grading coefficient.

7.3 Composition of a Photovoltaic Device

As mentioned before, a solar cell is a semiconductor that photogenerates EHPs by absorbing photons incident upon the junction. For this reason, we must account for a few factors when deciding upon the location and angle of which the solar cell will face.

7.3.1 Light Basics

Light propagates through space as an electromagnetic wave. If we set the direction of propagation to the z-axis, its electric field component to the x-axis, and its magnetic field component to the y-axis, we can represent its electric field by Equation 7.12 (Kasap 3):

$$E_x(t,z) = E_o(\omega t - kz - \phi_o)$$

Equation 7.12

In Equation 12, ω represents the angular frequency, k represents a quantity known as the wave number, ϕ_o accounts for the initial phase of the wave, and E_o represents the magnitude of the wave, while t and z are variables representing time and direction of propagation, respectively. Angular frequency can be represented as follows, where f is the frequency:

$$\omega = 2\pi f$$

Equation 7.13

The frequency of a wave is an important characteristic. Energy is generated and transmitted in discrete amounts. The smallest discrete amount of energy carried by a light wave is called a photon. The amount of energy contained in one photon is proportional to the frequency of the light wave and a fixed number, called Planck's constant, $h = 6.6260693 \cdot 10^{-34}$. The expression for this energy is given in Equation 7.14:

$$E_{phton} = hf$$

Equation 7.14

The wave number, k, is given by the following expression, where λ is the wavelength of the wave:

$$k = \frac{2\pi}{\lambda}$$

Equation 7.15

We can find the phase velocity, v_p, by dividing the change in distance by the change in time (Kasap 4):

$$v_p = \frac{\Delta z}{\Delta t} = \frac{\omega}{k} = f\lambda$$

Equation 7.16

The resulting expression given in Equation 7.16 can be used to find either the frequency or the wavelength of a wave given the rate in which it propagates through a certain medium, depending on two important characteristics of the medium. These two very important properties are its permittivity, ε, and its permeability, μ. A medium's permeability is given as a product of the permeability of free space and the relative permeability of the material:

$$\mu = \mu_o \mu_r$$

Equation 7.17

For most mediums, the relative permeability is equal to one. With our knowledge of Equation 7.4 and Equation 7.17, we can analyze the expression for phase velocity through a given medium (Kasap 7):

$$v_p = \frac{1}{\sqrt{\varepsilon\mu}} = \frac{1}{\sqrt{\varepsilon_o \mu_o}} \cdot \frac{1}{\sqrt{\varepsilon_r}}$$

Equation 7.18

The relative permittivity of free space is equal to 1. Therefore, we can compute the velocity of light in free space, *c*:

$$c = \frac{1}{\sqrt{(8.8542 \cdot 10^{-12}) \cdot (4\pi \cdot 10^{-7})}} \cong 3 \cdot 10^8 \, m/s$$

Equation 7.19

If we substitute Equation 7.18 into Equation 7.19 and we can find a ratio of the speed of light to the phase velocity through a medium (Kasap 7):

$$\frac{1}{\sqrt{\varepsilon_r}} = \frac{c}{v_p} = n$$

Equation 7.20

In Equation 7.20, *n* represents the refractive index of the medium. A medium's refractive coefficient plays a large role in determining how a medium reflects or absorbs light waves. The ratio of refractive indexes between two mediums controls how waves will be reflected or transmitted at the boundary between the two mediums. If the angle is of an incident wave upon a medium is too large, an occurrence called total internal reflection will occur. This maximum angle is labeled as θ_c. Its expression is given in Equation 7.21, where n_2 is the medium on which the wave is incident (Kasap 15):

$$\theta_c = \sin(\frac{n_2}{n_1})$$

Equation 7.21

For this reason, we must have an accurate tilt to the solar panel if it is to receive the optimal amount of light.

7.3.2 Photovoltaics and the pn-Junction

The main principle behind the photovoltaic cell is the fabrication of a *pn*-junction that will produce a current, *I*, when light is incident upon it. When a photon of sufficient energy is absorbed by the junction, the energy will cause an electron to break its covalent bond, leave the valence band and enter the conduction band. This is called the photogeneration of an Electron Hole Pair (EHP). This phenomenon is illustrated in Figure 7.9:

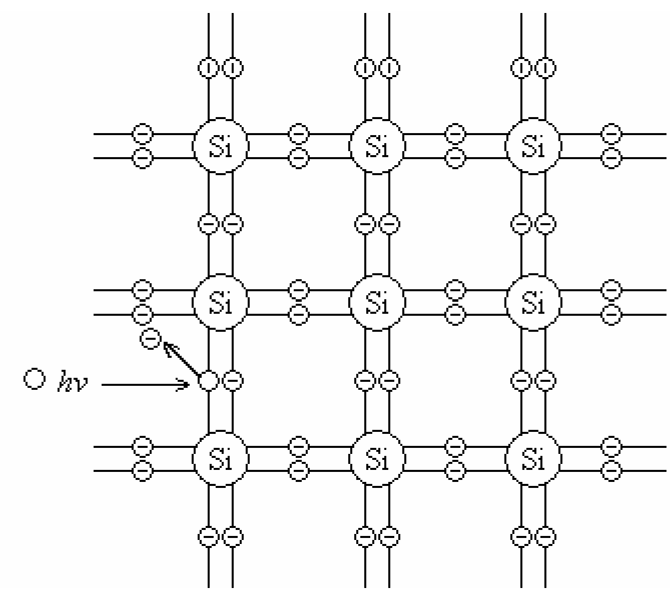

Figure 7.9: Creation of an EHP through Photogeneration

The creation of EHPs will only occur if the absorbed photon contains enough energy to overcome the bandgap energy:

$$E_g = E_{phton} = hv$$

Equation 7.22

As more and more EHPs are created, holes in both the *n*-type material and the *p*-type material will begin to gather at the electrode attached to the *p*-type material. Likewise, the freed electrons will begin to gather at the electrode attached to the *n*-type material. This would not be able to occur without the built-in electric field, E_o. The resulting effect is shown in Figure 7.10†:

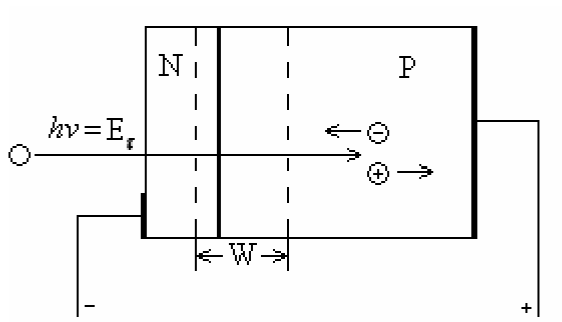

Figure 7.10: Movement of Charge within a Photovoltaic pn-Junction

The narrow width of the *n*-type side is necessary since it is the side through which the photons will enter the junction. This will cause most of the photons to be absorbed in the depletion region and the in the *p*-type side. We also note the connection of a finger electrode to the *n*-type side. The connection of a bridge of finger electrodes to the whole *n*-type side of the solar cell will allow light to penetrate into the *n*-type side, and still collect the excess electrons that will accumulate at the edge of the *n*-type side. Since light does not need to penetrate the *p*-type side, a solid backing can be used (Kasap 258).

† Photovoltaic *pn*-Junction image is based on images found in Optoelectronics and Photonics: Principles and Practices. Kasap, S.O.

8 Solar Panel Manufacture

8.1 Chemical Vapor Deposition

Chemical Vapor Deposition (CVD) plays a large role in the manufacture of semiconductor materials, such as the ones used in solar panels. Through CVD, almost any element and compound can be produced (http://www.ultramet.com/cvd2.htm). Some of the other advantages of Chemical Vapor Deposition include its ability to form highly dense material, its ability to form pure significantly pure material (99.99 – 99.9999%), and the cost efficiency of its production (http://www.ultramet.com/cvd2.htm). CVD is capable of evenly coating multiple substrates at once.

In CVD, gaseous compounds enter a deposition chamber. Inside the chamber, the gases are heated until they begin to react with one another. A solid compound (or element) begins to accumulate on a substrate, located at the bottom of the deposition chamber. After the reaction, bi-products (some hazardous) leave the deposition chamber. There are many ways of forcing the gaseous mixture to react, the most common of which are Plasma Enhanced Chemical Vapor Deposition (PECVD) and Low Pressure Chemical Vapor Deposition (LPCVD).

8.2 Physical Vapor Deposition

Another similar process used for the manufacture of semiconductor materials is Physical Vapor Deposition (PVD). PVD uses vacuums to stimulate a physical reaction of the gaseous vapors of the deposition process, and is very similar to CVD. In fact, the main difference between Physical Vapor Deposition and Chemical Vapor Deposition is that, for PVD, a physical reaction causes the resultant of the reaction to accumulate on the substrate, while, for CVD, it is a chemical reaction. Generally, CVD is used in the manufacture to thin film technology, while PVD is used in the manufacture of metal layers. The most common forms of PVD are evaporation and sputtering.

Photovoltaic devices have been limited by two main factors: cost and price. The most promising piece of information is that improvements are currently being made in both areas. The main reason for the cost limitation is the fact that high efficiency photovoltaic technology is still relatively new. As this technology ages, effective methods for fabricating the technology will be implemented. Subsequently, the cost will go down.

9 Photovoltaic Materials

9.1 Silicon

Semiconductor devices made out of silicon have been around for a little while. For this reason, efficient methods of producing semiconductive silicon have already been developed. Currently, there are three main types of silicon solar panels: amorphous silicon, monocrystalline silicon, and polycrystalline silicon.

9.1.1 Amorphous Silicon

Unlike crystalline silicon, amorphous silicon (abbreviated a-Si) does not have an organized lattice structure. Each silicon atom still contains a bond to four other silicon atoms. The main difference is that, for crystalline structures, the bonds tetrahedral. For amorphous silicon, all the bonds are random. Amorphous silicon is manufactured through CVD.

An advantage to amorphous silicon in large scale photovoltaic applications is the fact that it is unvarying in consistency. Also, since it has naturally occurring defects in the silicon bonds, impurities do not have a considerable impact on the general function of the material. Since it can be produced as a ribbon, it is flexible and durable. For this reason, amorphous silicon is being used at and increasing frequency for residential applications. The main downside to amorphous silicon is its low efficiency, which ranges from 8 – 10% (Kasap 271).

9.1.2 Crystalline Silicon

Crystalline silicon solar cells are also manufactured by CVD. The existence of crystals cause crystalline silicon to be more brittle than amorphous silicon, although amorphous silicon is not as efficient as polycrystalline silicon. Polycrystalline silicon (solar cells with multiple silicon crystals) efficiencies range from 12 – 19% while monocrsytalline silicon (solar cells with a single silicon crystal) efficiencies range from 16 – 24 % (Kasap 269).

9.2 Cadmium Telluride

Cadmium telluride consists of multiple crystalline molecules (polycrystalline) of CdTe that form a thin ribbon. As a semiconductor material, its main use is in photovoltaic cells. The main factor limiting its widespread use is its inability to be mass produced efficiently. While CdTe photovoltaic efficiencies have reached from 15 – 16 % in laboratories, its efficiencies in solar panels have only measured around 6 – 8% (http://www.nrel.gov/ncpv/cdteteam.html). Until it can be produced in a more efficient way, it will not be competitive with silicon solar panels.

9.3 Gallium Arsenide

Gallium arsenide (GaAs) is a semiconductor material formed from the two elements gallium and arsenic. Gallium arsenide is formed when the metallic element gallium reacts with the gaseous element arsenic. GaAs is use in many devices, including light emitting diodes (LEDs), transistors used for high speed switching applications, and solar cells. It is the most efficient photovoltaic material, with efficiencies reaching as high as 39%. The main problem with gallium arsenide is its cost, which is also the greatest out of any photovoltaic material. It is priced at around \$40/cm^2. This high price makes GaAs an unlikely choice for home residential solar panels. Its use in solar cells is usually confined to expensive technologies such as satellites and space probes. Gallium arsenide is also great for solar cell applications in space since it is very resistant to radiation damage. Another minor problem with gallium arsenide is that its production must be preformed carefully, since arsenic is a poisonous gas.

9.4 Photovoltaic Efficiency Considerations

As we have seen earlier, the refractive indexes of two mediums and the angle of an incident wave upon one of them must meet certain requirements in order for the wave to be transmitted. For this reason, we must make certain that light incident upon a photovoltaic cell is at a certain angle. If this is not the case, the photons will be reflected instead of absorbed. This factor plays a large role with solar cells. Light waves from the sun do not always make it through the earth's atmosphere without changing direction. The fact that the earth's atmosphere scatters light waves can hinder solar cells greatly. In order to optimize photovoltaic solar cell efficiency, a material with a refractive index less than, but close to 1 (the refractive index of air) should be selected. This will allow for light to be incident at angles of close to 90^{o} without being reflected. Finding such a material is into always easy.

As EHPs are generated, the electrons and holes will move in the direction of their respective electrodes. This does not mean that they will actually make it there. On the way to the negative electrode, some of the electrons will actually enter into another covalent bond with a different hole from which it left. This occurrence is called recombination. This happens at an especially high rate near the surface, causing losses up to 40% (Kasap 260).

10 Cost

The main factor that limits that implementation of solar panels is its cost. If it takes too long for a return on investment to occur, people will not be willing to invest in a solar panel system for their house, especially if they are unsure they will be living at that house for an extended period of time. Also, solar panels need to be affordable enough so that the average home owner can afford the initial investment. Nevertheless, the cost of solar panels has declined rapidly over the last 25 years. This can be seen in Figure 10.1:

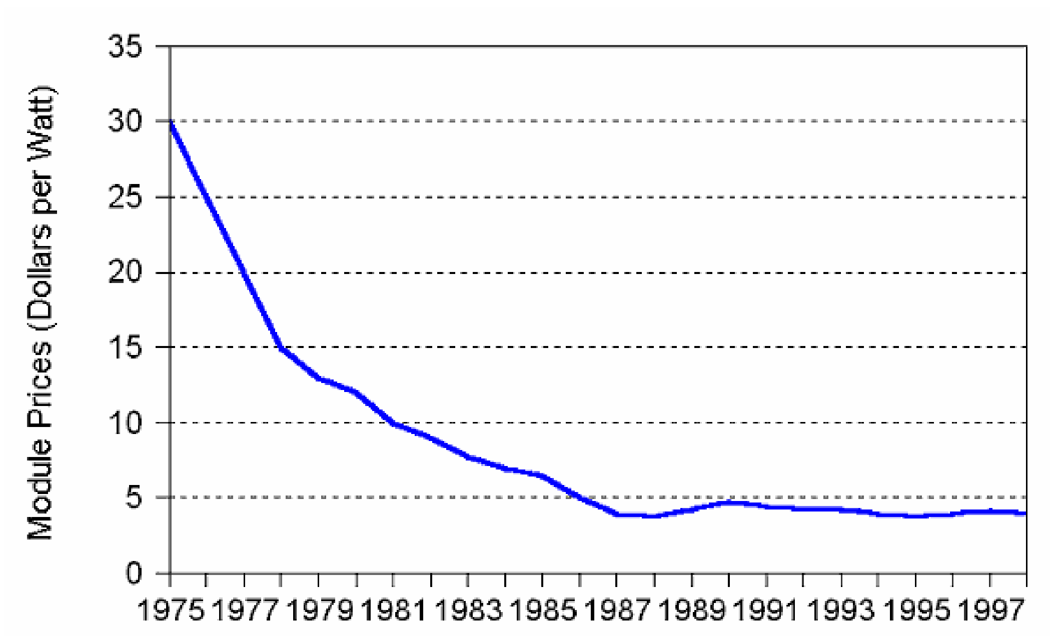

Figure 10.1: Cost of Solar Panel Modules‡

We note that the cost has decreased at an increasingly rate. After using Excel to add a power trendline, we arrive at Figure 10.2:

‡ Graph taken from: < http://www.eia.doe.gov/cneaf/solar.renewables/rea_issues/fig1s.html>

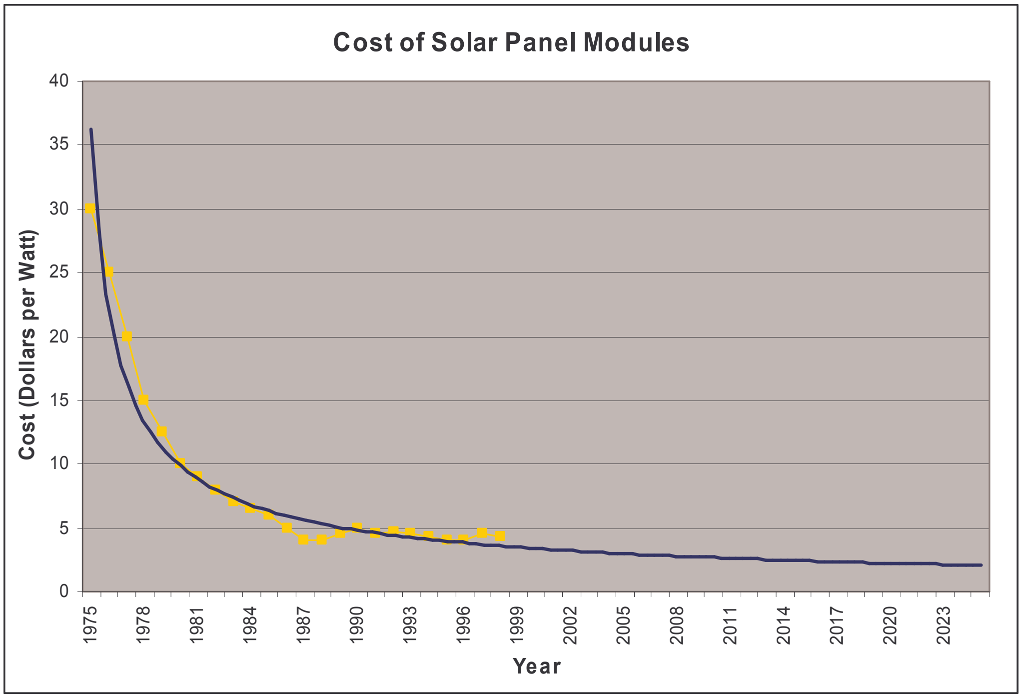

Figure 10.2: Extrapolation of Solar Panel Module Costs

We can determine that the rapid decrease in price will continue to level off, but there is still a notable decrease in the price by 2025, which appears to be around $2.50 per Watt.

11 Efficiency

Another limiting factor for preventing the wide spread use of solar technology is its efficiency. The efficiency of a solar panel refers to how much power it produces in comparison to the energy that reaches it. As has already been shown in Equation 7.14, the amount of energy that reaches the solar panel is equal to the amount of energy contained by the light incident upon the solar panel. The expression for the efficiency, η, of the solar panel is displayed in Equation 2, where P_{out} represents the output power of the system:

$$\eta = \frac{P_{out}}{E_{in}}$$

Equation 11.1

11.1 Efficiency Progress

Photovoltaics, though old in concept, is still a relatively new technology. There is still much room for improvement. The chart shown in Figure 11.1 depicts the improvement of solar panels over the last 30 years.

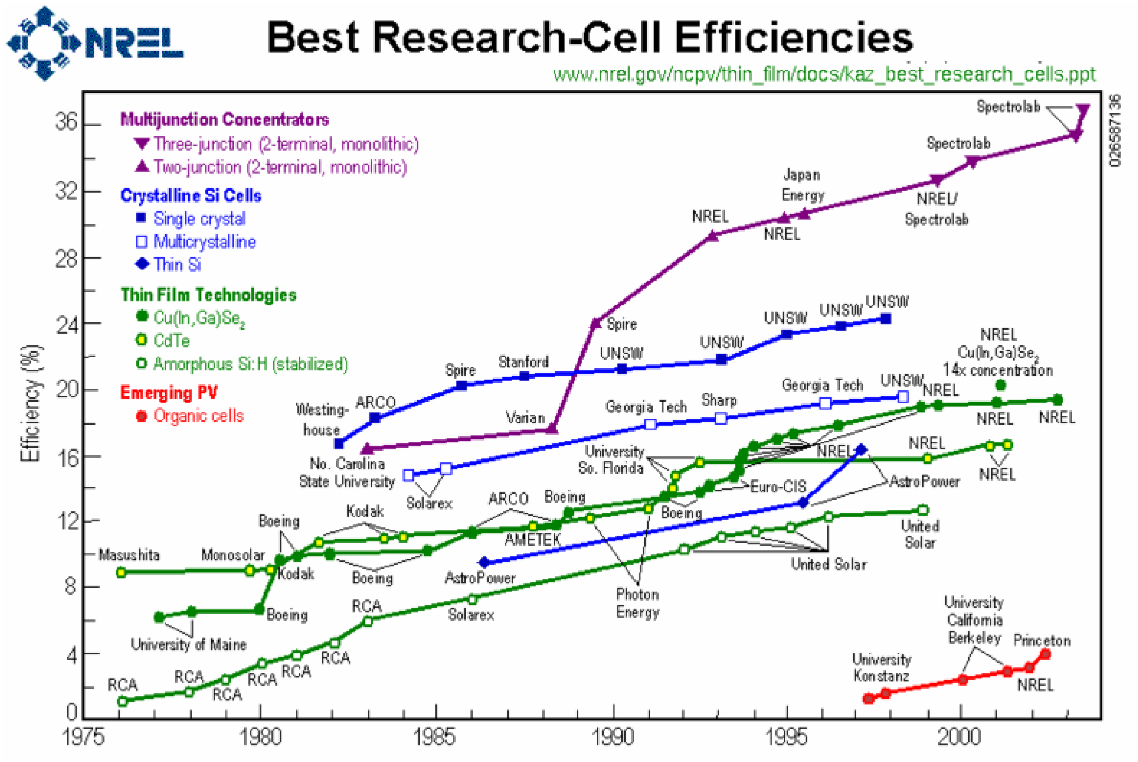

Figure 11.1: History of Photovoltaic Efficiencies§

We can use the information depicted in Figure 11.1 in order to project the photovoltaic efficiencies in the future. Figure 11.3 illustrates a linear extrapolation of the efficiencies data shown in Figure 11.2:

§ Graph taken from:
< http://www.nrel.gov/pv/thin_film/docs/kaz_best_research_cells.ppt >

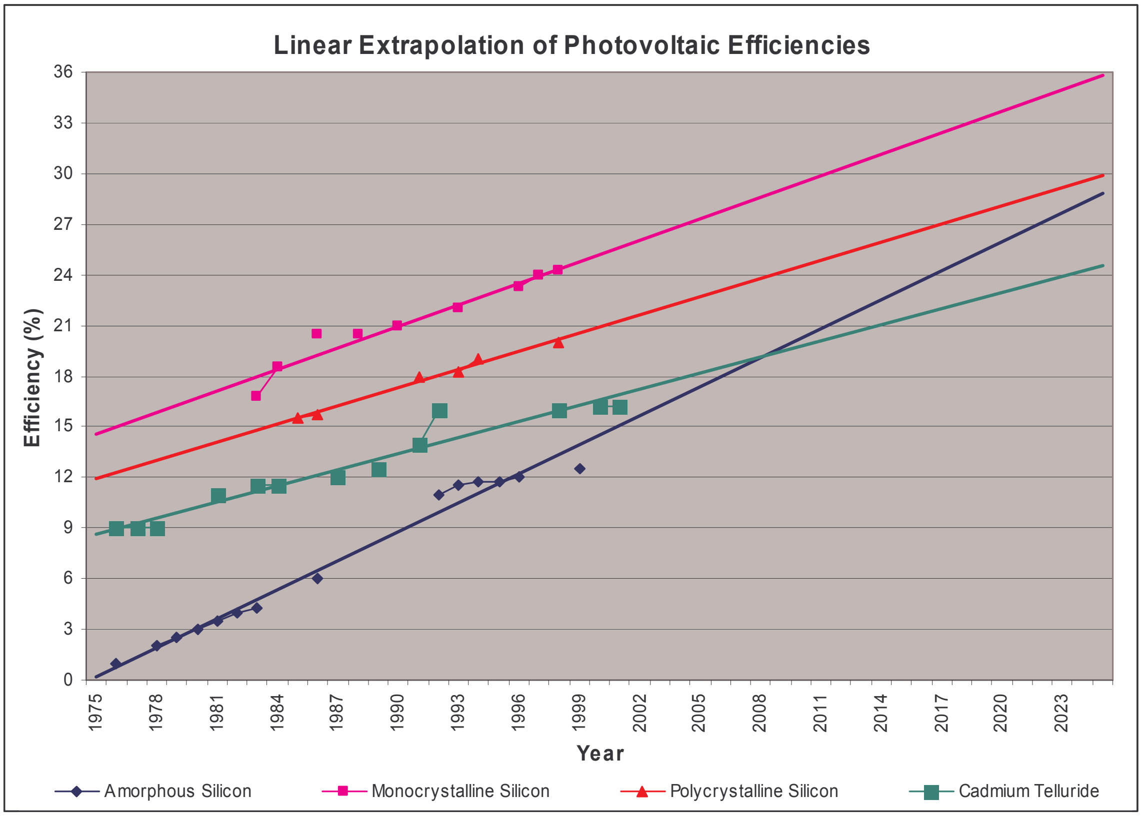

Figure 11.2: Linear Extrapolation of Efficiency Data

The linear trendlines seem to fit the data relatively well, but they fail take into account that the efficiencies have a possibility of hitting a plateau. Eventually, developments will level off. For this reason, we must also consider other forms of extrapolation. A logarithmic extrapolation shown in Figure 11.3:

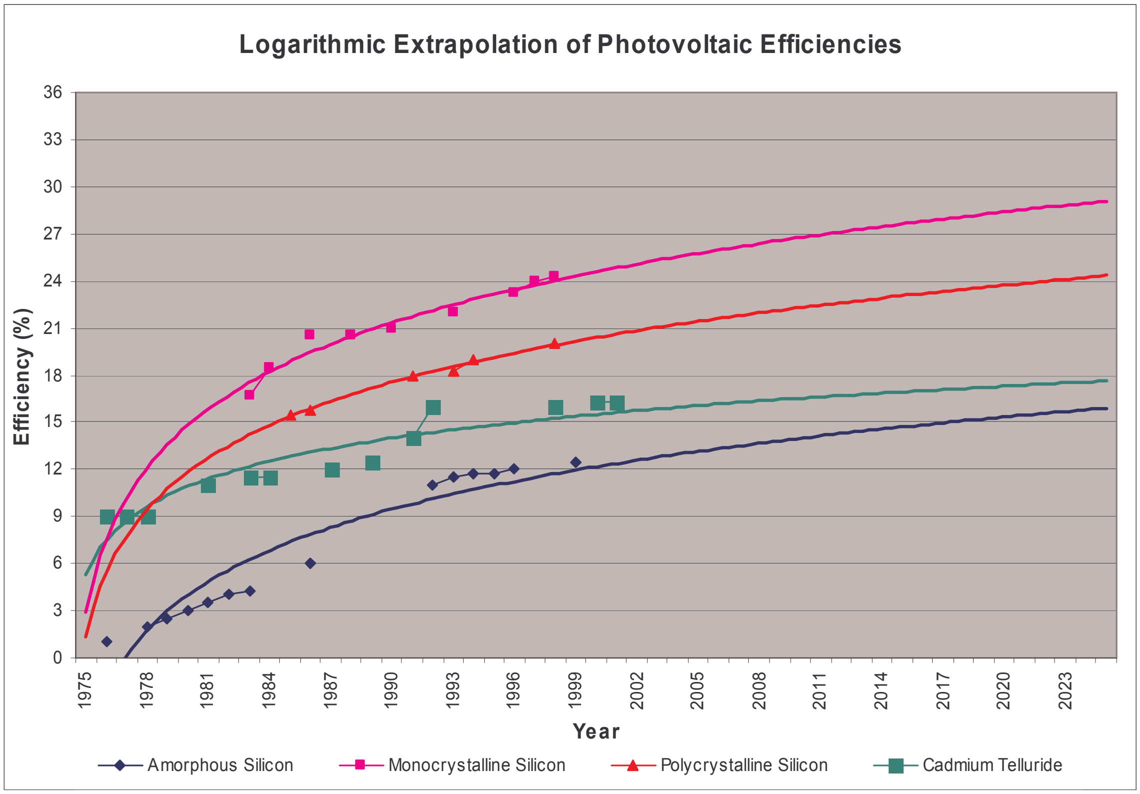

Figure 11.3: Logarithmic Extrapolation of Efficiency Data

The logarithmic trendlines shown in Figure 11.3 also match the data relatively well. If we compare the two graphs we can see that they are both realistic predictions of what the photovoltaic efficiencies will be by 2025. However, we will use the linear extrapolation since it fits the data points a lot better and seems to be more realistic.

12 Local Installation Examples

There are examples of solar houses everywhere around the country that boast significant returns. They are backed mainly by governmental and non-governmental funds that are interested in seeing what effects photovoltaics cells (PV) can have on energy consumption inside the home. Even though the initial costs at this point can seem steep, incentives given by public and private funds allow paybacks in a relatively short amount of time. The purpose of this analysis is to determine what type of solar cell that particular houses use, what the orientation of the roof is in relation to the sun, how much sun does the PV cells collect (how many kWh are produced), what is the effect on the electric bill, and lastly what is the life or warrantee on these cells. These are all critical points in deciding whether or not PV cells are the right choice. By analyzing these houses, a better understanding of what types (or styles of PV cells), companies, financial choices, and production efficiencies are available.

12.1 The Watson Solar House

The Watson solar house in Boston, MA was installed by Conservation Services Gropu (CSG) Renewables, a local company out of Westborough, MA. The particular system seen at the Watson house is described as a quad system because of the 48 style array of the panels (a 5 kW system) (Watson). A 5 kW system is defined by the maximum amount of energy it could produce at a discrete point in time- 5 kW. They also come in a set of 12- a single system, and 24- a dual system. The dual system is most believed to be the best choice for families wishing to produce energy and cut costs (roughly a 2.5 kW solar system) (Watson). There are many factors that go into deciding where and how the panels will be installed. Optimal settings are usually those that set the panels at an angle (roughly 30-45 degrees), with a southward exposure. This gives optimal readings because of the ability of the panels to be exposed to and absorb the sun throughout the day. Exposure tuned heavily in any direction will cut down on the peak exposure. The Watson house in this example had an ESE exposure, which is slightly less optimal and a 30 degree roof tilt, which is mostly optimal (Watson). Despite the ESE exposure, CSG expected an 80% peak (actual production verse maximum sun production in the area) because of these housing characteristics. From data collected from the house and electric company, the Watson house has produced roughly 5,400 kW (or 5.4 megW) on a yearly basis (Watson). This has exceeded projections of 5,000 kW on a yearly basis (Watson). The PV array of this Boston house has a warrantee of 20 years, after which CSG predicts the cells will produce 80% of the installation production levels (Watsonv). Older houses adapting for such a change externally need only an efficient enough line capacity into the house to handle the flow of electricity. Lastly, the Watson house brings up an interesting point in that even though the house produces electricity, it is not able to keep creating electricity if it is off of the electric grid. This is because the inverters convert the electricity from the Direct Current (DC) produced by the PV cells to the Alternating Current (AC) that is used by household appliances. This is a problem, however, that could lead to a promising solution for those off the grid because of storms or other mishaps.

12.2 The Compaan Solar House

The Compaan house in Toledo, OH had thin film cadmium telluride photovoltaics installed on their house, manufactured by First Solar, LLC. This house has a 96 solar panel (each panel is roughly 2ft by 4 ft) array that collects a maximum of 4.3 kWh at high sun with clear skies per day. Individual panels produce roughly 60 volts at 0.75 amps, when translated to DC power this is a maximum production of 360 volts per panel (Compaan). All output measurements in this analysis were taken after the inverter converted the DC to AC. This means that it does not include any energy lost during the conversion. These panels from the Compaan house produced a total of 6229 kWh in 2005 compared to the average multiyear database that predicted a total of 6508 kWh for the same year. Even though the database is an average/prediction for the year; this is roughly a 90% absorption rate probably pointing to many efficient characteristics like exposure and electronic efficiencies.

12.3 The Lord Solar House

The Lord house in Southern Maine is an interesting example of a house utilizing the available solar power with a design built by ASE of Billerica, MA. Each side of the southeasterly facing roof houses two different sets of panels. One half of the roof contains the photovoltaic cells that power the electricity in the house while the other half of the same roof holds solar thermal panels used for heating two-500 gallon water tanks (Lord). The photovoltaic system uses sixteen 4 ft x 6 ft panels to gather 4.2 kWh at peak power output (Lord). On an average year the system (which has been active for 10 years) will generate roughly 4 MWh, with the last two years producing 4.6 MWh for 2004 and 4.46 MWh for 2005 (Lord). Combining this photovoltaic system with the thermal system for water heating, the Lord's pay on average $8 per month for electricity, which is just for the hook-up charge to the local energy company (Central Maine Power) (Lord). Maine uses an interesting policy with those who are producing as well as using power, called the "Annualized Net Metering Policy", similar programs are found in many other states. This policy allows producers with solar systems to bank their excess produced power as credits for usage in low production months. This helps contribute to the near zero dollar amount the Lords pay per month for electricity. Both Massachusetts and Ohio have also enacted a similar program, making PV systems more attractive by the double payback (decreased input from the grid and return investment on energy sold to the grid). A table summarizing the analysis can be seen in AbstractAppendix A**Error! Reference source not found.**.

12.4 Environmental Durability

Since the panels are always exposed to the elements, questions of durability and consistency (through storms) are certainly important. The owner of the Watson house described rain as no problem, and said that rain is beneficial to keep them clean. Snow, however, would seem to be a larger problem. Evidence from the Watson and Maine houses seem to displace this idea as well, as roofs with angles will have snow slide off like any other roof The only difference is that the sun will warm the panels and melt the rest of the snow, allowing the generation of energy to rise throughout the day.

Other than having strange outputs from the solar panels (when snow builds up and blocks input for some time) it is believed that there is no damage to the panels. Both of these observations are important, especially to New England inquirers, where snow fall is high.

The owner of the Watson house, in an email response, cited that panels get cloudy throughout the years, which he believed to be the cause from bad sealing or poor materials. Aside from that, there has been no damage to them in several years of use.

Another note in relation to output over the winter is that it seems as if solar output does not change dramatically during the cold months, an important finding. According to the owners of the Maine house, “the colder it is in the winter, the clearer the sky. Therefore, the panels are more efficient due to the cooler temperatures and the house absorbs heat more readily with the sun at a lower angle” (Lord). Although the winter heat may not be as intense as the summer heat, the colder air does lead to less clouds and a close to maximum amount of sunlight absorption for those conditions. So even though the winter time does lead to a decrease in net production, it may not be as much as expected. A last observation is that these panels will also increase the longevity of any type of roof. For the most part, panels will occupy large sections of the roof, absorbing most of the brunt from the elements.

By analyzing the differences of output and type of each house, it is easy to see that even though the photovoltaic solar panel industry is small and developing, there are many routes available. While the houses analyzed here have mainly large systems (roughly producing 4-5.5 kWh at max) it is more likely that lower budgeted residences will make use of smaller 2 or 3 kWh producing systems. Although the output will not be comparable to the previous houses, there will still be significant change to the electric bill. Without extensive research it is hard to predict exactly how much a person will spend on a PV system for their house. Not only are there differing sizes and types of cells available, but ranging on location there are differing funds as well. Massachusetts residents are able to receive money from their electric company, called credits, so the company can have a certain amount of “green energy”. Maine residents are able to have 1/3 of the installation and material cost be taken care of by the state. Some states, such as Ohio, fund projects through the Department of Energy. Also depending on location, private groups like the Massachusetts Technology Collaborative (MTC) will give incentives for investing in environmentally friendly technology.

At this point in the development of photovoltaic cells for residential use, it seems as if there is a plethora of sources to decrease the initial investment which may range between $10,000 to $40,000. Because of the young age that PV cells are at, the incentives will eventually decrease as use becomes higher and more popular. This will lead to governmental and other private or public funds becoming stretched too thin monetarily to keep handing out large incentives to every homeowner willing to invest. However, with increased research, the manufacturing techniques will help decrease the initial investment by lowering the cost of the materials and installation. Hopefully this reaches a point where the decrease in incentives is offset by the decrease in the initial investment, allowing PV cells to continue being an attractive alternative option to homeowners. Figuring out this feasibility is one of the primary aims of this project.

13 Developing the Cost of a PV System

After analyzing homes that utilize the sun's energy for daily electricity use, it is important to research the companies involved in manufacturing, distribution or installation. Although it was helpful to see what specific people have, it is more imperative to this report to see also what is available. One local company- CSG Renewables of Westborough, MA and two national companies- SCHOTT solar (formally of Beverly, MA) and First Solar, LLC of Ohio will be evaluated.

13.1 CSG Renewables

CSG Renewables is a non-profit organization that "specializes in the design, development, and delivery of energy efficiency and renewable energy programs" (CSG). By working with clients the CSG organization assists in making the right choices for a more environmentally conscious home. Mainly specializing in new home development to increase the function of new technology and building practices, CSG also operates on existing houses.

The programs and services available to those not looking to rebuild are a complete home performance assessment where they provide a

> "detailed analysis of how your entire house uses energy as a system and measures you can take to improve its performance. Computerized testing of airflow (blower door analysis), duct system performance (duct blaster) and carbon monoxide testing helps to identify and measure air leakage and sources of energy waste and potential health and safety problems" (CSG)

CSG also offers upgrades of HVAC systems, lighting and appliances, insulation, and air sealing. In the state of Massachusetts in 2005, CSG gave 5947 of these home assessments costing roughly $3 million dollars between residences and utility companies resulting in a savings of 69,287,504,452 BTU's (CSG).

CSG also has an impact in the community where an energy fitness program was utilized in the inner Boston area catering to roughly 20,000 residents. During this one year time period, members of CSG guided residents in energy efficiency and the importance of saving. By coordinating a whole group of installers of different appliances, CSG was able to save urban residences at least 300 kWh per year in lighting, 75kWh per year in air conditioner maintenance, 36kWh per year in refrigeration maintenance, and reduced hot water use by 1.5 gallons per minute (CSG). Lastly, CSG was able to show that residences in these mainly low income areas retained these practices 92 to 98 percent of time (CSG).

Although no longer in the business of residential PV installations, CGS still works in helping to contract new energy efficient homes that are currently being built. In order to be available for the benefits, new homes must be 30% more efficient than a regular home under the standard Massachusetts building code (CSG). In renewable credits, a sector where CSG specializes, they offer many types of rebates for those going solar. There is a First Round base incentive worth $3.00 per watt DC, and additions to this base can include: $0.50 (per watt DC) addition from MA-manufactured components, specified target area (for example Worcester), low-income or affordable housing, back for critical loads, and building integrated PV worth a $1.00 addition per watt DC (CSG). The total availability can range upwards of $5.00 per watt DC and end up saving $200 to $600 annually depending on the size (which CSG offers up to a 3.5 kW-DC system)- not including the savings from using the PV system as well. Therefore CSG, although not a main distributor of residential PV systems, will contract the work out, and more significantly be a primary buyer of renewable energy credits- one of the most appealing components of using a PV system.

13.2 SCHOTT Solar

SCHOTT solar is a company that bought out ASE of Billerica, MA, which was formerly part of Exxon Mobil’s division of renewable energy research. SCHOTT is now an international company working on, among many other projects, photovoltaic power for commercial and residential use. SCHOTT provides the SunRoof FS System for commercial buildings and the SunRoof RS system for residential use along with being able to customize and cater to an individual project (SCHOTT). SCHOTT carries a 20 year power guarantee plan for all PV systems, but insist that they last much longer than that.

SCHOTT uses a very simple calculation to assist in making the right decision for those wishing to invest in a PV system. It is as easy as collecting the electric bills for a one year period and totaling

> "up the Kilowatt (kWh) usage for that year, divide by 365 (days) to calculate a daily average; then, divide that figure by the number of average daily sun hours for your location. Example: 3600 kWh/yr divided by 365 days/yr equals approximately 10 kWh/day, divided by 5 sun-hours per day (for locations in Middle America), and equals 2 kW" (SCHOTT).

This example therefore predicts that a 2kW system is necessary for meeting the annual needs of this particular house. However, this is based off of a 5 sun hour day which obviously may be more or less in certain areas. Therefore, it is important to keep in mind the location and the typical energy use to determine the ultimate value of the PV system. SCHOTT also provides two websites: http://www.dsireusa.org/ and http://www.seia.org/. These websites offer a complete listing of all state and governmental incentives and tax rebates.

Although not providing any prices for their PV systems, they provide information on several systems they create along with the necessary support structures, wiring, meter, and inverters that comprise the full system. SCHOTT focuses on two main types of technology for their cells- crystalline and thin-film. Even though the list of incentives for states like Massachusetts is long, it is even more critical to know the installation and material costs for a PV system.

13.3 First Solar, LLC

First Solar, LLC is a company with locations around the world willing to help in PV system development. The most local sites of First Solar are in Ohio and Pennsylvania. This company utilizes CdTe (Cadmium telluride) technology, which is an environmentally friendly choice. The technology transforms these highly volatile chemicals from zinc smelting that assists in taking it out of the environment and the burning of fossil fuel. CdTe is also especially appealing because of its low cost ability to make solar panels in a time where cost-effectiveness is vital.

Part of First Solar's key product design features is its front and back soda lime glass that has been particularly manufactured to withstand almost anything over its 25 year warrantee (First Solar). The cost of a solar panel also resides in the use of semiconductors, the extremely expensive and vital piece of the PV to absorb and conduct electricity. However, the company has been able to decrease the usage of semiconductor material by 20%, and now it requires only 1% of the structure. This breakthrough and continued research will allow companies to produce less semiconductor material to sell residential users PV systems at lower prices.

First Solar is the largest thin film PV producing company in the world and sold 330,000 solar modules in 2005 accounting for 20+ mW of electricity (First Solar). Once again, it is vital to know the cost of such systems so that planning and estimating for residential use is possible. An email was sent to First Solar requesting such information.

13.4 Assessing a PV System

There are many decisions to be made prior to contacting a manufacturer, dealer, or builder with hopes of installing a PV system. One of the main issues to assess is whether or not a PV system is a smart and efficient choice for the home in question. Many factors play into the decision on how efficient the system can be in a certain place. First of all, can the electric bill be lowered by other means? As cited before, companies like CSG Renewables has the means to lower electric use without installing a renewable energy system. Instead of spending large amounts of money on a PV system, an upgrade on the house energy efficiency should be considered first. If this has been considered and the house is still using large amounts of electricity (the average American home uses 840 kWh per month), then a PV system is certainly the right choice.

The next step in the consideration of a PV system is the location of the house. The angle of the roof, the position of the roof in relation to the sun, whether a ground array is better than a roof array, how much shading does my house get, and other similar questions are all vital considerations in terms of installing a PV system. For most common PV systems, a flat-tilt array on a roof with a 45˚ is best, that is if the house resides above the 45˚ latitudinal line. The best direction for a roof is the 180˚ mark (south), where 90˚ is directly east and 270˚ is directly west. It is also important to limit the amount of shading, usually to less than 10% so absorption can be strong and unhindered throughout the day. These characteristics allow for the most sunlight pickup throughout the day. Shallower or flatter systems, or roofs facing mostly northward may not be utilized as efficiently and the owner may want to continue with a ground array. These types of PV systems are also very popular in residences as they allow for easier installation and can be placed in the most optimal location for sun absorption.

Next and most importantly, is the consideration of the size of PV system needed. A typical American house will probably require 2-4 kW system that will be able to cut the electric bill by roughly 50%, while still being an attractive economic decision. A 2 kW system can cost between $18,000-21,000, a 3 kW system costs between $26,000-$28,000 and a 4 kW system costs between $35,000-$41,000 (SunWize). Owners who are wishing to displace their full electric bill may consider a 5 or 6 kW array which can reach upwards of $50,000 to $60,000. These costs include the full package needed to install the system- inverters, mounting structures, pre-wired power center, interconnect cords and wire clips, PV grounding system, and a PV fused combiner. The cost does not include installation, mostly because these packages include an installation manual. If the installation is outsourced it may take only a week for a roof system to be installed and roughly double that for ground systems.

Subsequently, it will be important to consider how to pay for the cost of a solar system. It is true that incentives and rebates may deduct up to 50% of the cost and along with large annual savings on electric bills, however, PV systems can be very expensive. Paying for a solar system usually comes in the form of financing, either as home equity or a loan. A home equity consists of taking out another mortgage for the house, allowing the owner to obtain long-term financing and having that interest become tax deductible. Taking out a no lien signature loan would be the same as any other loan and is dependent on which company the loan is coming from and for how long the payments are expected to last. Lastly, an option similar to taking out a home equity is refinancing which allows the cost of the PV system to be added to the existing mortgage- usually allowing a payment period of 30 years in some cases.

Finally, it is important to consider the payback of any PV system. Without incentives and rebates the payback of a typical PV system may be upwards of 30-40 years if you are saving roughly $1,000 off your electric bill annually. However, the tax credits, rebates, and extent of the kWh production could decrease this number by 50 or 60%. Hopefully manufacturing technologies will help continue the trend of decreasing renewable energies like PV systems. It also helps that energy prices, which have doubled in the past five years and are projected to double again soon, make the PV system much more appealing.

14 Risk Analysis of Solar Energy Investment

In order to better understand how the potential purchase of a solar cell system on a residential home in Worcester, MA would inevitably work out, it was necessary to create a model to forecast when the money put into the system would be returned, or the Return on Investment (ROI). This model takes the view that this purchase is an investment and there are numerous variables affecting the final ROI. This is a departure from most estimations of the return on the investment of solar panels. Most estimations are based on the premise that this is a static investment, which it is clearly not. However, by adding the element of uncertainty, this model produces a more accurate number and demonstrates the monetary risk involved with the purchase of the photovoltaic system.

In order to produce an accurate estimation of the return of investment, it was necessary to research the probabilities of certain events occurring. Once these probabilities were discovered, they were programmed based on which type of probability they were.

Cost of Solar Panels	212
MA Energy Costs	85.76
System Needed	4
Cost of Panel System	33000
Installation Costs	11000
MA Energy Costs	0.134
MA Energy Usage	640kWh
MA Sunlight Hours	4
Post-Install Costs	533.3333333
Federal Tax Breaks	2500
MA Tax Breaks	1600
Rebates	0.4
Time Value of Money	0.06
Lifespan of Panel	48.33333333
Inc. Energy Costs	0.045
Extra Energy Value	20
Needing Energy Cost	13.33333333
Extra Energy Chance	0.675
Needing Energy Chance	0.325

Discrete Functions

Table 14.1: Discrete Random Function

The base research showed that there were two variables that were appropriately programmed as discrete functions- the type of system installed and the rebate available on the purchase of the system. The type of system needed was researched to show that about 10% of the systems installed in MA were 2kw, 20% were 3kw, 20% were 4kw, 30% were 5kw and 20% were 6kw. As for the rebates available about 30% were 20% off, 50% were 40% off, and 30% were 50% off. These variables were programmed into the system along with the other variables that were based on different programming variables.

The most utilized in the program was a triangulation variable. This variable is based on selecting a random variable based on the minimum most likely value and the maximum value.

Cost of Solar Panels	212
MA Energy Costs	85.76
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Extra Energy Chance	0.675
Needing Energy Chance	0.325

Triangulation Functions

Table 14.2: Triangulation Random Functions

This was used on the lifespan of the system (35[minimum], 50[most likely], 60[maximum]), the post-installation costs (100, 500, 1000), the value of extra energy (0, 20, 30) and the cost of needing extra energy (0, 10, 30).

The final variable that was utilized in this program was the uniform variable. This is based on the probability of a number being selected between the minimum and maximum values being exactly the same.

Cost of Solar Panels	212
MA Energy Costs	85.76
System Needed	4
Cost of Panel System	33000
Installation Costs	11000
MA Energy Costs	0.134
MA Energy Usage	640kWh
MA Sunlight Hours	4
Post-Install Costs	533.3333333
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Extra Energy Value	20
Needing Energy Cost	13.33333333
Extra Energy Chance	0.675
Needing Energy Chance	0.325

Uniform Functions

Table 14.3: Uniform Radom Functions

This variable was utilized for the installation costs (10000[minimum], 20000[maximum]), the time value of money (.04,.08), the increase in energy costs (.03,.06) and the chance of producing extra energy (.6,.75).

Once these variables were researched and calculated, they were combined with the constants and turned into the Net Present Value Equation (NPV).

NPV= Initial Cost+å ((Value-Cost)*(P/A,X,N))

P/A= Conversion from Annual Value to Present
X= Time Value of Money
N= Year

Equation 14.1

This equation is based on the principle that money can change values over time. This brings in the importance of the time value of money, which is the interest that can be made on the money invested if the investment never took place.

The NPV equation starts by calculating the initial investment, which is multiplying percentage rebate by the cost of the system plus the cost of installation.

Initial Cost= (System Cost+Installation Cost)*(1-Rebate)

Equation 14.2

Then, the annual costs and values are calculated over the course of 50 years. 50 years was used because the best warranty available on solar panel systems was for this time frame. This was done by calculating the value- preformed by adding in the value of producing extra energy (the value of extra energy times the chance of needing it times 12 months; plus the savings of energy times the increase in the value of energy; plus the tax rebates given out for installing a solar system [available for 3 years])

Value= (Energy Savings)+(Energy Value)*(Chance)+(Gov Help)[3 Years]

Equation 14.3

and then subtracting the costs of owning a photovoltaic energy system (the cost of needing energy times the chance of needing it times 12 months; plus the cost of post-installation costs times the chance of needing it which is done through a discrete random variable with a 5% chance of needing repairs).

Cost= (Energy Cost)*(Chance)+(Post-Install Cost)*(Discrete Variable)

Equation 14.4

This is then programmed into the NPV function which sums the annual value each year and shows the current value of the system in that year in relation to the time value of money. However, there are a couple special features that needed to be programmed into the NPV function in order to make the program more accurate. These features include a discrete annual random variable and a cutoff of the system in the event of system death.

Discrete Variable= ({0,1},{.95,.05}) [0-10 Years]
= ({0,1}, {.9,.1}) [>10 Years]

Equation 14.5

The discrete random variable is in place in order to add in post-installation costs into the year if necessary.

This is done by creating a discrete variable with a 95% chance of being 0 and a 5% chance of being 1, which changes to a 90% chance of being 0 after 10 years without the need for post-installation costs. If the model produces a 1, the post-installation cost produced by the iteration is added into the year. The other function that was added was a system death clock. This function is one that judges whether or not the year that the program is on more or less than that of the estimated system death. If it is less, then the system continues to run uninhibited; if it is more, then the system turns off and only continues to show the value of the system when it died.

$$\begin{aligned} NPV= & ((\text{System Cost}+\text{Installation Cost})*(1-\text{Rebate})) + \\ & \textstyle\sum(((\text{Energy Savings})+(\text{Energy Value})*(\text{Chance})+(\text{Gov Help})[3 \text{ Years}]) \\ & -((\text{Energy Cost})*(\text{Chance})+(\text{Post-Install Cost})*(\text{Discrete Variable})) \\ & *(P/A,X,N))) \end{aligned}$$

Equation 14.6

Once these numbers have been created, a program is then installed to show the year when the system gains a positive value. Once all of this is programmed into the system, the program is set to run 1000 iterations, which will randomize the variables 1000 times and calculate the minimum, maximum, average, variance, etc.

After this was finished, the final result showed that the least amount of time it will take to recoup the initial investment is 3 years and the most amount of time is over 50 years. However the most important piece of information is that the average time to return the investment is 19.597 years. In the risk analysis, there are also enclosed numerous graphs which demonstrate the percentage chances of time in which it will take to have the investment returned and which factors weighed most heavily on the final outcome. This final outcome shows us a very good estimation of when the an individual can expect to recoup the investment and can thus determine whether the investment is worth it and what needs to be done in order to make it more worth the initial investment.

15 Quantitative Analysis

In order to truly gauge whether or not the current solar energy systems are feasible for installation in Worcester, MA; it was necessary to establish several goal numbers to strive for. After these were set up a model was then created according the pre-established goal numbers. The first step in this process was to talk to an expert on what they considered to be appropriate goal numbers.

We approached this process in two steps; the first step that was undertaken was to perform an informal poll of several people around the WPI campus; ranging from students to staff to professors. This poll was to see what ROI would need to be in place to have them consider investing in a solar energy system for their homes. The general range that was most common was an ROI of about 5 years. We then talked to an expert, WPI Economics Professor Oleg Pavlov, who told us that an appropriate range would have to be fewer than 5 or 6 years because of the incredibly high level of initial investment in a system. After accomplishing these two tasks we set our goal ROI at 6 years, and therefore the investment of a photovoltaic system would need to be returned in 6 years us to qualify the system to be a wise and feasible investment.

After establishing these numbers, we took the numbers that were produced by the solar practicality risk analysis model.

	Investment Return	50 Year Value
Minimum	3	-9874.518
Maximum	50	81877.74
Mean	19.597	23067.76
Standard Deviation	11.01371	15057.84
Variance	121.3019	2.27E+08

Table 15.1: Standard ROI

The most important number produced by this model was the mean Investment Return, which was 19.597 years. This number is showing that it can be expected that the ROI would be between 19 and 20 years. Another important piece of information is the standard deviation of 11.01371, which is showing there is around a 68% chance that the

ROI will fall between 8.5 and 30.5 years and a 95% chance that the ROI will fall between 3 and 41.5 years.

The other important number that this data shows is what the value the system will hold at the end of the 50 year time period; with an average of $23,067.76 and the possibility of having a value of up to $81,877.74, but also the possibility of it still costing $9874.52. These numbers can help affect the value the house will hold if resold in the open market and what value the system holds at the time of purchase.

After analyzing this data that the model produced, with a difference of around 15 years between the necessary time to be practical and the actual time estimated by the model, it is clearly shown that the prospect of installing solar cells on a residential home in Worcester, MA is completely impractical. However, this answer poses the question as to what it would take to make the prospect of solar energy a practical energy alternative for the residents of Worcester, MA. In order to first analyze that, it necessary to look at the factors that affect the final outcome and figure out which factors can be controlled.

Cost of Panel System	33000
Installation Costs	11000
MA Energy Costs	0.134
MA Energy Usage	640kWh
MA Sunlight Hours	4
Post-Install Costs	533.33333
Federal Tax Breaks	2500
MA Tax Breaks	1600
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Extra Energy Chance	0.675
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Controllable Factors

Table 15.2: Controllable Factors

The categories that can be controlled are the efficiency of the panel (and subsequently the cost of the system) and the government aid given to people who install solar panels in their homes. By adjusting these factors to different possible situations, it gives a better perspective on what could happen in the future and could show a sign of when solar technology will be a viable alternative in Worcester, MA.

The first major change that could happen would be that the government could step in and offer more funding to those individuals who invest in solar cells in their homes. One option that the government could take would be to extend the years of funding available from 3 to 5 years.

Minimum	3	-3981.341
Maximum	50	98298.93
Mean	12.719	29560.67
Std Var	8.374973	15603.25
Variance	70.14018	2.43E+08

Table 15.3: 5 Year Government Subsidization

This chart shows that if the government did extend the time limit of funding to 5 years, it would reduce the average ROI for the investment from19.5 years to 12.719 years. This reduction in the ROI represents a major difference in how the investment would be viewed by a potential investor.

The other change that the government could do, would be to increase the amount of funding that is advocated to individuals who invest in solar energy in their homes. In the scenario that we laid out for the new model, it would increase the federal government funding from \$2500 to \$3500 and state government funding from \$1600 to \$2500 a year in tax breaks.

Minimum	3	-6384.209
Maximum	50	82880.63
Mean	13.754	28172.96
Std Var	9.430929	15288.48
Variance	88.94243	2.34E+08

Table 15.4: Increase in Government Subsidization

In this breakdown, the numbers that were picked would only be a small percentage of the government funding already allocated for energy investment, but would be enough to make a significant impact on the potential investment of a solar system. The final outcome shows that taking this action would be slightly less effective than extending the funding to 5 years; since the ROI would only decrease to 13.754 years, instead of the 12.719 years.

However, one other possible situation would be for the government to combine the two prior possibilities. This would increase the government funding and extend the funding to 5 years.

Minimum	3	-66.90485
Maximum	50	99520.09
Mean	6.981	37574.63
Std Var	4.606936	15528
Variance	21.22386	2.41E+08

Table 15.5: 5 Year Government Subsidization and Increase in Government Subsidization

In this possibility, the ROI was significantly reduced to 6.981 years- just about 7 years. This reduces it to a level where solar energy might be deemed plausible as a large means of energy for residents of Worcester, MA. If this policy was taken by the federal and state governments, solar energy would have to be considered to replace more common fossil based fuel sources without having to improve the current solar technology.

The alternative option that could happen to improve the possibility of making photovoltaic systems a plausible alternative for homes in Worcester, MA is to have the efficiencies of the current systems to improve and thus reduce the price. In this example, we took the premise of what would happen if the efficiency of the systems doubled and would thus halve the price of the systems for the consumer. Although this is probably not an exact estimation of what would actually happen, it was a close enough estimation for our forecasting purposes.

Minimum	2	8840.576
Maximum	24	93013.12
Mean	7.012	34077.52
Std Var	3.747519	14224.53
Variance	14.0439	2.02E+08

Table 15.6: Doubled Efficiency

This example shows that if the efficiency of the systems doubled, the ROI would diminish from 19.5 years to about 7 years. A drop of that much in the ROI would make a considerable impact on how the product would be viewed by the consumer and make it a much more viable alternative, not only because it would lessen the ROI, but it would also halve the initial investment, which can allow the consumer to raise what they will be willing to accept as the ROI on the system.

As a final example, we decided to test what would happen if the two best possible improvements were applied on the ROI. This would be the example of combining the potential doubling of the efficiency of the system and extending the government funding to 5 years.

Minimum	2	12805.15
Maximum	11	94486.55
Mean	4.344	40503.78
Std Var	1.314303	14548.17
Variance	1.727391	2.12E+08

Table 15.7: Doubled Efficiency and 5 Year Government Subsidization

In this last example, a number is finally produced that lies within the parameters that were established before the alternatives were decided on and calculated. A predicted ROI of 4.344 years is well within the limits set in the beginning of 6 years. This would make the purchase of a photovoltaic system an incredibly strong and worthwhile investment for any potential consumer who is looking to move away from more traditional fossil fuel based home energy systems.

This number is also potentially low enough to make people take into account such systems who were previously not considering switching their energy system over to a solar energy based system. This shows that if the government was willing to direct money not only into the funding for homeowners who are installing solar panel systems, but also to the companies manufacturing the systems so that they can increase their efforts in the area of research, solar energy could possibly become one of the major sources of energy in this country. If this were to happen, there would be numerous beneficial consequences; be they economic, political and social.

16 Current Renewable Energy Potential

16.1 Solar Power Plant Systems

16.1.1 Solar Parabolic Troughs

As fossil fuels become an unstable source of energy in the near future, the U.S. has been developing different ways to supply the energy needs of the greatest energy consuming nation in the world. In order to do this, the government has been developing renewable energies, based off of the always present elements in our day to day lives- sun, wind, and water. The first of these elements includes the use of solar polar and may be the most promising. The amount of solar energy that reaches the surface of the earth on a daily basis is enough to power the world's energy needs for a year (the earth produces 122 petawatts, while humans consume 13 terawatts in a year) (Smil). Solar therefore seems to be one of, if not the most, promising renewable energy.

The problem is how do you capture it? One type of technology being readily used today is the parabolic trough. By assimilating mirrors in a trough shape, the sun is localized directly onto the panels heating a tube containing heat transfer fluids. The fluids are "heated to 734°F and pumped through a series of exchangers to produce superheated steam which powers a conventional turbine generator to produce electricity" (ERN). Systems like these are usually integrated with a fossil fuel source to provide energy during the night or during atmospheric situations that do not allow for efficient solar absorption.

Although there are questions about the efficiency of such a system, the parabolic trough network has the ability to be not only the lowest costing wide-scale production of solar energy, but also has the most potential for the future. Some key advances in the last ten years for the parabolic troughs are the highly improved tough concentrators and receivers, reductions in both maintenance and operating costs. Lastly, and probably the most important- the continued research and development of a storage system for solar energy collected and unused throughout the day. A large factor leading parabolic troughs to be so popular and versatile around the world is the fact that it is made up of common materials- glass, steel, concrete and other various power generation equipment- and can be easily deployed anywhere (DoE). Cost reduction also figures to increase as suggestions such as scaling up the plants to 200 MW or larger, development of more advanced technology that was described previously, and “cost reductions through plant deployments” (DoE). Combined with the increase of electric cost because of future fossil fuel availability, “parabolic trough technology appears to have the potential to begin competing directly with conventional tower technologies within the next 5 to 10 years” (DoE).

16.1.1.1 Solar Energy Generating Systems (SEGS)

The Solar Energy Generating Systems (SEGS) were developed in part by FPL Energy, a power generation company based out of Florida, but with assets in 20 states in the U.S. These SEGS utilize parabolic trough technology to harness the solar thermal energy from the sun. Many of the SEGS are in the Mojave Desert, an optimum solar region in the southwestern part of the U.S. spanning Utah, Nevada, California, and Arizona. The electrical capacities of SEGS III-VII are 30 MW, while SEGS VIII and IX have an operating capacity of 80 MW (FPL).

The seven solar facilities combine for a total of 900,000 mirrors occupying 2,000 acres and produces electricity for Southern California Edison electric company (FPL). Even though these numbers seem like an immense amount of power production, they only generate electricity for roughly 90,000 homes during the day (FPL). However, the SEGS fill less than 1% of the 25,000 square miles of desert in the Mojave (U.S. Parks). To supply electricity to the entire southern part of California, the operating region of Southern California Edison and at least four other subsidiaries working in southern California, they would need 620 mi^2 (roughly half the size of Rhode Island) to supply the day time electrical needs of approximately 18 million homes. One large promise of the SEGS is in the fact that “SEGS generation offsets approximately 3,800 tons of pollutants annually that would have been produced if the electricity had been provided by fossil fuels, such as oil” (FPL). Even though there is a relatively small amount of electricity being produced at this time, these SEGS represent the promising future of solar trough energy.

16.1.1.2 Nevada Solar One

A similar design to the SEGS, Nevada One is currently being produced with trough technology and will be the third largest solar electric plant in the world, hoping to produce 65 MW (ENS).

16.1.2 Dish-Engine Systems

Another type of useful solar heating on a large scale is the dish-engine systems. Instead of using a parabolic trough, a parabolic disk mirror (similar looking to a satellite dish) is used to localize the solar rays onto a focal point on the dish. The fluid heated in this mechanism (to 1,382°F) flow directly into a cycle engine to produce electricity (ERN). The optical efficiency and low startup costs/losses make the "dish/engine systems the most efficient (29.4% record solar electricity conversion) of all solar technologies" (ERN). The flexibility of this type of model is seen in its ability to operate in the range of megawatts as in a remote area, or in the area of kilowatts as part of a grid-connected alternative.

16.2 Quantum Dots

Quantum dots are three dimensional nanostructures containing groups of electrons and holes. These nanostructures can be used as semiconductors by applying a negative voltage across the structure. In essence, the nanostructure acts like a transistor, using quantum physics in order to conduct charge. Quantum dots are much smaller than their typical silicon based counterparts, measuring around 10 nanometers in diameter. They also possess the ability to have a larger bandgap energy, allowing them to absorb more energy than larger, traditional semiconductors.

The biggest problem with current photovoltaics is that one photon is only capable of freeing up one electron. If a photon incident upon the atom or molecule contains energy greater than that of the bandgap, the electron will be freed and an excess energy will be released in the form of heat.

Quantum dot technology would allow several electrons to be freed by one photon. The generation of multiple excitons, known as freed EHPs, occurs through a chain reaction. As we already know from our study of photovoltaics, a photon carrying an amount of energy at least equal to the bandgap energy of the atom will create an exciton. After the generation of the first EHP, quantum dots differ greatly from conventional semiconductors. The generated EHP can undergo an effect called impact ionization:

> "In this process, an electron or hole with kinetic energy greater than the semiconductor band gap produces one or more additional electron-hole pairs. The kinetic energy can be created either by applying an electric field or by absorbing a photon with energy above the semiconductor band gap energy." (Ellingson, Randy J., et al.)

The excess energy from the photon is therefore absorbed by the EHP and converted into kinetic energy instead of being dissipated as heat. Impact ionization does occur in conventional semiconductors. However, certain effects counteract any improvement in efficiencies created by impact ionization:

> "Impact ionization has not, however, contributed meaningfully to improved quantum yield in working solar cells, primarily because the [impact ionization] efficiency does not reach significant values until photon energies reach the ultraviolet region of the spectrum. In bulk semiconductors, the threshold photon energy for [impact ionization] exceeds that required for energy conservation alone because, in addition to conserving energy, crystal momentum must be conserved. Additionally, the rate of [impact ionization] must compete with the rate of energy relaxation by electron-phonon scattering." (Ellingson, Randy J., et al.)

Due to the confined nature of the charge carriers, quantum dots do not experience these effects.

For photovoltaic technology, a smaller bandgap will allow for a greater current, while a larger bandgap will allow for a greater voltage. Since there are applications where both are desirable, it is advantageous to have an easily adjustable bandgap. Quantum dots have easily adjustable bandgaps, while traditional semiconductors do not. (Weiss) Another advantage to quantum dots is that they can be created with a radiation protective shell. This will allow for a longer lifetime than conventional solar cells, which experience radiation deprecation.

Quantum dot technology is relatively promising, with the possibility that the next generation of photovoltaics will incorporate its technology. Although a lot of the theory is still being worked out, a few photovoltaic prototypes have been constructed:

> "Some researchers have made prototype photodetectors and solar cells from quantum dots. For instance, Difei Qi of Louisiana Tech University in Ruston and her colleagues mixed a conductive, photosensitive polymer known as MEH-PPV with lead selenide quantum dots. Under visible light, a device incorporating dots at only about 5 percent by weight generated 50 percent more current than expected if each photon yielded one exciton, the Louisiana team reported in the Feb. 28, 2005 *Applied Physics Letters*." (Weiss)

Such a high efficiency is promising for quantum dot technology. If an effective method to mass produce this technology is created, quantum dot solar cells may not be far removed from implementation.

16.3 Potential of Virus-Based Solar Materials

Harmless viruses, called bacteriophages, are being used in unconventional ways at the MIT laboratories. Scientist Angela Belcher and her team have worked on experimenting with nanoparticles, such as the M13 virus used in her lab, to find the potential to decrease Li ion battery size and expand its energy holding capabilities by two or three times. "However, to maximize this potential, monodisperse, homogeneous nanomaterials and hierarchical organization control are needed. Biosystems have the inherent capabilities of molecular recognition and self-assembly and thus are an attractive template for constructing and organizing the nanostructure" (Belcher). The researchers must first manipulate the DNA of the virus to become essentially "metal-loving" by encoding roughly 2700 coat proteins that will function in binding with certain conducting metals (13). Then after recoding the genome of the M13 virus, the researches soaked it in a cobalt chloride solution, reduced the compound with $NaBH_4$, and with "spontaneous oxidation in water, monodisperse, crystalline Co_3O_4 nanowires were produced" (Belcher).

With x-ray diffraction techniques the researches were able to confirm their hypothesis that this method produced a mineralized lattice of cobalt oxide (Co_3O_4).

After creating an electrode with these nanocarbon particles, the researchers tested this material against current electrodes. They found that the M13 virus-based battery had a "reversible capacity ranging from 600 to 750mA*hour/g", which is roughly twice the capacity of the current carbon electrodes (Belcher). The electrochemical advantages like structural integrity of using these nanoparticles were astounding, but were not without downfalls. Combining particles at the nano level can be expensive, time-consuming and can be much more difficult to create uniform structures.

With this thought in mind, the researchers went ahead and tried to redesign the virus to have an affinity for a hybrid between gold and cobalt oxide ($Au\text{-}C_3O_4$). They believed that this would raise the potential for oxidizing and thus create a better material for an electrode in a battery where pure cobalt oxide was falling short. Once again they created the structure through genome manipulation and tested it for a crystallized structure. Their hypothesis was proved correct as "the virus-mediated hybrid composite generated higher initial and reversible lithium storage capacity than the pure Co_3O_4 nanowires when tested at the same current rate. The higher lithium storage capacity may result from the formation of Au-Li intermetallic compound or the conductive or catalytic effects of Au nanoparticles on the reaction of Li with Co_3O_4" (Belcher).

All of the research done by this team at MIT proved that viruses could create crystallized structures with astounding affinity for structure and electrochemical properties. Not only did these structures work in Li ion electrodes, but also made them more efficient with a less amount of materials. This is a promising development in the case of solar cells and photovoltaics. Specifically, they used the cobalt oxide on a fuel cell collector and "the cell was found to sustain and deliver 94% of its theoretical capacity at a rate of 1.12 C and 65% at a rate of 5.19 C, demonstrating the capability for a high cycling rate" (Belcher). Additionally the team suggested that the efficiency could be improved with a different stacking arrangement or through the use of the hybrid gold-cobalt oxide nanowires.

Even though these are the initial stages of a brand-new type of technology, they are promising. Like any other type of breakthrough technology, there are downfalls and large areas that need development. The wires as of now cannot be made to be as large as proposed or to be super efficient as they may become, however, the potential is there. The ability to spread a solution of these harmless viruses onto a conducting surface such as a Li ion battery to increase the charging capacity could prove to be huge. This would increase the battery capacity while decreasing the size. This would also make solar cells and photovoltaics more efficient and more viable in home use to alleviate the cost of appliance use in the summer or home-heating in the winter.

16.4 The Future of Hydrogen Energy

The direction in which renewable energy resources will lead us away from fossil fuels is uncertain. With both the public and private sector working on renewable energies such as solar, wind, and electricity, the often discussed future of hydrogen is the most intriguing. Proponents for a hydrogen economy cite its useful characteristics in that one day hydrogen will be able to entirely replace our present petroleum economy. On the other hand, those against a hydrogen economy believe that it is not only a risky endeavor, but at this point it is unsafe, equally polluting, and energetically unfavorable to invest so much time and hope. Although the potential of hydrogen is high and the current information expresses concern of its potential, it is most likely that the funding for research and development will strike somewhere in between both views. It would be the most constructive policy to engage research for hopes in finding a breakthrough for a hydrogen economy while at the same time exploring other domains from which renewable energies may come.

In a quotation by Dr. Robert Hirsch in the *Chemical Engineering Progress*, he exclaims that "H_2 is one of the few options that we can now conceive for the period after world oil peaking and for the very long-term future" (Hirsch). H_2 is of course diatomic hydrogen, the promising energy resource that has for at least two decades been an idea that one day will completely alleviate our need of fossil fuels. However, the road to the fulfillment of this potential has been and will prove to be long and winding. Among those who are against the government setting its sights on hydrogen being the primary successor in fuels is Dr. Reuel Shinnar. Dr. Shinnar believes that "H_2 and fuel cells may have many applications, but they will not solve large-scale energy or pollution problems" (Shinnar). This has been the consistent argument against hydrogen that is similar to the potential of nuclear fusion- promising yet for the most part still fruitless.

The main reason why scientists and the public alike stand against a hydrogen economy is because of the amount of obstacles needed to be overcome to reach the goal. Issues of safety, pollution, infrastructure, storage and feasibility are all problems needed to be dealt with. Not only is money for development going to be a problem in the near future, but time will as well. There are many "educated" guesses as to when oil will peak, but no matter when it does, it will hit the earth fast and hard making it pertinent that renewable energies are in place before it happens. This would make development on not one type, but many types of renewable sources beneficial. Even though there are so many doubts about the future of hydrogen, it may prove to be one of the most important technological breakthroughs in the history of humankind. It may also prove to be a bust very similar to nuclear fusion, but at this point there are only so many avenues for the development of renewable energies to go down.

16.4.1 Safety

Safety is the largest public concern about the use of hydrogen in vehicles and homes. The combustibility of hydrogen is well-documented as evidence shows that as little as 4% concentration in the surrounding air, H_2 will become flammable and burn (Ogden). The flame and burning of hydrogen is even more dangerous as it is colorless and odorless. Couple this with the ability for hydrogen to diffuse into and brittle metal very quickly and cause a leak, it creates an "undetectable suicide bomb" (Shinnar). Engineering a hydrogen car would have to take into account this problem and utilize expensive metal alloys increasing the cost of such a vehicle making it less desirable to the public. Although heat detecting paints and infrared scanners are now being used to easily detect such a hydrogen leak, it is unlikely that this alone will make car buyers more comfortable.

The adaptation of hydrogen fuel cell cars will also take patience on the consumer end to deal with learning how to use hydrogen. This is similar to the learning needed when self serve gasoline stations became widespread and when plug-in electronics were a new technology. The bulk of the safety issues, however, reside with the governmental role in research and development. Money adequately spent on creating safe products and marketing their safety will be just as crucial to the public acceptance. One positive in the safety sphere of hydrogen is that hydrogen is not a new chemical. Hydrogen generation has been around for several decades as an industrial staple for companies relying on its use in labs. In turn this has given the hydrogen economy a head start in knowing how to safely deal with and transport hydrogen.

16.4.2 Pollution

Pollution is also a familiar problem with using hydrogen. In making hydrogen, a process called steam reforming is utilized where hydrocarbons (methane, ethane) are reacted at high temperatures to make a gas consisting of H_2, CO, CO_2, CH_4, and water vapor. This mixture is then separated and purified to obtain only H_2. Even though using hydrogen fuel cells in transportation vehicles will not pose a problem to the environment, the plants in which hydrogen is separated will. Since carbon monoxide and carbon dioxide are created, they will either have to be released back into the air or "sequestered".

Sequestering carbon is a new idea that many believe will eliminate the problem of pollution from hydrogen. In an article in Physics Today in 2002, author John Ogden states that "it would be possible to separate and capture CO_2 and pipe it to secure sequestration sites, such as depleted hydrocarbon reservoirs or deep saline aquifers" (Ogden). Hydrocarbon reservoirs are tanks or underground areas where hydrocarbons such as methane, ethane, propane, or butane have been stored. Old oil fields also pose as possible deposit sites because they are common and well studied. Deep saline aquifers, another option, are even more appealing because they are common and have geochemical benefits that help absorb the CO_2 into the bedrock and contain natural trapping mechanisms that make it unlikely for it to seep into the atmosphere. However, saline aquifers also are a relatively new discovery and more research is needed to keep the costs of storing down and to be sure of the elimination of possible seepage into the surrounding environment.

A US DoE estimate shows that the current production of hydrogen will be increased from 9 megatons per year to almost 150 megatons per year by 2040 (Crabtree). This will pose a large problem if development cannot find a way to accurately store this amount of hydrogen byproducts. A lack of doing so would make a hydrogen economy more polluting than a petroleum economy.

Many new technologies are being looked at to create hydrogen more organically by using non-carbon resources “such as the electron–hole pairs excited in a semiconductor by solar radiation, the heat from a nuclear reactor or solar collector, or an electric voltage generated by renewable sources such as hydropower or wind” (Crabtree). Another intriguing venture includes the observation of biological systems that have produced hydrogen for billions of years- plants and microbes. These organisms efficiently create and use hydrogen for their homeostasis on a regular basis while only having oxygen as a byproduct. This type of technology is far off, but requires an in-depth knowledge of the complex proteins and metabolic pathways that are used for photosynthesis and other hydrogen catabolism mechanisms in these organisms.

16.4.3 Infrastructure

Even if hydrogen becomes feasible and safe at some point it may take decades to upgrade the current petroleum infrastructure (e.g. gas stations) to be able to utilize it. Centralized production stations and localized refilling stations would have to be created almost simultaneously to fill the needs of the country’s widespread transport system. The cost and labor alone would have a huge effect on the rest of the economy, limiting funds spent elsewhere or making taxes skyrocket. The other danger with setting up a hydrogen infrastructure is that it would be unknown how the public would react and adapt to such a large change. Today, there are safety concerns of gasoline, but since it has such a low detonability, it is fairly safe and can be used by average citizens. Hydrogen would call for an extensive education of the people of the extreme dangers of handling it because of the risk it poses of even such a small leak. Also, if extensive studies are not preformed on the longevity of such an infrastructure there could be major problems down the road in five, ten or twenty years. Since dealing with hydrogen would be relatively new in such an aspect it would be hard to tell how easily the fuel could be transported, how dangerous the vehicles really are, how well the infrastructure remains intact over time, and whether or not the environment plays a large determining role in handling and storage.

The government once again plays a large role in helping citizens adapt to such a different energy source. Research and development could be used to make the infrastructure similar to that of the previous petroleum one to help stabilize fears and help keep some aspects the same. The government would also help push an infrastructure by using subsidies and tax breaks to private contractors and to citizens who buy the hydrogen fuel cell cars.

Through all the obstacles hydrogen still has a huge upside of being able to be produced from many different sources almost anywhere in the country. This supports local businesses and cuts down hundreds of billions of dollars a year spent on protecting energy supply lines and importing and transporting from foreign lands. One report argues that it will eventually be able to be piped in just like natural gas is, making refueling simple and convenient. Although this idea is both far-fetched and quite unlikely, it reinforces creative thinking that will help lead to new and better ideas in dealing with hydrogen storage and transport. However, research is still in its initial stages and while infrastructure poses a huge obstacle, it may not be tackled until after the technology is developed, which could further set back the ability to displace large amounts of fossil fuels for hydrogen fuel cells.

16.4.4 Storage

Storage of renewable energy is currently is a major problem, but the use of photovoltaic fuel cells has become promising over the past few years. Photovoltaics have an energy conversion efficiency of up to 32% when expensive materials are used or 3% when cheap organic materials are used (Crabtree). The use of advanced electrolyzers that are able to split water freely of noxious gas byproducts has 80% energy conversion efficiency (Crabtree). Researchers are hoping to combine these two processes for a photochemical effect that will have a much higher efficiency and more widespread uses. Another method, storage by liquefaction has largely been discounted in on-board use because of its energy losses (roughly 40% of the energy may be lost during this process) (Crabtree).

Production stations and large refilling stations will be able to store by use of simple cylinders and both liquid and high pressure gases. This has been the norm for the hydrogen industry and will better accommodate the large weights and volumes needed in the future. However, the on-board hydrogen fuel cell is the issue of the future. The main problem with storing such a chemical like hydrogen is capacity and cycling performance. Even though hydrogen has the ability to store half the amount of what gasoline uses because of high efficiency, “the energy densities of the most advanced batteries and of liquid and gaseous hydrogen pale in comparison to gasoline” (Crabtree). This is because both volume and weight are issues when dealing with sufficient amounts of hydrogen for vehicle travel because of its chemical characteristics. On-board fuel storage for transportation will require hydrogen densities to be stored higher than its liquid density. Therefore a material with a high mass fraction and volume density of hydrogen will be the most efficient (Crabtree). However, to achieve acceptable storage capacities, low weight is an important factor. This

“requires strong chemical bonds between hydrogen and light−atom host materials in stable compounds, such as lithium borohydride ($LiBH_4$). But to achieve fast cycling at accessible conditions requires weak chemical bonds, fast kinetics, and short diffusion lengths, as might be found in surface adsorption. Thus, the high−capacity and fast−recycling requirements are somewhat in conflict" (Crabtree).

Materials that would be suitable to achieve such characteristics chemically end up being extremely heavy to carry onboard a vehicle.

Nanostructures have also come into the blend of hydrogen absorption materials to solve this chemical riddle. Since nanostructures have the ability to be coated with catalysts to assist in dissociating hydrogen and are lightweight, they are ideal in creating a fast cycling substrate for vehicle use. Although nano compounds offer many promising venues, they are relatively new and unknown. Much basic research is still needed to fully understand the capture and release cycle involving "molecular dissociation, diffusion, chemical bonding, and van der Waals attraction" (Crabtree). Nonetheless, it is a promising area of research that may lead to breakthroughs not only in hydrogen use but in other facets that use nanostructures as well.

16.4.5 Feasibility

The largest question after all this discussion and research is whether or not a hydrogen economy (Figure 16.1) is truly feasible. It has the potential to alleviate the strain on energy availability once oil production has peaked, but at what cost? There are doubts of whether or not we can sequester enough noxious gases to keep hydrogen a clean fuel. There are doubts of whether or not hydrogen can be stored safely in vehicles. There are doubts in the ability to install a nationwide infrastructure that is able to support the heavy transport system of the United States. There are even doubts as to whether or not the potential of hydrogen to act as an efficient energy source can be even utilized.

At this point, a 500 kilometer drive for a prototype hydrogen fuel cell costs roughly $3,000 per kilowatt of power produced which can be compared to $30 per kilowatt for gasoline engines (Crabtree). Although mass production of these prototype fuel cells plan to reduce the cost factor by 10, a large amount of basic research is needed to be done to substantially lower the cost. However, these fuel cells (also called proton-exchange-membranes (PEM), Figure 16.2) combine with hydrogen's natural affinity for them, have a 60% efficiency rate compared to that of 22% for gas and 45% for diesel (Crabtree). Most of the large costs come from the expensive materials to create the storage tanks of hydrogen to prevent metal brittling and leaking.

Even though the future of hydrogen use as the primary backup to petroleum may look bleak, it is still hopeful. It may not provide the relief that most supporters are hoping for, but it will most likely provide a lift to renewable energy sources. The main point to keep in focus is that there is a wide array of renewable energies available to humans. Solar energy, thermal energy, nuclear energy, electricity, hydrogen, wind power, hydro power, and biomass will all provide energy to the masses in the future. It would be foolish to choose only one of these sources as the energy of the future. More choices may be even more of a benefit because there are so many directions that energy can go in. It will provide jobs and business to all areas of the globe and if hydrogen never pans out as many people hope, the strain of hydrogen and oil peaking will not pose such a large crisis on humankind.

The governments of the world have the largest role in adapting such a change in the infrastructure of energy use. Creative thinking and smart spending may lead to faster results if the right steps are taken. Although there have been pros and cons for a hydrogen economy, it cannot be ignored, but it also cannot be the only option. Funding should increase for research and development on all aspects- safety, storage, fuel cell, etc.- of the hydrogen system, yet funding for more efficient nuclear plants, solar, wind and hydro systems should also receive large amounts as well.

One issue of hydrogen that is clearly visible is that *if* it becomes the forever fuel of the future, it may put an end to poverty in developing nations faster than any other measure. Since petroleum has governed foreign policy for many of the largest nations to secure their energy interests, developing nations without oil potential have suffered. A hydrogen economy has the ability to be produced in many places, without regard for national boundaries. Since the energy is renewable and clean, the developing nations of the world will get an instant boost in economy. The electricity produced without oil and coal will lead to the creation of businesses, schools, lighted neighborhoods, heated homes and probably most important of all- clean water produced as the byproduct of hydrogen electrolysis.

The initial setup will not be cheap and will also require creative and humanitarian thinking on the part of the private sector as well. Logistical and monetary supplements will be largely needed in these poor developing nations, along with education and patience to install the first pieces of the infrastructure. However, it will only be in the benefit of these lending institutions to do so, as a more developed world for the future leads to progress for all and eliminates the diseases and poverty so often found in these areas of the world. So even though hydrogen may end up not being the final or only answer, it will certainly be one large part in the multi step equation of solving the oil peaking crisis.

16.4.6 Figures

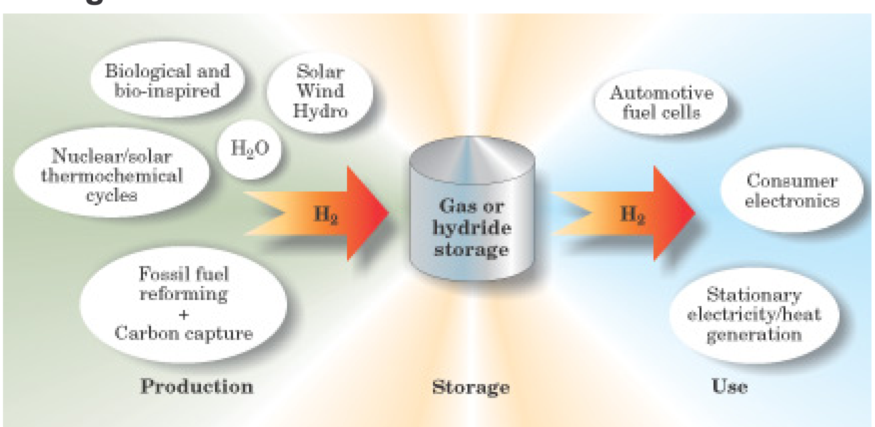


Figure 16.1: Hydrogen Economy

Figure 16.1 is a visual depiction of the hydrogen economy. Hydrogen is a flexible energy source that may be produced almost anywhere and can be linked to numerous other energy forms such as electrical, nuclear and renewable. (Crabtree)

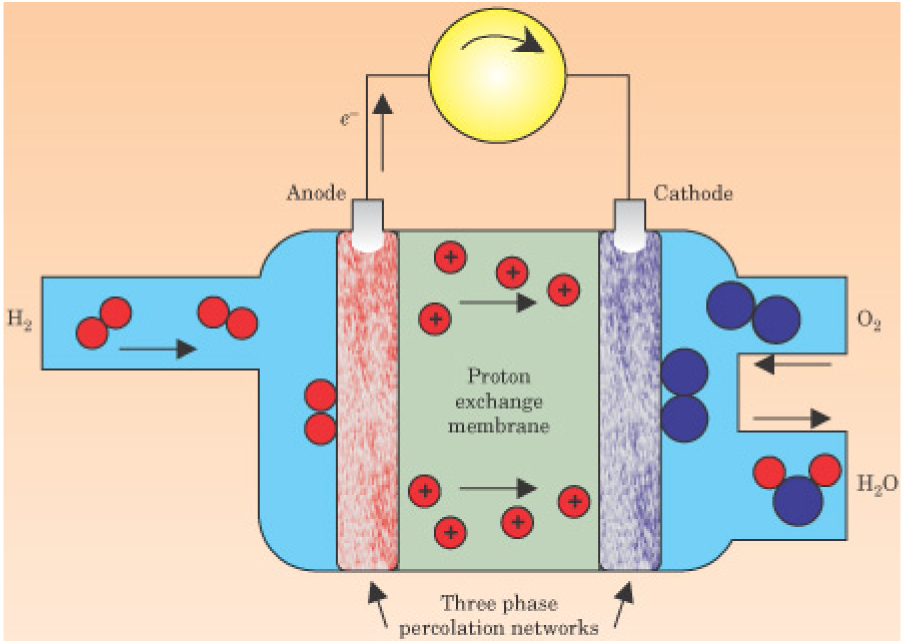


Figure 16.2: Proton Exchange Membrane

Figure 16.2 is a visual of a proton exchange membrane (PEM), a device that allows hydrogen and oxygen to react without explosive effects. The system has a surprising 60% energy conversion efficiency making it appealing to be used in cars and other domestic areas.

17 Impacts of Using Solar Energy

17.1 Environmental and Health Impacts

17.1.1 Beneficial Impacts

With the rise in health risks and increasing evidence of environmental degradation due to human hands, the promise of solar technology is a welcomed one. With the sun providing enough energy to power the globe several times over, the only problem is harnessing it. Solar technology of tomorrow should see higher efficiencies and the ability to store collected energy for us at night. However, today's technology only allows the sun to be efficiently collected during the day. Despite this fact, solar energy still has an important impact in displacing large amounts of pollutants.

In a study performed by MIT's Laboratory for Energy and the Environment's Analysis Group for Regional Electricity Alternatives (AGREA), it was shown that it is important to utilize solar power in places where there is sun *and* currently dirty electricity production. By examining "hourly electricity generation from photovoltaic systems and matched it with the per-kilowatt-hour emissions from fossil-fuel-fired units in the same power grid, in the same hour" (Stauffer), the group determined several important factors. These factors include that even though states in the Southwest will produce up to 30 kWh more than those in the Ohio Valley, there will be a higher reduction in sulfur dioxide. This can be explained by the fact that most power plants in the Ohio Valley use a higher concentration of sulfur dioxide, and by replacing them with photovoltaics, would therefore do more for cleaner air.

Another factor includes a difference in weather, such as can be found in Texas. Even though there is a higher kWh production in the summer, Texas will see a greater reduction in pollution during the winter. This is because "Texas brings on more expensive, cleaner natural-gas-fired methods of generating electricity to meet air-conditioning needs, so the first units to respond to the solar-generated electricity are the cleaner ones" (Stauffer). Although just an initial report from AGREA, this study shows the significant impact solar energy and especially photovoltaics can have.

In a different study done by the Electric Power Research Institute (EPRI) it was determined that the extra cost to displace 0.264 metric tons of CO_2 from coal would cost $14.00 per MWh (Hughes). The same cost ($14.00) would at the same time displace 0.090 metric tons of CO_2 from natural gas. The extra cost from using solar photovoltaics can be compared to other renewable technologies such as geothermal ($7.00), wind ($10.00), or solar thermal ($47.00) (Hughes). This shows that the cost of displacing CO_2, one of the most harmful gases to the environment, is relatively small.

To analyze this cost and see what it would be to displace a coal fired plant, we can look at the Springerville Generating Solar System (stationed near Tucson, AZ) which is currently the largest photovoltaic system of its kind in the U.S. This plant generated 7,532 MWh in 2005 for the Tucson Electric Power Company (Lenardic). The average household in the U.S. uses 8,900 KWh of electricity in a year (Electrical). Therefore, if the power was concentrated from the generating station directly to homes, the station would be able to power roughly 850 homes. Beside the cost to initially develop and build the station, it would cost another $12,000 per year per MW of electricity to displace the pollutants from a coal-fired plant by using a photovoltaic plant. If these numbers can be at least somewhat reliable, it is a relatively small cost in comparison with the billions of dollars governments may have to spend on cleaning up the environment in the future.

In a report carried out by Vasilis Fthenakis and Sam Morris of the Environmental Sciences Department at the Brookhaven National Laboratory, they used a MARKAL analysis to research the photovoltaic potential and CO_2 emission reduction in the U.S. The MARKAL model is a "demand-driven, multiperiod, linear programming model that captures the complex interrelationships of energy systems and their environmental emissions across the spectrum from energy resources to ultimate energy services" (Fthenakis). By selecting technologies that aim to minimize cost, and then factoring in the limitations on both pollution emission and technological growth, the model analyzes the total energy system. All facets of the energy system are included

> "from extraction of resources; processing operations such as refineries; electric, gas, and oil transmission and distribution operations, and end-use technologies such as lighting, industrial heat production, and transportation technologies (from automobiles to ships and airplanes)" (Fthenakis).

Applying such an intricate model that contains several hundred types of technologies and that can be constantly updated, enables us to see the present and future promise of photovoltaics in helping to reduce pollutants in our environment. Using rising energy prices, declining manufacturing prices for photovoltaic cells and rising amounts of cells being employed the MARKAL model made a 30 year prediction on the effects of photovoltaic cells.

> "The continuing increase of PV capacity can make a significant impact in preventing future emissions of pollutants and carbon dioxide from fossil fuel power plants. Photovoltaic grid installations in the United Sates at the 2030 predicted levels, would prevent the emissions of $62x10^6$ tons of carbon dioxide per year, 242,000 tons of $SO_{2\ per}$/year, 58,000 tons of NO_X/year and 9,000 tons/year of fine particulates" (Fthenakis).

If the estimated CO_2 emissions for the U.S. remain at roughly 6.5 billion tons, the use of photovoltaics would displace almost 10% of that amount (EIA). Under the acid rain program, the U.S. is planning to limit SO_2 emissions to 10 million tons by 2010 (EPA). Through the MARKAL model, this would mean that solar energy could displace 2.5% of total SO_2 emissions in the U.S. Finally, nitrogen oxides will be reduced to only 2.1 million tons per year (also under the acid rain program) by 2000 (EPA). Photovoltaics would then be able to displace 3% of the total emitted NO_X gases every year in the U.S. Although these seem like insignificant numbers, solar energy is still in the early stages of development and is only one of several renewable technologies that will be employed to depose noxious gases in the atmosphere.

The U.S. is not the only country looking to overcome environmental risks as Germany has been a world leader in not only manufacturing solar cells but also in harnessing the suns energy. Germany is home to eight of the ten largest solar photovoltaic plants in the world, with the largest being 12MW- more than double the capacity of the next largest in another country (Japan-5.21MW) (Lenardic). These plants have been measured to reduce on average 6200 tons of CO_2 annually, with the largest plants displacing more than 10,000 tons on a yearly basis (Lenardic). "In 2005, the electricity from renewable energy paid for under the EEG [Renewable Energy Sources Act] resulted in avoided emissions of 38 million t CO2, 13 kt SO2, 27 kt NOx and 3 kt" resulting in avoided costs of almost $2.2 billion (€2.8 billion) (Krewitt). Based on this type of production in Germany, the EU is planning on building several more of these plants to battle fossil fuel emissions in the upcoming decade.

The environmental and health impacts of using solar photovoltaics cells are positive. Solar cells do not emit any harmful gases, do not use or expel any water or other liquids, and become a solid investment for any company or country. As in Germany's case, photovoltaics can both displace harmful toxins in the environment and save large amounts of money. If more countries follow this course of action, solar technology will be able to take a firm grasp in the market of renewable energies in the plight to separate our globe from fossil fuels.

17.1.2 Negative Impacts

There are three large issues when considering the use of solar photovoltaics. The first is the energy used to produce and manufacture the cells. It is certain that fossil fuels will be used during this process because of the required development means of silicon, polysilicon, cadmium telluride, and gallium arsenide. The second issue is the hazardous health risks in handling and disposing of these deadly chemicals. All of these chemicals have a potential ability to get into the ground or emitted into the air from the manufacturing process. Lastly, a negative environmental impact is the land usage needed to gather enough sunlight. Although some photovoltaics will use no land because of placement on existing structures, there is a possibility that huge amounts of land will be cleared to make room for large solar systems.

As is the case with many renewable technologies, the energy in fossil fuels that will be needed to produce the materials is inevitable. Considering this fact is very important in assessing the use of renewable technologies to see whether the fossil fuels used in production compare to regular energy systems. The production of photovoltaic cells relies heavily on manufacturing procedures derived from the direct use of fossil fuels. Considering that the industry of photovoltaic production is relatively new, it is important for the government and manufacturers to monitor the use of fossil fuels. As research and development progresses, the efficiency and experience of the industry will hopefully lower both the cost of the systems and its dependence on fossil fuels to create renewable technologies that are supposed to separate us from these very same fuels

Another concern with solar power is the materials used in manufacturing solar panels. Chemicals such as arsenic, cadmium, and silicon are all main components of photovoltaic modules and each are considered hazardous as well. Not only are the materials used dangerous, but during the process of creating the cells, large amounts of hazardous liquids are also used. "These chemicals are primarily used for the cleaning of wafers or to remove impurities from raw semiconductor materials" and they include 1, 1, 1-trichloroethane, acetone, diethyl zinc, and trimethyl gallium (Ladwig). Toxic and highly explosive gases such as hydrogen, diborane and tungsten hexafluoride are also employed during manufacturing procedures.

The major concerns of dealing with these highly dangerous chemicals lie in three areas: air emissions, off-site treatment, and off-site disposal. Although the photovoltaic industry is new, it relies heavily on experience from the very similar semiconductor industry in knowing how to manage these dangers.

In dealing with the release of hazardous chemicals through the air, there are two main outputs- air stack emissions from the plant and fugitive air emissions. The release of chemicals into the air usually comes from the etching and cleaning of the photovoltaic cells. In a study performed by the Public Interest Energy Research Program (PIER), all six of the examined photovoltaic facilities reported emissions from air stacks. These compounds included 1, 1, 1-trichloroethane, acetone, ammonia, and methanol (Ladwig). In contrast, only four of the six plants reported fugitive air emissions, which ranged from

Freon, hydrochloric acid, lead, and sulfuric acid. Each of these chemicals poses a risk to the public as they are all deemed hazardous.

Off-site treatment refers to third party systems created to manage the chemicals produced by the photovoltaic and semiconductor industry. "The types of treatment facilities used include POTWs (publicly-owned treatment works), metals recovery systems, solvents/organics recovery systems, and energy recovery systems" (Ladwig). Four of the six companies researched sent chemicals to POTWs, while three of the six sent chemicals to facilities that recovered metals or solvents (Ladwig). Off-site disposal refers to the recycling or waste treatment of photovoltaic cells. The most common type of disposal method for wastes used in the production of cells is land filling and incineration. Once again, since the photovoltaic industry is still in a relatively early stage, it is hard to specify exactly what will be done with the aged panels because the lifetimes usually guarantee at least 20 years. Recycling is thought to be the future, however, of aged photovoltaic systems. Most companies are hoping to employ a "cradle to cradle" approach where old materials, particularly toxic ones, are reused in new products. This cuts down both the production of new hazardous material and eliminates the need to put the old waste into the environment.

Dealing with these types of chemicals is not new to the chemical industries of the world; however, it is too early to say how large of an impact these particular chemicals will have on the health of the people and the environment in the surrounding area. It is also difficult to predict if there is any danger from the use of the cells themselves and their constant interaction with their surrounding environment. Considering that nearly all solar photovoltaic modules are placed into continuous contact with people and the environment, research will likely needed to be conducted to make sure there is no threat of having these cells close to humans and the environment. Knowing that nearly all of the chemicals used cause either carcinogenic or serious non-carcinogenic effects (i.e. reproductive, muscular, nervous system, etc.), it is important that the industry pays close attention to their procedures of handling both on-site and off-site treatment of all the chemicals used in manufacturing photovoltaic cells.

One more issue of environmental impact is the large use of land area in assembling large solar energy generating systems. Since the energy required in producing large amounts of solar electricity depend almost solely on the area that is able to absorb the sunlight, photovoltaic generating systems must take up large amounts of land. "The large amount of land required for utility-scale solar power plants-approximately one square kilometer for every 20-60 MW generated-poses an additional problem" (Brower). There are actually several of these problems to consider. One issue concerns the wildlife in the area and the ethical battle between creating renewable energy and removing animals from their natural habit. Some large generating systems report that at first wildlife disappears from the area during construction, but small wildlife do return and take shade underneath the photovoltaic panels. A second concern is the actual construction of the photovoltaic panels on-site. Similar to assembling any type of power plant, there is land degradation and large amounts of fossil fuels released into the air to run the machinery.

One large positive to solar photovoltaic modules, which are unlike most of their renewable energy counterparts, is their ability to be dispersed on a small-scale. Even though large generating systems will require large amounts of area, photovoltaic modules can be placed any where and can be of great use. It is likely that companies and contractors will make use of extra space on top of buildings, homes, and in industrial and urban lots to gather electricity from sunlight (Brower). Although renewable energies, such as solar power, are promising ventures for the future after fossil fuels, the industry is still in its initial stages. This will require more funding and research to widen the gap between the use of fossil fuels by renewable energies for production and the energy produced from them.

17.2 Economic Advantages of Renewable Energy

One of the major goals of our country for the next generation is to move over to a renewable energy based economy. We have established that this cannot be done via one alternative energy source, but will require a mix of many different energy sources working together in order to provide the ever increasing amount of energy our country consumes. While this will require a great deal of effort from individuals, laboratories and more importantly the federal and state governments, the impact this would have on our lives would be truly remarkable, with possibly the biggest influence being over our economy.

One of the biggest impacts that transferring over to a renewable energy based system would be that the federal government would be able to save incredible amounts of money that is currently being spent on involvement overseas to protect our interests in oil rich areas of the globe. Renewable energies will also save the money that is spent to subsidize oil companies to ensure that they keep producing ever increasing amounts of oil to meet the demand and the money that is lost in other areas while the government is spending time and money dealing with the major issues associated with having a petroleum based system in place.

This money that is saved can be utilized in a variety of ways because the amount is so great that no one has yet been able to pinpoint exactly how much money would be returned to the government. The best possible idea that the federal government could attempt to do is to return our country to a surplus instead of the record deficit we currently have in place. Not only could this be done, but there should also be a substantial amount of money left for other ventures that the government could begin to undertake, like improving our school system to eliminating poverty to many other noble activities that the government has tried to undertake, but has not had sufficient resources to successfully pull it off. There should also be enough money to allow for pork, small time projects in certain regions of the country to entice representatives of our government to vote for major bills, to be passed through to ensure projects would actually be performed with all of this money that is saved.

However, this transfer would not only be beneficial to our government, but it would also provide a great boost to our economy in general. Since the United States has moved away from major manufacturing towards a service based economy in recent years, this has made our economy more and more reliant on energy, and it has become one of the biggest influences over our current economy. Since the current energy system we have in place is highly unstable and reliant on forces we are unable to have complete control over- switching to a renewable energy based system would allow for a great deal more stability in our economy as a whole. This stems from the fact that the factors such as shortages are eliminated from the equation and as all economists know, eliminating uncertainty from an equation allows for more accurate predictions of what will happen in the economy and thus allow for more prosperity.

This change from a petroleum based system to a renewable energy based system to supply our energy needs would also be highly beneficial to the average citizen of the country. It would allow for the average citizen to be able to pay a great deal less for their energy needs if energy companies received their energy supply from renewable energy sources or to even not have to pay for their residential energy needs outside of the initial investment of the system. While the initial investment of a system in their homes would be a great deal, it should be made affordable with subsidies and other assistance from the government.

Lastly, this will allow for the average citizen to keep more of the money that they earn and thus have that money go back into the economy and strengthen other parts of our it that have been hurting in recent years. With this influx of money into many waning aspects of the market, our economy should receive a jumpstart and once again be able to grow at the astonishing rate that was seen about a decade ago.

18 Conclusion

In light of the fear of an upcoming peak in oil production, the attention toward renewable energy sources has greatly intensified in the past decade. Our project focused on several different factors of both fossil fuels and renewable energies, and more specifically, solar energy. An in-depth concentration on the mechanics and chemistry of photovoltaics was taken in order to assess both the effectiveness and efficiency of solar panels. Along with this technical description, a risk analysis was performed to determine first whether or not it will be economically feasible to install solar arrays on a house in Worcester, MA as the primary source of energy. Secondly, the quantitative analysis was coupled with the projected efficiencies of photovoltaic materials to determine when and under what circumstances installation of these panels on residencies would be feasible.

While oil prices continue to bother consumers, a concern of a possible oil production peak has crept into the picture. Oil peak is the point at which oil will begin to decline in production as it becomes less and less available in the ground. At this point, it is only a matter of time petroleum will run out. The United States has the most at stake because it uses 1 out of every 4 barrels produced and has shown a decreasing reliance on domestic resources. Even though reserves, such as the SPR, have remained largely untapped, we determined that there is approximately a months worth of oil once production ceases. It is more likely, however, that the United States will have to curb its appetite on oil as the world's oil production curve also slopes downward. Even though a 2003 estimate placed the world's reserves at 1.27 trillion (SPE), which would last 44 years, it is likely that with the increased population and industrialization of the third world that this number will decrease. Although this decreasing production signals an end to the petroleum monopoly, it does allow the world time to transition to renewable energy resources.

Renewable energy sources are defined as energy that does not require the use of fossil fuels or release of harmful toxins into the environment. Renewable energy comes in many different forms- wind, biomass, geothermal- and the focal point of our project, solar. Solar energy is any energy collected and used from the sun. Solar cells or photovoltaics are used to collect this energy and chemically change the photons into usable electricity. Photovoltaics can come in two main forms, either as large generating power systems that can be seen in the Southwest United States or as small residential or commercial systems. Our project focused on the latter, and its possible large scale deployment in residential areas, mostly in the Northeast. The deployment of such systems would help alleviate the increasing costs of electricity.

The dependence of such a large scale use for home systems largely depends on two factors- the efficiency/price of the materials and the return investment from electric savings. The efficiency and price of the materials to create the photovoltaic cells that are used to collect the suns energy are both rare to find and expensive to manufacture into the cells. Both of these factors dramatically raise the price, sometimes as expensive as $40 per cm^2. The materials used to produce photovoltaic devices include silicon, cadmium telluride, and gallium arsenide. Each of these materials all consists of highly toxic aspects and must be controlled on a very stringent level. Crystalline silicon can produce efficiencies up to 24%, cadmium telluride can produce up to 8% efficiency and gallium arsenide produces the most- 39% efficiency. Cheaper kinds of silicon, such as amorphous silicon, are more durable and cheaper to produce yet it gives up a third of the efficiency. Cadmium telluride is both too expensive to manufacture and too inefficient to be taken seriously as a leading competitor in photovoltaic material manufacturing. Lastly, gallium arsenide is so expensive to create that it is only used in satellites and other space electronics. At this point the photovoltaic industry needs to increase both the efficiency of the material and decrease the manufacturing process to create competitive, reasonable prices for residential consumers. This correlates in a higher return of investment for the photovoltaic generating systems needed to alleviate the increasing expense of the monthly electric bill.

One major issue that this report demonstrated was that the investment of a photovoltaic cell system in a residential home in Worcester, MA would not be practical at the current time. This stems from the fact that the return on investment is over 19.5 years with a standard deviation of over 11 years. These two factors come together to create an investment that would not be considered wise. While it is regarded as impractical at the current time, technological progression along with increased levels of governmental involvement will make the system more practical.

A large problem lies in the efficiencies of the current solar technology. Of the examples that we analyzed, the quickest return on investment (around 4.3 years) occurred when the efficiencies doubled and the government extended the subsidization to 5 years. If the efficiencies of current solar technology match the extrapolations we performed, the efficiencies will not double by 2025. Not even a governmental increase in funding will make this investment more viable. The best hope for making an investment in solar energy is the advent of new solar technology, such as quantum dots.

If these kinds of systems can be deemed as a practical alternative to more common varieties of energy in New England, such as petroleum and natural gas, then it would certainly be viable in almost every other part of the country. The reason for this is because the conditions of the Northeast are the least suitable for the installation of the solar collecting systems. This transition over to renewable energy for residential energy needs could help to usher in a new era for our country. Such a shift into a clean and renewable energy source will have a great impact on nearly every aspect of our lives including our political structure, our environment and our economy.

19 Recommendations for Future Projects

Although this paper discussed many of the important issues surrounding renewable energy, there is still room for further discussion on these topics and issues related to these topics. This paper touched upon the impacts and limitations of certain fossil fuels, such as oil (petroleum), coal, and natural gas. Future projects could focus on an in depth analysis of the worldwide impacts of our dependence on these fossil fuels. This report could include a breakdown of the consumption levels of fossil fuels worldwide and the impact this has politically, environmentally, and economically. Another project could discuss the recent reappearance of coal energy as well as the development and production of cleaner burning coal energy plants.

While this paper looked at a few aspects of the hydrogen economy, a project could focus solely upon the hydrogen economy. Hydrogen energy possesses the ability to change the landscape of renewable energy. However, an investigation into hydrogen energy must also consider the discouraging theoretical impacts of the use of hydrogen.

This paper focused on the use of solar arrays for residential energy. Topics involving solar energy for future projects include: the use of solar arrays for commercial energy, the application of solar energy in the area of residential water heating, the availability of photovoltaic resources and the impact on the solar cell production industry, the analysis of manufacturing processes by which photovoltaic materials are produced, and the use of quantum dots, viruses, and other experimental technologies to improve photovoltaic efficiencies. These topics could certainly have a profound economic and/or political impact.

20 Table of Figures

21 Table of Tables

22 Table of Equation

23 Appendix A

Location:	Maine	Mass.	Ohio
Family:	Lord	Watson	Compaan
Type:	N/A	Silicon Wafers	Thin-film Cadmium
PV system:	4.2 kW	5 kW	4.3 kW
# of Solar Cells:	16	48	96
Size of 1 PV Cell:	24 sq. ft.	11 sq. ft.	8 sq. ft.
Total Area of PV Array:	384 sq. ft.	528 sq. ft.	768 sq. ft.
Most Recent	2005	2005	2005
Yearly Production:	4.46 mW	5.45 mW	6.23 mW
Yearly electricity use:	3.6 mW	4.7 mW	N/A
Average Current Electric Bill:	$63	$8	N/A

Table 23.1: Summary of Installation Examples

24 Appendix B

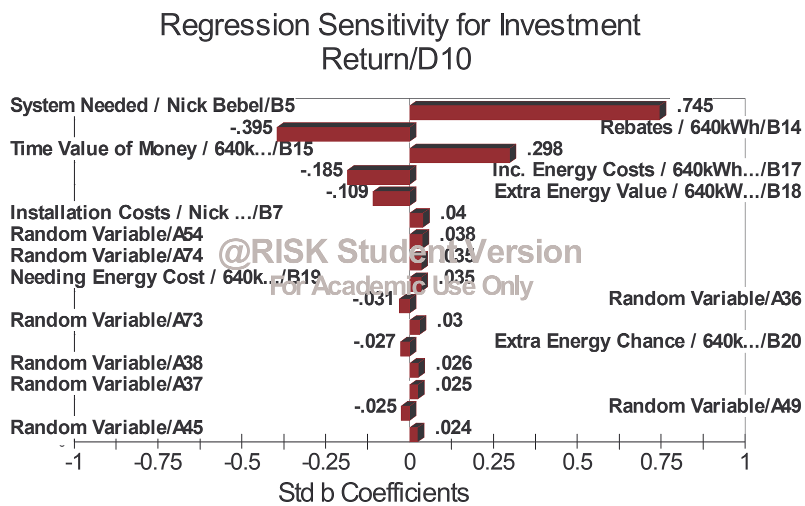
Solar Practicality

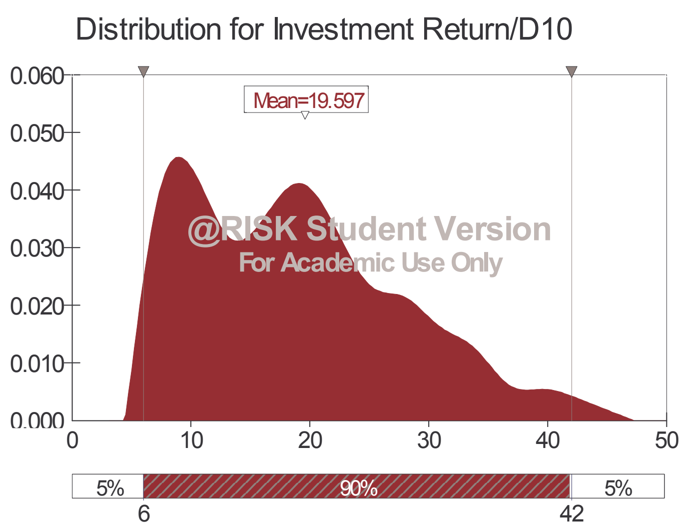
Cost of Solar Panels	212
MA Energy Costs	85.76
System Needed	3
Cost of Panel System	24000
Installation Costs	11638.753
MA Energy Costs	0.134
MA Energy Usage	640kWh
MA Sunlight Hours	4
Post-Install Costs	469.66015
Federal Tax Breaks	2500
MA Tax Breaks	1600
Rebates	0.4
Time Value of Money	0.0424579
Lifespan of Panel	51.681777
Inc. Energy Costs	0.030484
Extra Energy Value	24.496568
Needing Energy Cost	14.310557
Extra Energy Chance	0.6703338
Needing Energy Chance	0.3296662

Investment Return
0
10
10
10
10
10
10

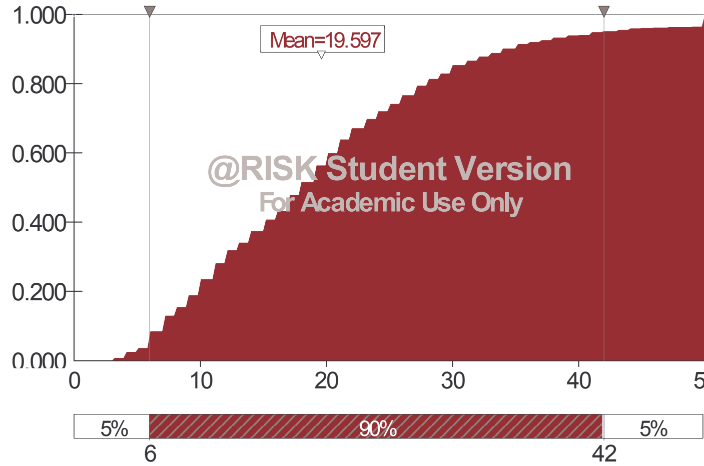
50 Year Value
$33,027.18

	Invest Return	**50 Year Value**
Minimum	3	-9874.518
Maximum	50	81877.74
Mean	19.597	23067.76
Std Var	11.01371	15057.84
Variance	121.3019	2.27E+08


Regression Sensitivity for Investment Return/D10
System Needed / Nick Bebel/B5
.745
Rebates / 640kWh/B14
-.395
Time Value of Money / 640k.../B15
.298
Inc. Energy Costs / 640kWh.../B17
-.185
Extra Energy Value / 640kW.../B18
-.109
Installation Costs / Nick .../B7
.04
Random Variable/A54
.038
Random Variable/A74
Needing Energy Cost / 640k.../B19
.035
-.031
Random Variable/A36
Random Variable/A73
.03
-.027
Extra Energy Chance / 640k.../B20
Random Variable/A38
.026
Random Variable/A37
.025
-.025
Random Variable/A49
Random Variable/A45
.024
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1
Std b Coefficients
@RISK Student Version
For Academic Use Only


Distribution for Investment Return/D10
Mean=19.597
0.060
0.050
0.040
0.030
0.020
0.010
0.000
0
10
20
30
40
50
@RISK Student Version
For Academic Use Only
5%
90%
5%
6
42

Distribution for Investment Return/D10



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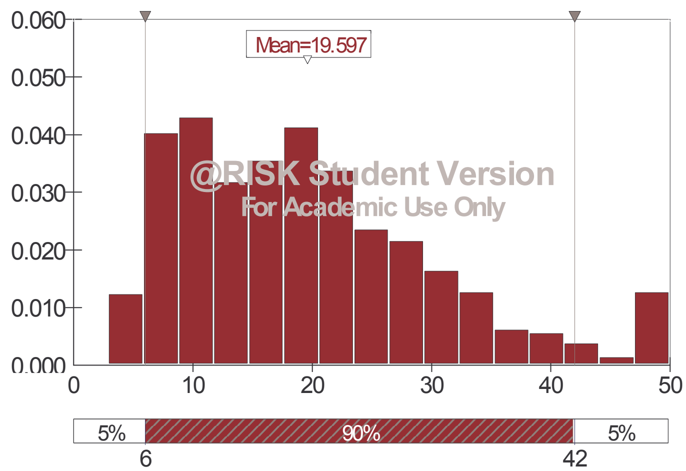
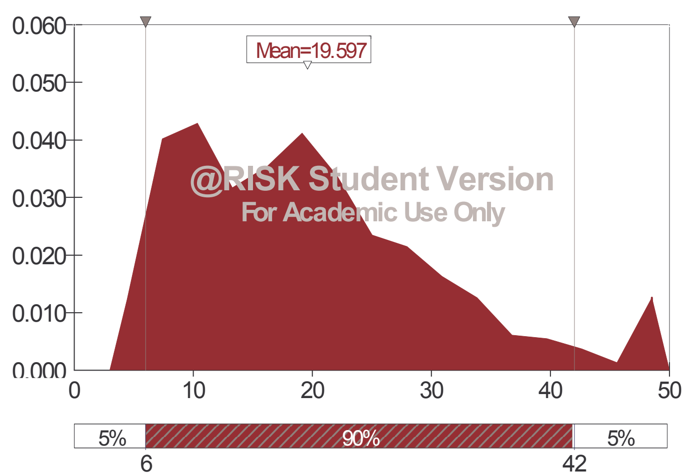


Distribution for Investment Return/D10



Alternatives

Double Eff

Minimum	2	8840.576
Maximum	24	93013.12
Mean	7.012	34077.52
Std Var	3.747519	14224.53
Variance	14.0439	2.02E+08

5 Year Gov Funding

Minimum	3	-3981.341
Maximum	50	98298.93
Mean	12.719	29560.67
Std Var	8.374973	15603.25
Variance	70.14018	2.43E+08

More Gov Funding

Minimum	3	-6384.209
Maximum	50	82880.63
Mean	13.754	28172.96
Std Var	9.430929	15288.48
Variance	88.94243	2.34E+08

5 Year And More Gov

Minimum	3	-66.90485
Maximum	50	99520.09
Mean	6.981	37574.63
Std Var	4.606936	15528
Variance	21.22386	2.41E+08

Double Eff and 5 Year

Minimum	2	12805.15
Maximum	11	94486.55
Mean	4.344	40503.78
Std Var	1.314303	14548.17
Variance	1.727391	2.12E+08

Random Variable	Year	Fixed Cost	Savings	Costs	Net Value	NPV	Panel Death
	0	($21,383.25)			($21,383.25)		
0	1		$5,363.55	$58.34	$5,305.21	($16,294.12)	1
0	2		$5,402.07	$60.12	$5,341.95	($11,378.44)	1
0	3		$5,441.76	$61.95	$5,379.81	($6,629.56)	1
0	4		$1,382.66	$63.84	$1,318.82	($5,512.82)	1
0	5		$1,424.81	$65.78	$1,359.03	($4,408.91)	1
0	6		$1,468.24	$67.79	$1,400.46	($3,317.67)	1
1	7		$1,513.00	$539.52	$973.49	($2,590.03)	1
0	8		$1,559.13	$71.99	$1,487.14	($1,523.72)	1
0	9		$1,606.65	$74.18	$1,532.47	($469.65)	1
0	10		$1,655.63	$76.44	$1,579.19	$572.30	1

1	11	$1,706.10	$548.43	$1,157.67	$1,305.03	1
0	12	$1,758.11	$81.17	$1,676.94	$2,323.18	1
0	13	$1,811.70	$83.65	$1,728.06	$3,329.64	1
0	14	$1,866.93	$86.20	$1,780.74	$4,324.54	1
0	15	$1,923.84	$88.82	$1,835.02	$5,308.02	1
0	16	$1,982.49	$91.53	$1,890.96	$6,280.19	1
1	17	$2,042.92	$563.98	$1,478.94	$7,009.58	1
0	18	$2,105.20	$97.20	$2,008.00	$7,959.55	1
0	19	$2,169.38	$100.16	$2,069.22	$8,898.61	1
0	20	$2,235.51	$103.21	$2,132.29	$9,826.88	1
0	21	$2,303.65	$106.36	$2,197.29	$10,744.49	1
0	22	$2,373.88	$109.60	$2,264.28	$11,651.57	1
0	23	$2,446.24	$112.94	$2,333.30	$12,548.22	1
0	24	$2,520.82	$116.39	$2,404.43	$13,434.57	1
0	25	$2,597.66	$119.93	$2,477.73	$14,310.75	1
0	26	$2,676.85	$123.59	$2,553.26	$15,176.85	1
0	27	$2,758.45	$127.36	$2,631.09	$16,033.01	1
0	28	$2,842.54	$131.24	$2,711.30	$16,879.34	1
0	29	$2,929.19	$135.24	$2,793.95	$17,715.95	1
0	30	$3,018.48	$139.36	$2,879.12	$18,542.94	1
1	31	$3,110.50	$613.27	$2,497.23	$19,231.03	1
0	32	$3,205.32	$147.99	$3,057.33	$20,039.14	1
0	33	$3,303.03	$152.50	$3,150.53	$20,837.96	1
0	34	$3,403.72	$157.15	$3,246.57	$21,627.61	1
0	35	$3,507.48	$161.94	$3,345.54	$22,408.19	1
0	36	$3,614.40	$166.88	$3,447.52	$23,179.80	1
0	37	$3,724.58	$171.96	$3,552.62	$23,942.55	1
0	38	$3,838.12	$177.21	$3,660.92	$24,696.54	1
0	39	$3,955.12	$182.61	$3,772.51	$25,441.87	1
0	40	$4,075.69	$188.18	$3,887.52	$26,178.64	1
0	41	$4,199.94	$193.91	$4,006.02	$26,906.94	1
0	42	$4,327.97	$199.82	$4,128.14	$27,626.88	1
0	43	$4,459.90	$205.91	$4,253.99	$28,338.55	1
0	44	$4,595.86	$212.19	$4,383.66	$29,042.05	1
0	45	$4,735.96	$218.66	$4,517.30	$29,737.46	1
1	46	$4,880.33	$694.99	$4,185.34	$30,355.53	1
0	47	$5,029.10	$232.19	$4,796.90	$31,035.06	1
0	48	$5,182.41	$239.27	$4,943.13	$31,706.79	1
0	49	$5,340.39	$246.57	$5,093.82	$32,370.80	1

25 Glossary

acceptors – positive charge in semiconductors

bandgap – the amount of energy required to make an electron leave the valence band and enter the conduction band, creating an exciton

conduction band – the energy level of an electron that can move freely

EHP – electron-hole pair, results once the an electron and "hole" have been separated from their covalent bond

exciton – an EHP

extrinsic semiconductor – an *n*-type or *p*-type semiconductor

depletion region – the area where in a *pn*-junction in which the *p*-type material is in contact with the *n*-type material; caused by the build-up of minority charge carriers, it creates a built-in electric potential

donors – negative charge in semiconductors

forward bias – occurs when a greater voltage is applied to the side of the *pn*-junction containing *p*-type material while a lesser voltage is applied to the side of the junction containing *n*-type material; semiconductor will conduct electricity while under forward bias

hole – the lack of an electron; results once an electron has enough energy to break the covalent bond

intrinsic semiconductor – a semiconductor composed solely of one element; usually a metalloid with four valence electrons, such as silicon or germanium

minority charge carrier – the excess electrons occurring in *p*-type material; the excess "holes" occurring in *n*-type material

net present value (NPV) – An equation that allows one to determine what the value an investment has at the time when the investment is made

***n*-type** – a semiconductor containing a negative charge; usually resulting from an intrinsic semiconductor being doped with atoms containing five valence electrons, creating a loose electron

photogeneration – the creation of an EHP by a photon incident upon the semiconductor

photon – an elementary particle of electromagnetic radiation, considered the smallest discrete unit of light

photovoltaic – possessing the ability to generate a voltage and/or current when exposed to electromagnetic radiation, usually visible light

***pn*-junction** – the resulting semiconductor when *n*-type material is placed adjacent to *p*-type material; conducts electricity only when a sufficient positive voltage is applied to the side containing *p*-type material

quantum dots – three dimensional nanostructures containing EHPs

***p*-type** – a semiconductor containing a positive charge; usually resulting from an intrinsic semiconductor being doped with atoms containing three valence electrons, creating a "hole"

return on investment (ROI) – The amount of time it takes to have the money spent on an investment returned

reverse bias – occurs when an insufficient voltage is applied to the *pn*-junction, preventing the flow of electricity

time value of money– The change in value that happens to an investment over time.

valence band - the energy level of an electron bound by a covalent bond

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