Feasibility Study of a Solar Learning Lab™ at WPI

by

Haitham Al-Beik

Joseph Chapman

Joseph Ledue

Jason Wailgum

Sponsor / Liaison
Heliotronics / Mathew Arner

Advisors
Professor Richard F. Vaz
Professor Kankana Mukherjee

HELIOTRONICS
products as reliable as sunrise

WPI

Abstract

Our group conducted a feasibility analysis for the installation of a Solar Learning Lab™ at WPI. The Solar Learning Lab™ is a concept developed by our sponsor, Heliotronics, which combines a solar photovoltaic array and a data acquisition system. To achieve our goal, we interviewed stakeholders, gathering information concerning logistical considerations, learning of contributions that they could offer, and discussing possible benefits of the installation. We analyzed the results to determine the feasibility of installation, incorporation into educational programs, and overall sustainability.

Authorship Page

Everyone in our group contributed equally to this project.

Acknowledgements

We would like to thank our project advisors, Professors Richard Vaz and Kankana Mukherjee for supporting us throughout this semester and help us achieve a level that would not have been possible without them.

In addition, we would like thank our project sponsor Heliotronics and especially its liaison, Matthew Arner. His support was quintessential to the successful completion of our project.

We would also like to thank Solar Now Inc. for their generous donation of eight solar modules to better solar education in Worcester.

Finally, we would like to thank our families and friends for their constant support and patience throughout the semester.

Executive Summary

Introduction

Conventional energy sources pollute the environment and adversely affect public health. They have been linked to acid rain, increased mortality rates in infants, and global warming. In the short term, these effects are often overlooked and disregarded by the public; however, they represent potentially devastating problems threatening the global environment in the long run. Furthermore, conventional energy production uses finite resources that will be depleted if current consumption rates are to continue. It is therefore only logical to conclude that the world will have to develop and use other energy sources in the future at some point in time if our civilizations are to continue to develop and improve.

Scientists have realized that the world's choice of energy sources is critical to the global environment, especially as world energy demand increases. They have been calling for non-conventional energy sources that do not have harmful byproducts, and do not rely on expendable fuels as conventional energy sources do. These sources of energy are known as sustainable energy sources and renewable energy sources.

Currently, sustainable energy accounts for less than one percent of energy produced in the world today. It has been around in some forms for decades, yet it has not been adopted into common use. The most common explanation for this is that sustainable energy sources are not cost-effective when compared to conventional energy sources and that the technology must improve to bring costs down before it will be adopted. However, it is evident that awareness also plays a role in the widespread use and adoption of sustainable energy. Sustainable energy will not likely be adopted until awareness of its necessity is increased.

Project scope

To promote wider understanding and use of sustainable energy sources, we decided to raise awareness of their value to society. Through our research and discussions on environmental education programs with our stakeholders, we found that there was no formal course or program at WPI that focused on sustainable energy, and that there was minimal education in Worcester public schools about it.

Since the schools in Worcester, including WPI, seem to have minimal sustainable energy education, we decided that we should start a program on campus at WPI. We decided that a solar photovoltaic (PV) demonstration would be a good way to start. Our project sponsor, Heliotronics, markets and distributes products that help educators and energy consumers learn about the potential of solar PV energy. They specialize in data acquisition systems (DAS) for solar PV arrays and also in interactive software that allows users to browse the collected data in a user friendly environment. They have developed a concept called the Solar Learning Lab™ which is essentially the coupling of one of their DAS with a solar PV array. We found that a Solar Learning Lab™ at WPI not only could meet our needs for a demonstration, but also could exceed them by providing a teaching tool that could be spread into the Worcester public school system.

Project Goal

Our main goal was to conduct a feasibility analysis for installing and using a Solar Learning Lab™ at WPI. This feasibility analysis included first identifying and categorizing the involved stakeholders, interviewing them to determine the costs of the Solar Learning Lab™ to them and the potential benefits that it has to offer to them. Finally, we analyzed the data obtained from the interviews to compare the cost/benefit tradeoffs to determine feasibility.

We separated our stakeholders into following three interest groups:

- Academic stakeholders
- Marketing stakeholders
- Material stakeholders

We learned through our interviews that all of our stakeholders were interested in the concept of a Solar Learning Lab™ at WPI. In addition, we found that the Solar Learning Lab™ could potentially enhance the educational outreach programs held at WPI and also the science curriculum in the Worcester public schools. Our marketing interest group was composed of individuals in the University Development and Relations department at

WPI. These stakeholders had interest in our project, but claimed that they did not see marketing value in it until educational activities utilizing the Solar Learning Lab™ were in place. Finally, the materials stakeholder interest group consisted of stakeholders from the Plant Services at and the Information Technology Departments at WPI. These stakeholders had no problems with installing the Solar Learning Lab™, provided that the components used were all UL listed and National Grid approved tying the array to the grid.

Results of the Feasibility Analysis

Our feasibility analysis addressed four main issues: feasibility of installation, feasibility of educational use, economic feasibility, and feasibility of sustainability. From our analysis, we developed the following conclusions:

- **The installation is feasible if ownership can be established for the Solar Learning Lab™**

  The installation was determined to be feasible if some entity at WPI or combination thereof takes ownership and plays the role of business manager. Currently, no entity at WPI has officially claimed ownership for the Solar Learning Lab™. We have written a proposal to WPI to formally start the ownership process, but it has not been submitted yet.

- **The Solar Learning Lab™ could feasibly be incorporated into education if activities are developed utilizing it**

  Our educational stakeholders indicated to us that they would be willing to help future projects develop educational activities that utilize the Solar Learning Lab™. Our primary contacts for these purposes were the director of K-12 outreach at WPI, Martha Cyr and the Science Curriculum Liaison to Worcester public schools, Joseph Buckley. They specifically stated that if future groups could develop activities, they would help incorporate the activities into the curriculum in Worcester schools and in WPI outreach programs.

- **Installation is economically feasible if additional funding is received**
  We currently need $3,160 in additional funding to purchase a Solar Learning Lab™ for WPI. A more detailed analysis is shown in the table below.

Heliotronics	Data Acquisition System (DAS)	$4,697
Solar Works Inc.	Power Generation System: 1kW PV Array & Inverter	$12,274
Total costs of combined systems		**$16,971**
Class of 1975 donation		– $10,000
Estimated MTC installation credit		– $3,811
Initial costs / funding required		**$3,160**

Through an economic analysis of the proposed array, we determined that an initial investment of $3160 could be returned within 10 years. This return comes from two sources, a production credit capped at $1633 from the Massachusetts Technology Collaborative (MTC) and savings on electricity (approximately $150 annually). Our sponsor has stated that a reasonable lifetime for the Solar Learning Lab™ is 20 years, so this initial investment could potentially return $1500 before the Solar Learning Lab™ at WPI is decommissioned or renovated.

- **Overall sustainability is feasible if the Solar Learning Lab™ is maintained and utilized**
  We concluded that the Solar Learning Lab™ could sustain for a long period of time if educators use it and if it is properly maintained. Development of meaningful educational activities could increase the likelihood of its long term use and establishing a clear ownership could ensure that it is maintained.

Recommendations

The following are the most important recommendations that we have for individuals who continue our project:

- **We recommend that the Solar PV array be installed on the North Side of the Morgan Residence Hall roof at WPI.**
  Plant Services recommended that we install it on the roof of Morgan Residence Hall. From the two possible locations on that roof, we further narrowed it down to the Northern most location because of its convenient accessibility and high visibility.

- **We recommend that the next project group find a way to acknowledge our sponsors, Heliotronics, the WPI class of 1975, and Solar Now Inc. on or around the main kiosk display.**
  Our sponsors have shown interest in being acknowledged publicly for their donations. In addition, Heliotronics and Solar Now Inc. have indicated that they are interested in the marketing potential that such an acknowledgement would have. Finally, Solar Now Inc. specifically requested to be acknowledged somewhere on the final demonstration.

- **We recommend that the next project group contact the Information Technology (IT) department about obtaining a PC to run the SunServer™ software.**
  The costs of a PC for the SunServer™ software were not included in our economic analysis. We assumed that obtaining an older PC from WPI would not be a problem. The Information Technology department is the entity at WPI that would be most likely to be able to provide such a donation. This donation has been discussed with the Manager of Network Operations, Sean O'Connor, but was never confirmed.

- **We recommend that the next project group create one or more activities utilizing the Solar Learning Lab™ for a target audience of grades 6-8.**

  We suggest this because our educational stakeholders claimed that this would be the best way to incorporate the Solar Learning Lab™ into educational activities in Worcester. They also suggested that a middle school audience would be the most appropriate for these activities. We further recommend that the next project group work directly with the WPI director of K-12 outreach, Martha Cyr, and the Science Curriculum Liaison to the Worcester Public School System, Joseph Buckley while developing such activities.

- **We recommend that the next project group develop a mobile demonstration for the solar modules donated by Solar Now Inc. for outreach and educational purposes.**

  This was a direct recommendation from Joseph Buckley, the Science Curriculum Liaison to the Worcester Public School System. He suggested that this mobile demonstration could be useful for schools, which either cannot afford a field trip to WPI or cannot afford purchasing SunViewer.net™ licenses. We created drafts of the bracket style frame, which holds multiple panels. Machinists in the Washburn shops have offered to donate their services to machine the frame.

Table of Contents

List of Figures

List of Tables

1. Introduction

Conventional energy sources pollute the environment and adversely affect public health. Every year, the U.S emits over six billion tons of carbon dioxide and over one million tons of nitrous oxides into the Earth's atmosphere. These gases and other byproducts of fossil fuels have been linked to acid rain, increased mortality rates in infants, and global warming. In the short term, these effects are often overlooked and disregarded by the public; however, they represent potentially devastating problems threatening the global environment in the long term. Furthermore, conventional energy production uses finite resources that will be depleted if current consumption rates are to continue. Because of these problems, many scientists around the world have concluded that the development and use of other, non-conventional energy sources is essential if the world is to continue to rely on energy as it does today.

Conventional energy sources are flawed in that they are non-sustainable; they meet the need of the present while compromising the ability of future generations to meet their own needs. The non-conventional energy sources that most scientists advocate today are sustainable. These sources by definition do not have any harmful byproducts and do not consume expendable fuels. They hold the promise of sustaining the world's energy needs for millions of years.

Currently, sustainable energy accounts for less than one percent of energy produced in the world today. It has been in existence for decades, yet it has not been adopted into common use. The most popular explanation for this is that sustainable energy sources are not cost-effective when compared to conventional energy sources. However, awareness also plays a role in the widespread use and adoption of sustainable energy. It is reasonable to conclude that sustainable energy will not be adopted until awareness of its necessity is increased.

Schools in Worcester currently provide a minimal amount of education about sustainable energy. In addition, WPI does not currently make any effort to promote sustainable energy education at the institutional level.

Our group's overall goal was to bring sustainable energy education to Worcester in some form. We chose to establish a Solar Learning Lab™ at WPI in order to complete this goal. The Solar Learning Lab™ is a product from our sponsor, Heliotronics, which is designed to educate students and energy consumers about the benefits of sustainable energy. It consists of a solar photovoltaic array, a data acquisition system, and an interactive software program that displays the collected data and other information about sustainable energy.

Our main objectives were to conduct a feasibility analysis for the installation of a Solar Learning Lab™ at WPI. Moreover, depending on the results of the analysis a proposal will be written and presented to the proper WPI stakeholders. In order to complete the feasibility analysis, we interviewed stakeholders, gathering information concerning logistical considerations, learning of contributions that they could offer, and discussing possible benefits of the installation. We analyzed the results to determine the feasibility of installation, incorporation into educational programs, and overall sustainability.

We learned of many benefits that a Solar Learning Lab™ could provide to the Worcester area from our stakeholders. A Solar Learning Lab™ at WPI could provide to the Worcester area. In terms of marketing, the installation that we propose could show the public in Massachusetts that WPI is willing to make a commitment to a better environment. Our project sponsor, Heliotronics may also benefit from the publicity that they would receive by installing their products at WPI. Environmentally, the installation that we propose would displace more than 1,200 pounds of carbon dioxide emitted into the atmosphere annually. Though these benefits may be valuable to our stakeholders, we do not believe that they can compare to the value of increased awareness of sustainable energy. This is because the education that a Solar Learning Lab™ can provide will help future generations make responsible decisions about energy.

2. Background

This chapter includes discussions of the future of energy demand, various aspects of current energy supplies, and solar energy, which is viewed by many experts to be part of a sustainable solution to world energy needs (Boyle 1999; Morrison 2000). In addition, previous and current attempts to promote solar energy are also discussed.

2.1. Demand and Consequences of Energy Use

This section discusses the various advantages and disadvantages of current energy production techniques, as well as attempts to curb the harm caused by current energy production.

2.1.1. Energy Demand

Energy demand has grown worldwide at an increasing rate for the past 50 years (Energy Information Administration [EIA] 2002). As the world continues to develop, and its population grows, the need for energy will continue to increase. The World Energy Council predicts that the world population will reach 10 billion by 2050 and as a result, the global energy needs will double (U.S. Department of Agriculture 2003). In addition, The United States of America in particular may have an energy demand grow at greater rates than the worldwide average. The U.S. used close to 25% of all energy consumed globally in 2002, more than any other nation, yet its citizens represented less than 5% of the total population (EIA 2003; U.S. Census Bureau 2003). It has been observed that the increase in demand for energy in the U.S. isn't solely due to population increase, but also due to increase in energy demand per capita. The EIA asserted that the energy use per capita in 2001 was roughly 5% greater than it was in 1970, and predicted that energy usage per capita in the U.S. will be approximately 25% higher in 2025 (EIA 2002).

2.1.2. Current Fossil Fuel Usage

The world's growing energy needs have been met by a diverse number of sources. However, according to the EIA, fossil fuels are used to supply more than 80% of the world's energy today (EIA 2003). Even though they are used widely, they have been linked to increased mortality rates, acid rain, and global warming (Grigg 2002; Kennedy

2002; Gelbspan 1997). Policies have been made both internationally and nationally to reduce emissions from fossil fuels; however, because consumption of fossil fuels continues to rise, the amount of pollutants released have generally increased in recent years (EIA 2002).

Fossil fuels include coal, natural gas and petroleum based products. They account for more than 85% of the United States' energy production, nearly two-thirds of the world's electricity, and power virtually all motor vehicles globally (U.S. Department of Energy [DOE] 2003).

Petroleum is used in the forms of gasoline and diesel to power motor vehicles, and is also used to power aircrafts and most naval vessels. In addition, there are petroleum fired power plants in the nation, and it is also used in heating buildings. According to reports published by the EIA, the U.S.' alone in 2001 spent 28 billion dollars in to import petroleum because, domestic suppliers aren't sufficient to meet the demand (EIA 2002).

Coal is the United States' most abundant natural resource, with millions of tons being extracted from mines daily. It is also the cheapest fossil fuel in terms of energy production, averaging $1.26 per million BTUs. This makes coal the workhorse of the nation's electric power industry, supplying more than half the electricity consumed by Americans (DOE 2003). One quarter of the world's coal reserves are found within the United States, and the energy content of the nation's coal resources exceed that of the entire world's known recoverable oil supply (DOE 2003).

Natural gas is the cleanest burning fossil fuel (EIA 2003). It is used regularly in energy production, primarily for heating. However, it is also used for electricity generation. Currently it is the least used of the three fossil fuels (EIA 2002).

2.1.3. Harmful Effects of Fossil Fuels

Fossil fuels, though being widely used for energy production in the U.S., release many emissions that are harmful to the environment when combusted. Scientists throughout the world agree that fossil fuels create heightened levels of air pollution, help cause acid rain, and may even be causing a global warming (Grigg 2002; Kennedy 2002; Gelbspan 1997). In addition, with supplies being limited, fossil fuels will eventually have to be replaced by other means of energy production if the U.S. is to continue to meet its demand.

Many physicians have investigated the relationship between air pollution and public health. One such physician is Jonathan Marcus Grigg, who has received various awards and accolades for his work studying the biological effects of ultra fine particulate pollution. In an article published in 2002 for the British Medical Association, Grigg asserted that "Over the past 10 years there has been increasing evidence that particles generated by the combustion of fossil fuels adversely affect health." Throughout the rest of the article, he states that air pollution has been linked to higher mortality rates from all causes, but the most notable increases were from respiratory and cardiac causes (Grigg 2002). These findings indicate that fossil fuel usage may adversely affect public health.

In addition to adversely affecting public health, fossil fuels have also been linked to global warming. Ross Gelbspan, who has worked as an editor for the Boston Globe and the Washington Post, noted this point in the American Prospect Journal, stating "In late 1995, [2500 climate scientists] reporting to the United Nations, declared that the recent heating of the atmosphere is caused by carbon emissions from oil and coal combustion, not by the natural variability of the climate." The majority of scientists from all over the world have concluded that global warming is real, and is caused by carbon emissions (Gelbspan 1997). Global warming has been predicted to have potentially catastrophic effects on the global environment (Retallack and Bunyard 1999). For example, studies of the Pacific Ocean have shown that rising ocean temperatures in the past decade have corresponded to decreases in fish and wildlife populations by as much as 90%. The reason is suspected to be that some fish species' metabolic rates are directly proportional to the temperature of the environment around them, so higher water temperatures means higher metabolisms, which means that the fish need more food to survive. According to the researchers who conducted the study, environmental damage like that observed in the Pacific Ocean may worsen if the global ocean temperatures continue to rise (Mathews-Amos & Berntson 1999). Because of this and other potential risks of global warming, many scientists are urging policy makers to encourage the growth of clean, sustainable energy, and to curb the carbon emissions produced in the U.S.A. (Flavin & Tunali 1993).

There is also a consensus in the scientific community that emissions from fossil fuel combustion can cause acid rain. Although scientists have not yet determined the full extent of the damage caused by acid rain, initial studies indicate that the long term damage may be severe. Martin Kennedy, an earth scientist at the University of California, has been studying old growth forests in Chile for years, and recently published his findings. He noted that acid rain not only destroys leaves and needles on trees, but also depletes mineral deposits in topsoil, which plants depend on for healthy growth (Kennedy 2002). He further stated "[our study] proposes that [the U.S.] stable old growth forests are the most at risk from acid rain, and that it is a bigger problem, potentially, than we ever imagined." Kennedy's conclusions reinforce the idea held by many scientists that acid rain can severely damage the biosphere (Kennedy 2002; EPA 2003).

2.1.4. Measures to Reduce Fossil Fuel Byproducts

There have been multiple efforts made by governing bodies both internationally and nationally to reduce emissions of greenhouse gases and other harmful byproducts of energy production in the past. In December of 1997, for example, an international treaty known as the Kyoto Protocol was created. This agreement was negotiated by over 160 nations and overseen by the United Nations Framework Convention on Climate Change (UNFCCC). It called for several developed nations to reduce emissions of greenhouse gases to certain levels by 2008, and sustain that level for five years. The treaty has since been ratified by 119 nations worldwide (UNFCCC 2003). The United States initially committed to the treaty under the Clinton administration, but abandoned it under the Bush administration in 2001, making the U.S. the only industrialized nation in the world that does not abide by it. The Kyoto protocol is a good example of a major international effort to reduce greenhouse gas emissions.

A notable example of a national effort to reduce the harmful emissions caused by fossil fuel burning is the Clean Air Act. This act was first passed in 1963, and has been amended numerous times. It was the first example of legislation to regulate and control air pollutants in the U.S. It provided funding for state and local governments to limit the amount of emissions from mobile sources (motor vehicles) and stationary sources (buildings). Since its' introduction, the Clean Air Act has helped the U.S. control air pollution and reduce emissions from motor vehicles significantly. For example, one of the mandates from the act that was successfully implemented was a 90% reduction in emissions. "Industry devised the catalytic converter as its way of trying to achieve the mandated [90%] reduction," noted a former Environmental Protection Agency (EPA) administrator, Russel E. Train in a discussion of the six most important examples of environmental policy (Train 2002). The Clean Air Act was the first national effort in the U.S. to curb harmful emissions from fossil fuel processes, and is viewed by many to be a benchmark in energy policy (Fleming & Knorr 1999).

2.1.5. Nuclear Energy

Nuclear energy was initiated in the U.S. in the mid 1960's. Although it does not pump airborne pollutants into the atmosphere like fossil fuels, it still has byproducts that are harmful to the environment. Spent nuclear fuel is radioactive, and takes thousands of years to become stable again. Radiation in any form can cause cancer, which is why nuclear waste is so hazardous. In addition to the environmental problems that spent nuclear fuels present, there is also the risk of nuclear meltdown. Meltdown is a term that describes a situation in which a reactor overheats to the point of melting through the earth's crust, causing a cloud of radioactive particles to be ejected into the atmosphere. This threat is a significant one; as the world was reminded on April 26, 1986. On that day, a reactor at the Chernobyl nuclear power plant overheated, and literally blew off the steel and concrete roof. Everybody within a 30 kilometer radius, a total of 161,000 people, had to be evacuated because radiation levels were dangerously high (World Nuclear Association [WNA] 2001).

Many scientists agree that the harms of the Chernobyl accident have stretched far beyond a simple inconvenience to the public (UN Scientific Committee on the Effects of Atomic Radiation [UNSCEAR] 2000). In a report titled "Fifteen Years Later. Living After Chernobyl." The UNSCEAR noted that the adverse effects were apparent within months of the disaster (30 deaths from radiation poisoning) and are still being analyzed today using statistical methods (UNSCEAR 2000). Though the report admits that "given the low doses received by the majority of exposed individuals, any increase in cancer incidence or mortality will be difficult to detect in epidemiological studies," an article published in The Lancet explaining the UN report claims that the incidence of thyroid cancer has increased 100-fold since the disaster occurred in some areas (UNSCEAR 2000; Kapp 2000). Even if no conclusions can be drawn about the adverse effects of the Chernobyl disaster in terms of physical health, the long term psychological effects are clear (UNSCEAR 2000). According to the report, "Limited knowledge of the long-term effects of exposure to radiation and the inevitable [rumors] of hideous ailments and genetic mutants have induced psychological trauma and prolonged panic in the hearts and minds of millions of people." (UNSCEAR 2000). The Chernobyl disaster has caused harm to many people around the world, and even now, 17 years later, the world is still concerned with its effects.

Although nuclear energy can cause widespread harm in catastrophic situations, it has continued to grow and spread throughout the years. According to the Nuclear Regulatory Commission (NRC), there are 104 commissioned nuclear reactors in the United States, and they account for about 20% of the nation's electricity supply (NRC 2003). Since it is cost effective, nuclear energy is a technology that will likely be in use for years to come (EIA 2002).

2.1.6. The Case for Renewable Energy

Scientists have known for over half a century that conventional energy supplies cannot sustain global society indefinitely (Flavin & Tunali 1996). Nuclear energy and all fossil fuel energy alike utilize non-renewable fuels, and have byproducts that can cause harm to the global environment. In the short term, energy from fossil fuels and nuclear processes is cheap and abundant, but scientists believe that in the long term, it comes at the cost of the environment (DOE 2003; Flavin & Tunali 1996; Kennedy 2002).

Even though opinions are varied on how long it will take fossil fuel supplies to run out, they will eventually have to be replaced. Estimates for the world oil endowment have generally increased since 1950; however it is an indisputable fact that the supply is finite. The U.S. Geological Survey (USGS) estimated in 2000 that the world endowment of oil was just over three trillion barrels (USGS 2000). An experienced earth scientist, David Deming, analyzed this fact in a paper published for the National Center for Policy Analysis, predicting that conventional world oil supplies will be depleted by 2056 (Deming p.6 2003). Scientists see the need for replacing fossil fuels as an energy source, and have been calling for action for more than a decade now. Justin Lancaster, a published writer on the subject, stated that "[a] shift away from [petroleum] may become more difficult each decade the shift is postponed, because we will be forced to burn increasing amounts of coal until alternative sources fill the gap." Lancaster shares the position with many other scientists that alternative sources of energy to fossil fuels must be developed immediately.

Many scientists believe that the best long term solution to the world's energy needs will be a solution that utilizes sustainable energy. Sustainable energy is a term that is closely related to sustainable development, which, according to the International Institute for Sustainable Development (IISD), was first popularized in a report in 1987 known as "Our Common Future," or simply "The Brundtland Report," (IISD 1997). In that report, sustainable development was defined as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs," (p.43 World Commission on Environment and Development [WCED] 1987). Sustainable energy is a term that is commonplace amongst advocates of renewable energy, though exact definitions of the phrase vary from source to source (Iter Canada 2003; Queensland Government Office of Energy 2003; Jamaica Sustainable Development Networking Programme 2003). Even though the exact definitions vary, they all convey the same general idea. This idea is characterized in the Chambers Dictionary of Science and Technology in its definition of sustainable, which is "[i]nvolving the long-term use of resources that do not damage the environment," (Chambers Dictionary of Science and Technology). As it applies to energy, a source is sustainable if and only if it uses resources that will be available over a very long term and does not damage the environment.

Over the past decade, experts in environmental policy have tried to support the development of sustainable energy. One such expert is Christopher Flavin. Flavin is president of the Worldwatch Institute centered in Washington D.C. and has had his writing published in the *New York Times* and *Time* magazine. He also frequently appears on radio and TV shows for the BBC, CNN, NPR, and PBS. Flavin coauthored a book in 1996 entitled *Climate of Hope: New Strategies for Stabilizing the World's Atmosphere*. In this book, he calls for the "[acceleration of] commercial development of new, low-carbon energy technologies since it takes time for new systems to displace a significant portion of the devices currently in use," (Flavin & Tunali 1996). In other words, the change to sustainable energy cannot possibly be instantaneous; it will have to be a gradual transition, so the world should act now for the technology to positively affect take hold in the future generations (Flavin & Tunali 1996).

2.2. Solar Energy

There are a number of possibilities for sources of sustainable energy. Some of the resources include geothermal, wave, wind, tidal power, hydroelectricity, bio-mass, solar thermal and solar photovoltaic energy. Today, less than 1% of world's energy comes from clean, renewable sources. However, renewable energy sources have the potential to exceed today's energy demands (Public Interest Research Groups [PIRG] 2002). Thomas Tanton, a professional with over 28 years experience in the energy, environmental, and economic fields, states that the full spectrum of sustainable energy sources hold the "unique potential for providing clean, reliable, and affordable energy in the long term" (Tanton 2002). Solar energy is just one of elements that Tanton refers to in his spectrum of renewable technologies, but it is viewed by many as being a key part of a sustainable future. Over the past five years alone, solar industry experts have trumpeted that solar energy has "great," "huge," and even "enormous" potential, despite the admission that cost-effectiveness is currently the primary limiting factor (Boyle 1999; Morrison 2000).

2.2.1. Solar Energy History

While renewable solar energy sources are increasingly growing in the U.S. (DOE, 2000), there are still many people who think it is one of the recent innovations in the 21st century. The truth is that solar energy has been with us far longer than that. Ancient Egyptians, for example, harnessed the power of the sun to heat their homes and used the collected energy as part of their mummification process. Since then, many techniques and designs of collecting solar energy have emerged to support different applications and situations.

The world's first thermal solar collector was invented in 1767 by the Swiss scientist Horace de Saussure. (Dohn Riley, 2001) However, up until 1891 Clarence Kemp patented the first commercial solar energy collector named 'Climax' in the United States, which was primarily used to heat water (The America Solar Energy Society (ASES), 2002). Dr. Kemp's invention became so popular in the late 1800s, that hundreds have been installed throughout southern California and about one-third of the houses in Pasadena (DOE/EIA-0603(95), 2001).

Thanks to William J. Bailey of the Carnegie Steel Company, many of today's solar collectors are more efficient due to its copper coils and an insulation box design. Bailey invented this design in 1908 and, by the end of World War I, it had sold more than 4,000 solar water heaters to be used on rooftops, and more than 60,000 were in place by 1941 (ASES, 2002).

During the late 1950s Bell Labs developed photovoltaic cells to be primarily used for space applications. For example, the Hubbell telescope's makes use of its solar panels to produce energy for storage and use.

Renewable energy during the 1970s came to be an important topic within the government and the public after the oil embargoes of 1973 and 1979. Especially after the outbreak of the Arab-Israeli war in 1973[1], which in turn caused a ban to cease oil exports to the United States by OPEC (EIA/DOE 2003). In August of 1977, President Jimmy Carter stressed and outlined to the nation the importance of energy security and how the U.S. needs to become less dependent on foreign oil (EIA/DOE 2003). The President also signed the Department of Energy Organization Act, creating the cabinet-level U.S. Department of Energy, and the National Energy Act in November of 1978. In 1979, the world's largest PV manufacturing facility, ARCO Solar[2], produced more than 1MW of PV modules that year (EIA/DOE 2003).

During the late 1980s, research funds for enhancing PVs started to increase with thanks to the Renewable Energy and Energy Efficiency Technology Competitiveness Act. PV research ranged from increasing reliability and making modules more efficient to decreasing manufacturing/production costs.

2.2.2. Photovoltaic Technology

Photovoltaic (PV) technology transforms energy from solar radiation into electricity, providing the people with the means to use it in a variety of ways. Photovoltaic modules or panels are made of PV cells that allow sunlight to be converted directly into electricity

[1] OPEC also banned the U.S. from oil exports in 1979. In 1990, the Gulf War also sparked interest in non-fossil fuel energy alternatives in the U.S.
[2] In 1990, ARCO Solar was bought by Siemens A.G. Solar of Munich in West Germany

by means of the "PV effect." The PV cell is the basic building block of a PV system. The PV cell was discovered in 1954 by Bell Telephone researchers examining the sensitivity of a properly prepared silicon wafer to sunlight. Individual cells can vary in size from about 1 cm (1/2 inch) to about 10 cm (4 inches) across and can produce 1 to 2 Watts of power. Solar PV cells usually need other components to produce electricity that is useful for most applications (Renewable Energy Resource Center (RERC) 2003). Solar panels alone produce DC (direct current) electricity; however, most electrical appliances today use AC (alternating current) electricity. Power inverters are used to solve this problem, and are used in all grid connected systems. Some other components also used in solar PV arrays are batteries, sun path tracking systems, and data acquisition systems. Batteries are used for two reasons. First, they can provide power during the night, when there is no sunlight. Second, they can help ensure that the power output from the solar system is steady during the day so that factors like cloud coverage will not stop power from being transmitted. Tracking systems are used to boost efficiency of arrays, and they essentially try to position the solar panels so that they are always normal to the path of the sun's light. Data acquisition systems are used to keep track of parameters of interest from the arrays, such as power output, inverter efficiency, solar irradiance, and meteorological data (Aldous 2003).

2.2.3. Costs and Benefits of PV

Although there are some limitations, many analysts acknowledge that PV systems have a number of advantages over conventional power-generating technologies. Almost certainly, the most significant advantage is that PV cells do not create any harmful byproducts during normal operation. PV systems have the flexibility to be designed for a variety of applications, and can be used for either centralized or distributed power generation. In addition, PV systems have no moving parts, but are modular, and even portable in some cases. The fuel (sunlight) is virtually unlimited, and no noise pollution is created from operating PV systems. In general, PV systems that are well designed and properly installed require minimal maintenance and have long service lifetimes. Although they have many advantages, the current cost of PV systems seems to hinder its' widespread use (Barron 1999). However, today's PV systems are more reliable and cost less than previous generations. Analysts agree that this trend will likely continue for years to come as the technology advances (EIA 2003).

It has been established that the development of renewable energy would have a positive impact on the environment. Development of solar energy would be no exception, as most experts agree that solar energy should play a role in our future (Blankinship p.32 2003; Fies p.13 2001; EPA 2003). Unlike conventional sources of energy, solar energy has no expendable fuel, has no byproducts, and is manufactured from very common substances, which makes it sustainable by definition (Chambers Dictionary of Science and Technology). Reputed scientists around the world agree that solar energy is an environmentally sound source of energy (NREL 2003; EPA 2003; ISES 2003). This environmental soundness of solar energy could very well be one of the most significant reasons that people across the world support it (Earth Policy Institute 2002).

In addition to being environmentally sound, PV systems can be adapted to suit many requirements, small and large. PV cells are used in calculators and watches, but also in telecommunications equipment, highway construction signs, parking lights and navigational warning signals. Solar PV systems can be used anywhere there is light, and thus are suited for diverse energy needs. The versatility of solar PV technology has made it the best option for electricity in locations where connecting to the utility grid would be costly (Barron 1999).

With solar energy delivering power for PV owners, the energy is only stored and used locally. In some cases, owners end up generating more power than they typically need. To better take advantage of the excess energy, Distributed Generation (DG)[3] was implemented to share and distribute the energy by feeding it directly into the grid.

Whether DG is useful is still under debate, according to the National Conference of State Legislatures (NCSL), DG has its short and long-term advantages and disadvantages. In the short-term, DG systems are modular, and more convenient when compared to building new central stations that are more expensive, and require lengthy and bulky power lines. However, concerns still exist as to the reliability and longevity of such systems due to the lack of education within the general public. In the long-term, DG

[3] Also known as On-Site Power, Distributed Energy Resources (DER), and Cogeneration (Combined Heat and Power (CHP))

systems, due to their "line losses"[4] quality, are cleaner and more efficient when connected over long distances. However, the over all efficiency of individual DG systems (~30%) is less than that of central stations (~50–60%).

One of the major challenges with DG is integration (EPRI, 2003). With many DG systems connected together, it will become more difficult to control the performance and stability of all systems at once. Researchers within the electrical engineering field are currently working on overcoming such a challenge. The Institute of Electrical and Electronics Engineers (IEEE) and the Underwriters Laboratories (UL) developed standards to "help define the capabilities, performance, and design requirements of PV and balance-of-plant components" (Moore, 2003). Such codes and standards are the IEEE P1547 and the UL 1741 (NREL/Office of Electric Transmission & Distribution (OETD), 2003).

Energy security has been carefully reevaluated in the United States of America since September 11, 2001 (Resource Dynamics Corporation [RDC] 2001). With the realization that the nation's energy infrastructure was vulnerable, energy security became a major focus at the federal level. President Bush has referred to its importance in numerous speeches and addresses, while the former Deputy Secretary of the DOE, Frank Blake, stated "Energy security is DOE's number one priority." (DOE 2002). A broad approach has been taken to improve energy security across the nation, including increased security at critical points in the infrastructure and added redundancy to emergency backup systems nationwide (RDC 2001). However, most experts in renewable energy insist that solar energy and other DG technologies can also play an important role in energy security (RDC 2001). These experts contend that since solar PV systems do not require any fuel to function, they can serve as backup systems for critical points in the nation's energy and communication infrastructures (RDC 2001). For example, solar PV systems can be used to power communication towers and gas pipeline pumps, so in the event of power loss, critical services will not be compromised (RDC 2001). These experts admit that solar PV systems should not completely replace traditional backup supplies such as diesel generators, but rather, they could provide another layer of redundancy for critical applications (RDC 2001).

[4] Loss of *current* as it travels over great distances will be vastly reduced in most applications (NCSL 2003).

There are many attractive qualities that solar photovoltaic technology possesses; however, the technology will not likely hold a large share of the energy market until it becomes cost effective. Opinions are varied on the current cost effectiveness of PV technology for widespread use; however, there seems to be a consensus that it does make economic sense in certain applications, and that prices for PV will continue to drop (Baron p.45 1998; Blankship p.32 2003; Fies p.13 2001). The most common applications in which solar energy makes economic sense occur when the costs of running power lines to the remote location outweigh the initial costs of a solar PV system (Baron p.45 1998; Blankship p.32 2003). However, even though some think that solar PV technology is cost-effective in widespread residential use, the fact remains that it currently holds less than 1% of the energy market (EIA 2003).

When analysts say that solar PV energy is not economically viable, they usually indicate that the technology is not cost competitive with other electricity sources (Baron p.45 1998). Initial costs are high, and the payback periods for typical residential applications are estimated to be anywhere from 5 to 15 years depending on incentives and other factors like geography (Blankinship p.32 2003; Fies p.13 2001). Furthermore, even though costs of solar PV systems are dropping, experts believe that deregulation presents two problems for all renewable energy supplies (Blankinship p.32 2003; McVeigh 1999; Baron p.45 1998). First of all, from the perspective of the electricity consumer, deregulation is causing prices of conventional electricity to drop, which reasonably means that prices of solar energy will have to drop even faster to "catch up" (Baron p.45 1998). Second of all, according to an article published in *Power Engineering*, utilities working under a deregulated business model will be much less likely to invest in renewable energy plants - particularly solar energy plants - because they are not as cost effective as other means of electricity generation (Blankinship p.32 2003). A reasonable conclusion to draw from this evidence is that either prices of solar energy will have to drop faster than prices of utility supplied electricity, or prices of utility supplied electricity will have to increase before solar PV technology becomes cost effective.

Even though solar PV energy may not be cost-effective, it still may be economically viable to some. In most applications, PV technology has not been cost-effective since its introduction in the 1950's, yet the market has been growing steadily for decades (Fies

2002). This may be due to many factors such as financial incentives, but many believe that consumer interest is one of the most significant (Earth Policy Institute [EPI] 2002; American Wind Energy Association [AWEA] 1994; Blankinship p.23 2003). In an article published by AWEA, it was noted that almost two thirds of Americans surveyed thought that renewable energy should be one of the top two priorities for funding in the energy budget (AWEA 1994). In another survey conducted in Texas, it was again found that over half of those questioned thought that renewable energy should be the resource that utilities pursue first in meeting energy demand (NREL 2003). Additionally, it was found that thousands of consumers across the nation who value the positive aspects of renewable energy are willing to compensate (EPI 2001). For example, in 2000, an overwhelming majority of students attending the University of Colorado voted in favor of a $1 increase in annual fees to purchase energy supplied by wind turbines (EPI 2002). The market for solar energy has increased almost without fail for three decades, which seems to suggest that the cost-effectiveness of solar photovoltaics is not a significant factor in the decision to use them, at least for some consumers. Or perhaps, some consumers believe that the benefits of using solar photovoltaics outweigh the financial costs.

2.2.4. Outreach and Educational Programs

In an article published in the journal for the Electronic Power Research Institute (EPRI) in 2001, Brian Fies, an experienced writer in the energy industry, posed the question "…[W]ith so much working in favor of PV, why isn't there more of it?" (Fies 2001). Fies later answered his own question, stating "[c]ost provides much of the answer; perception provides the rest," (Fies 2001). After all, according to the EIA, solar energy accounts for less than 1% of the total energy produced in the U.S. (EIA 2003). Costs have already been discussed and established; however, public perception is a topic that has not been dealt with yet in this chapter.

The public's perception of solar energy plays a key role in whether or not it will flourish in the future. Experienced engineers and scientists published in such journals as the EPRI Journal and Power Engineering Journal believe that solar PV costs will come down and that the technology will continue to become more reliable (Fies, 2001; Blankinship, 2003). These experts, along with others, also argue that solar PV will benefit from an economy of scale (Fies, 2001; Blankinship, 2003, Aldous 2003; Barron 1999; McVeigh 1999). Knowing this, one could logically conclude that higher demand for solar photovoltaics from energy consumers would likely result in larger scale production facilities, which in turn, would lower costs. In this manner, the public's perception of solar energy could significantly alter its future. As to the public's current awareness of the potential of solar energy, it is found that most electricity consumers believe that development and use of renewable energies in general is important; however, a study conducted by a consulting firm in California for a major utility concluded that the majority of consumers surveyed in California were reluctant to pay more than a small percentage extra to support green energy (ICF Consulting 2003). This situation causes many advocates of renewable energy to try to educate the public about its potential benefits (NREL 2003; MTC 2003).

Organizations across the nation and across the world realize that outreach and education are important to the success of solar energy. For example, the Clinton administration, with the aid of the Department of Energy, announced the Million Solar Roof Initiative (MSRI) in 1997, a program whose goal was to establish one million solar energy systems on buildings across the nation by 2010 (MSRI 2003). Part of the way in which this was to be achieved was through financial incentives and outreach programs. Another example is the organization known as ASES, the American Solar Energy Society. This American branch of the International Solar Energy Society promotes outreach and education, and has 30,000 members worldwide (ASES 2003).

There are a number of financial incentives for solar energy offered at the federal, state, and even municipal levels. According to the Database of State Incentives for Renewable Energy (DSIRE) project, a project funded by the Interstate Renewable Energy Council, there are literally hundreds of financial incentives, loans and tax credits available to solar energy consumers nationwide (DSIRE 2003). More locally, the state of Massachusetts has created a quasi-public organization known as the Massachusetts Technology Collaborative (MTC), whose goal is to promote "renewable energy and the innovation economy." Part of the method that the MTC tries to achieve its goal is through outreach and education. For example, the MTC recently funded a series of workshops whose goals were to educate teachers on ways to incorporate solar energy into their lesson plans. The workshops were held in conjunction with groups and organizations that support renewable energy such as Solar Now Inc. More information about Solar Now Inc. can be viewed in Appendix C.

Overall, the United States government realizes that the development of a sustainable energy source is an important goal, and has demonstrated the need through its numerous outreach programs and financial incentives on the federal, state, and municipal levels (Bush 2001, MTC 2003,). There are literally millions of dollars in incentives and grants available to individuals and organizations that install solar collectors on their buildings (DSIRE 2003). The need for a sustainable energy source is apparent; however, if the public isn't convinced of that need, then the technology will not likely be widely used.

3. Methodology

Our goals were to complete a feasibility study for a Solar Learning Lab™ on the WPI campus and to write a proposal to WPI for the installation. The feasibility study consisted of analyzing issues surrounding approval, installation, and costs. We decided that the proposal should include an argument portraying the various benefits of the Solar Learning Lab™ on campus. We also intended to obtain sufficient resources to build a 1kW photovoltaic installation proposed above. The proposal will be presented to important stakeholders affiliated with our project for the purposes of getting approval to build the Solar Learning Lab™ on campus. To achieve our goals, we completed the following objectives:

- Identify the scope of solar education in Worcester
- Identify stakeholders
- Evaluate possible locations
- Identify material resources
- Write a proposal to WPI

The following sections describe how we achieved our objectives.

3.1. Identifying the scope of solar education in Worcester

Our first objective was to research Worcester's position and status in regards to solar education. The research targeted previous, current, failed, and successful PV installations that were targeted to solar education. This research helped create the necessary foundation to justify our project.

We gathered information from stakeholders that were involved in the Worcester public school system. We used their information and recommendations to determine the role of a Solar Learning Lab™ in Worcester public education.

3.2. Identifying our Stakeholders

Our second objective was to gather information from parties that play a key role in proposing our solar demonstration, or those people who otherwise had interests in our project. These important people were considered to be our stakeholders. We started by creating a list of all the possible things needed or thought to be beneficial for our project's progress. This helped us decide who our stakeholders were. By using WPI's online organizational chart (of administration, faculty, and staff members), Worcester's government site of officials, and recommendations from Heliotronics, we created a list of stakeholders who could possibly give us this information.

In order to determine each stakeholder's opinion, we first researched the individual or organization for public statements, or other indications. If our search for those opinions and statements resulted in insufficient data, we resorted to an interview. In most cases, we also wanted to meet the stakeholders so that we could make a strong impression on them. Each interview that we conducted was planned out beforehand with a list of goals, created by using the "idea trigger" method. We included information that we wished to gather, questions that we had for them, and ideas that we wanted to present to them for their approval and further input for our project. After we created the list of goals we arranged them in an order that we felt was appropriate to present to them.

If we felt that an interview was necessary, we sent the stakeholder an email that contained the basic goals of our project and why we thought they could help us. If we did not receive a response within three to four days, we made a phone call to inquire further. Once an interview was scheduled, we sent an additional email with a synopsis of our project's goals, vision, and the benefits to WPI, Worcester, or the company/organization we were contacting. If they were not part of WPI, a section about the WPI plan and the Interdisciplinary Qualifying Project (IQP) were included.

To make sure that we documented every helpful piece of information that we heard, we tape recorded interviews. Going in pairs allowed one person to talk and the other to take detailed notes. We kept the list of goals we created in front of us and make sure to address every point, while maintaining a productive and efficient interview. We made sure to ask if they had comments of how we could better accomplish our objectives.

Shortly after interviewing, we created overviews of the interviews using our notes and the recording. We documented each topic of discussion, the key points or arguments that our stakeholder presented, and any deliverables that they wished to receive. We pointed out if there were any results of the interview that would prompt additional research or additional stakeholders. Using the interview documentation, we were able to analyze the meetings in a much more time efficient manner. This also will help future project groups to make sure that they avoid repeat questioning or confusion about our stakeholder's stances. We created a matrix to keep track of people we interviewed, the dates of our interviews, and summaries of the results. This was helpful in analyzing the results.

3.3. Evaluating possible locations

Our third objective was to identify locations on the WPI campus for the PV installation. To complete this objective, we initially created a list of criterion that proper locations should meet. However, during one key interview with representatives from the IT department and Plant Services, the locations were narrowed down dramatically for us.

We compared the remaining locations in a matrix to objectively select the one that seemed the most appropriate.

3.3.1. Location criteria

The following is a list of issues and factors that played a part in our selection process:

- **Safety**

  This criterion is met if the location is safe for people installing, maintaining, and visiting it.
- **Space availability**

  This criterion is met if the location provides sufficient space for the solar array and all necessary interconnected devices.
- **Accessibility**

  This criterion is met if the location provides easy access for people installing, maintaining, and visiting the panels.
- **Security**

  This criterion is met if WPI does not have any security restrictions on the building.
- **Connectivity**

  This criterion is met if the location provides easy power and data wiring for all power generation and data acquisition connections.

- **Sunlight Exposure**

  This criterion is met if the PV array, when installed, has clear exposure to the Sun. It needs to face south towards the sun to be able to capture the maximum amount of sunlight to generate energy as seen in Figure 3-1

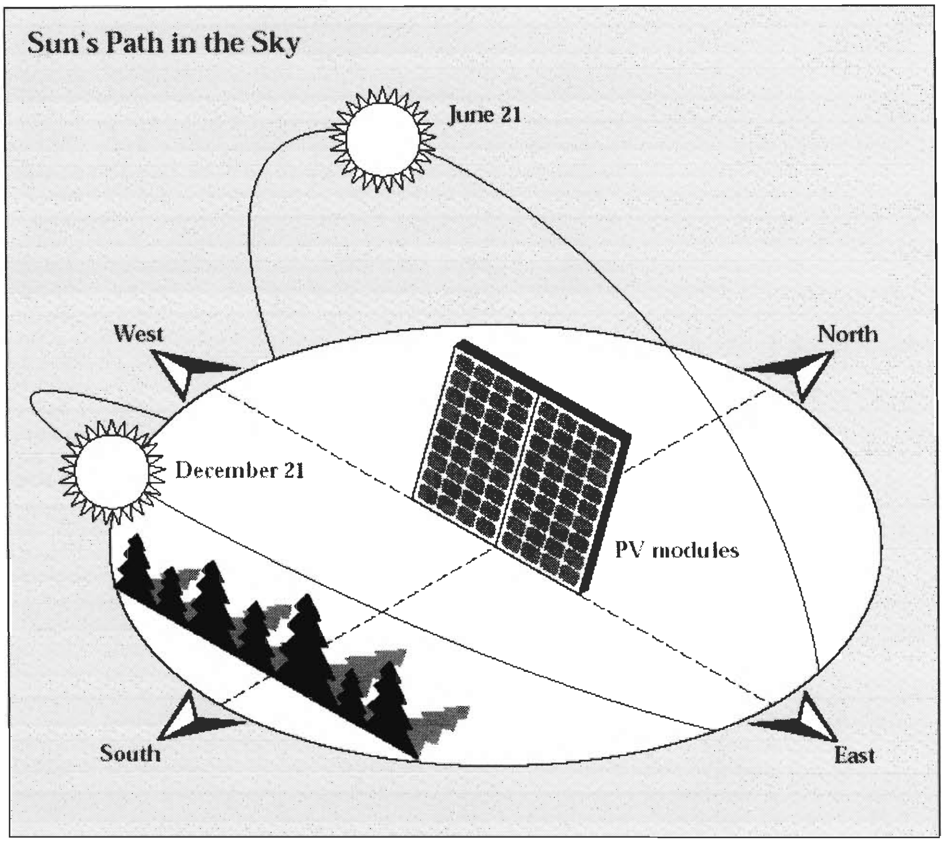


Figure 3-1: The sun's noontime height above the horizon changes seasonally. This is important to consider when sitting and positioning a PV array.[5]

The best way to analyze the location's clear view of the sun is to personally visit it. When visiting the locations, we observed any obstructions that could hinder the array's performance.

[5] Source: DOE/NREL, Photovoltaics: Basic Design Principles and Components http://www.eere.energy.gov/erec/factsheets/pvbasics.pdf

3.3.2. Grid tying considerations

After discussing with Plant Services the possibility of tying the proposed solar PV array to the grid, they requested that we make sure to follow guidelines set forth by Mass. Electric and National Grid. We contacted them just like any other of our stakeholders and through our communication, learned of the standards and procedures that had to be followed in order to tie the PV array to the grid.

3.4. Identifying material resources

The forth objective was to identify all of the material resources needed to install a Solar Learning Lab™. For this step we needed to obtain information from Heliotronics and other distributors of PV system components. We wanted the highest quality products at the most affordable prices. Heliotronics recommended that we conduct our business with a company known as Solar Works Inc. After contacting Solar Works Inc, they had us fill in a special site evaluation form located in Appendix E to reduce costs.

We began our process of identifying all components necessary for our PV system during the Solar Boston Tour, part of the National Solar Home Open House (October 4) where we were be able to see multiple working systems in private and public applications. We visited sites that had Heliotronics data acquisition systems in use.

We corresponded with Heliotronics and Solar Works Inc. through phone calls and email to give and receive important and detailed information of their products requirements of the location. We received estimates from Heliotronics and Solar Now Inc. and learned about the normal procedure of obtaining the materials.

The information that we collected was arranged in tables for analyzing prices. Arranging the information was important, not only for our project, but also for the benefit of our proposal, future projects, and for stakeholders to easily view.

3.5. Analyzing Feasibility

Our next objective was to analyze the feasibility of various aspects of installing and using the Solar Learning Lab™ at WPI. In order to do this, we reviewed our write-ups of the interviews that we conducted and weighed all of the relevant costs and benefits. The aspects of feasibility that we chose to analyze were:

- Feasibility of Installing a Solar Learning Lab at WPI
- Feasibility of incorporating a Solar Learning Lab into educational programs
- Feasibility of Sustaining a Solar Learning Lab at WPI

The feasibility of installing the Solar Learning Lab™ was determined primarily through interviews with personnel from the Departments of Plant Services and Information Technology at WPI. The feasibility of incorporating the Solar Learning Lab™ into educational programs was determined primarily from interviews with our educational stakeholders, while the feasibility of sustainability of the array was determined after all of our interviews were complete because sustainability depends on both educational use and physical maintenance.

3.6. Writing a Proposal to WPI

After completing the objectives listed above, we drafted a proposal for the next project team to revise and submit it to the proper stakeholder. Our process of gathering information via our stakeholders helped make it clear for us as to whom the proposal needed to go to. We determined using information gathered from our interviews that we should write one proposal for all of WPI that outlined the costs and benefits of the Solar Learning Lab™. In writing the proposal, we tried to tie up ownership issues for the Solar Learning Lab™ to ensure sustainability and longevity.

4. Results and Analysis

In this chapter we discuss the logistical considerations for a Solar Learning Lab™ on the WPI campus. We explain the costs and required services of such an installation and the resources that have come available to us since the start of this project. We also discuss the tangible benefits that a Solar Learning Lab™ will provide to our stakeholder groups. Finally, we discuss the feasibility of the installation and the educational outreach possibilities affiliated with a Solar Learning Lab.

4.1. Logistical Considerations for a Solar Learning Lab™

This section describes the components of a Solar Learning Lab™ and the costs of these components. We explain the process in which suitable locations for it were determined, the services required for installing it, and the suggested maintenance for the system.

4.1.1. Components of a Solar Learning Lab™

Since one of the main goals of our project was to conduct a feasibility analysis and write a proposal for installing a Solar Learning Lab™ at WPI, we felt that it was necessary to first understand the apparatus required. Through discussions with our sponsor and research on the Heliotronics website, we learned that a Solar Learning Lab™ consists of a grid connected solar PV array along with a data acquisition system. Heliotronics specializes in the data acquisition system components, while Solar Works Inc. specializes in the power generation components. Solar Works Inc. is a company based in Vermont, they distribute and install renewable energy systems. Our project sponsor, Heliotronics, often collaborates with Solar Works Inc. A diagram describing the relationships of the components of a typical Solar Learning Lab™ can be seen in **Figure 4-1**.

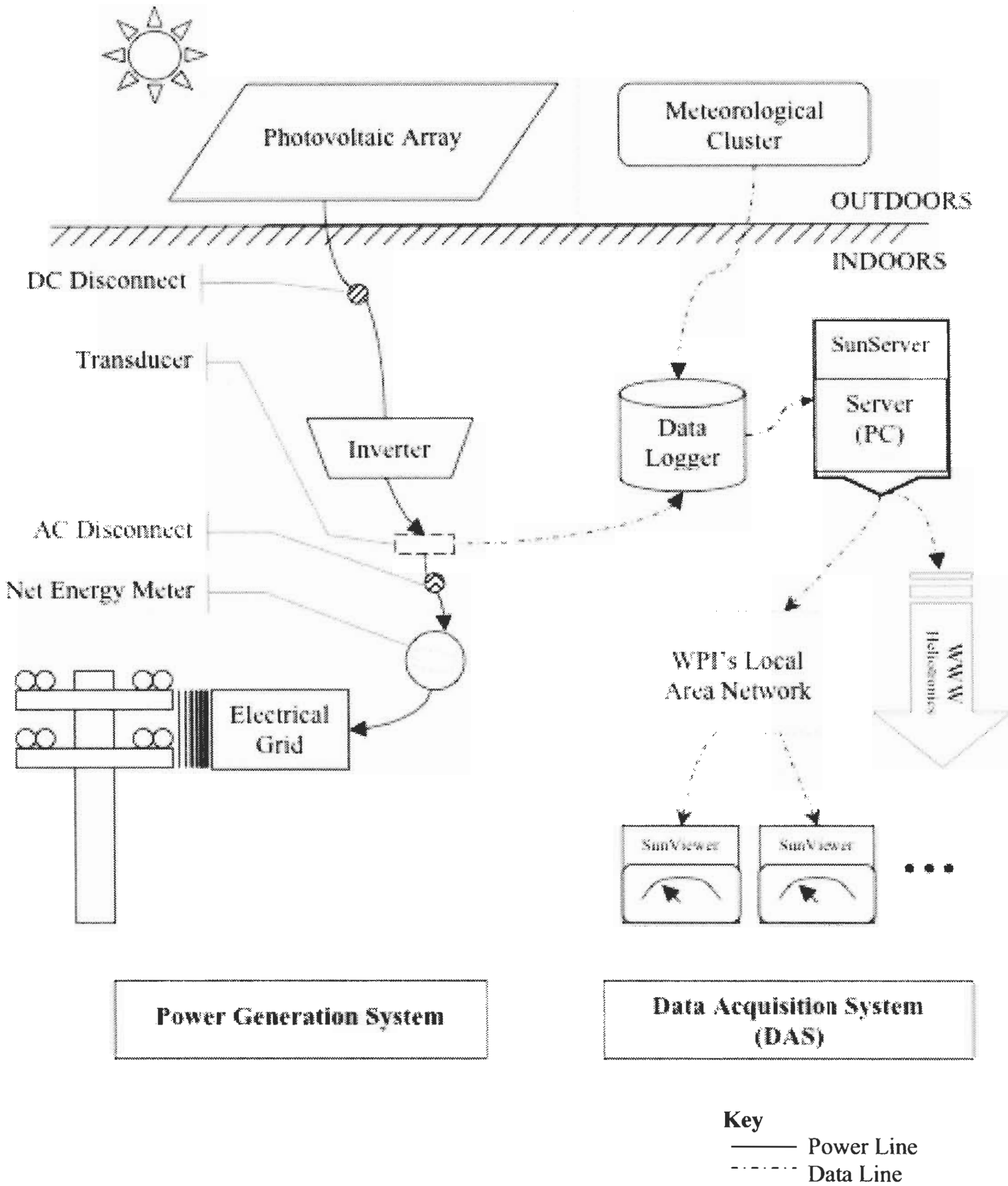


Figure 4-1: Solar Learning Lab™ Diagram

Everything to the left of the vertical line is associated with the power generation components of the system, while everything to the right is associated with the data acquisition components. Also, everything above the horizontal line is mounted outdoors, while everything below the horizontal line is mounted indoors. The solar PV array ties directly into an inverter, which then is tied into a quick disconnect device and a transducer to measure power output of the array. On the power generation line, there is a net energy meter, which reads out the energy produced in kilowatt hours by the solar PV system. The data from the transducer and the meteorological cluster is monitored by the Data Logger™, which in turn sends data to the PC running the SunServer™ software. The SunServer™ then serves out the data across a network to any other PCs running Heliotronics SunViewer™ software. In the future, there may be a World Wide Web interface along with data being sent directly to Heliotronics, so it is included in the diagram. Snapshots of the SunViewer™ software can be found in Appendix O.

4.1.2. Location for the Solar Learning Lab™

This section will present the logistical aspects and results regarding possible locations on the WPI campus. We learned of the suitable locations primarily in an interview with WPI's Vice President of IT Thomas Lynch, Vice President of Student Affairs Bernard Brown, Manager of Network Operations Sean O'Connor, and Director of Technical Trades Chris Salter. After we discussed the materials involved with the Solar Learning Lab, these stakeholders discussed decisive factors for selecting a location. In the meeting we were able to narrow down all the factors to major issues of (1) safety, (2) space availability, (3) accessibility, (4) security, (5) connectivity, and (6) sunlight exposure. The following is a description of each of the issues discussed:

1. **Safety**

   This criterion is met if the location is safe for people installing, maintaining, and visiting it.

2. **Space availability**

   This criterion is met if the location provides sufficient space for the solar array and all necessary interconnected devices.

3. **Accessibility**

   This criterion is met if the location provides easy access for people installing, maintaining, and visiting the panels.

4. **Security**

This criterion is met if WPI does not have any security restrictions on the building.

5. **Connectivity**

   This criterion is met if the location provides easy power and data wiring for all power generation and data acquisition connections.

6. **Sunlight Exposure**

   This criterion is met if the PV array, when installed, has clear exposure to the Sun. It needs to face south towards the sun to be able to capture the maximum amount of sunlight to generate energy as seen in Figure 3-1

After listing the above issues, we then started to list all possible locations on campus to analyze. Table 4-1 lists the analyzed locations with their results.

Major Issues / Location	Safety	Spaciousness	Accessibility	Security	Connectivity	Sunlight Exposure
Higgins Lab	✓				✓	✓
Goddard Hall			✓	✓		✓
Fuller Building	✓	✓			✓	✓
Stratton Hall		✓		✓		✓
Campus Center	✓	✓			✓	✓
Daniels Residence Hall	✓	✓	✓	✓	✓	✓
Morgan Residence Hall	✓	✓	✓	✓	✓	✓

Table 4-1: Location Results.
A ✓ indicates that the location meets the given criterion

The above results indicate that Daniels Residence Hall and Morgan Residence Hall do not have any of the issues that prevent them from being feasible locations. We were able to narrow down the location to Morgan. Morgan was selected over Daniels mainly due to the already ongoing projects on that building and the available conduits for connectivity purposes.

4.1.3. Costs of the Solar Learning Lab™

The equipment costs of our proposed Solar Learning Lab™ will be a combined amount from Solar Works Inc. and Heliotronics. Solar Works Inc.'s project estimate consisted of 11 EC-110 Photovoltaic Modules manufactured by Evergreen Solar, one SunnyBoy 1800 DC → AC inverter manufactured by SMA, a Unirac Tilt Leg mounting system, project management, balancing, and commissioning costs. Their total project estimate for these materials and services without factoring in installation came to a total of $12,274.

Included in their estimate was a MTC installation credit consisting of $3,811. These credits are not guaranteed, but Bob Fabian of Solar Works Inc. claimed that he was fairly certain that they will be available in 2004. This means that the total contract price after the MTC installation credit would be $8,830. The actual project estimate and details about the materials from Solar Work Inc. can be found in Appendix K.

Heliotronics quoted us for their Feynman DAS, a SunViewer™ Software site license, one 8 hour day of on-site installation support, one year of SunViewer.net™ web access (annual fee) and factored in a discount for the marketing value of future student projects (outreach to the city of Worcester and the Worcester Public School system). The total of these materials and services after the discount came to a total of $4,697. The specific detail of this quote and the material provided can be found in Appendix J. This makes the estimated combined price of our system $13,527. A summary of the costs is shown in Table 4-2.

Heliotronics	Data Acquisition System (DAS)	$4,697
Solar Works Inc.	Power Generation System: 1kW PV Array & Inverter	$12,274
Total costs of combined systems		**$16,971**
Class of 1975 donation		– $10,000
Estimated MTC installation credit		– $3,811
Initial costs / funding required		**$3,160**

Table 4-2: Cost estimate of the power generation and DAS components

These estimates do not include basic assembly, mounting, and connecting of our materials. We plan to do the majority of the installation ourselves, with some additional help from licensed electricians and skilled networking personnel. Economics and additional services are discussed in the following sections.

4.1.4. Required services for installing the Solar Learning Lab™

The installation process of the discussed materials in Section 4.1.1 will be proposed to be completed in the spring of 2004. It is estimated by Bob Fabian, the project manager of Solar Works Inc. to take three workers approximately two days to complete.

This project would require a licensed electrician, an experienced roofer, and workers who can follow assembly instructions. Normally, Solar Works Inc completes the installations, and includes it in their total project cost. However, in order to keep the total project costs as low as possible, Solar Works has agreed to let us (the students involved in this project) to do the majority of the installation. This means that we would need to provide our own electrician and roofer.

An additional task that we decided to take on ourselves, from the recommendations of Bob Fabian to alleviate additional costs, was filling out Solar Works' "Site Evaluation Form." This task would normally incur an additional fee from Solar Works. By filling it out ourselves we were able to save additional costs of our project. A copy of the Solar Works evaluation form can be found in Appendix E. Some of the major requirements of this form include:

- Creating a detailed draft and taking pictures of the possible locations

- Filling out information regarding connectivity to the electrical system
- Choosing a type of mounting system

With the cooperation of WPI's Plant Services department we were able to get roof access and take detailed measurements and pictures for the evaluation form of a suitable location. We were able to fill out the necessary information dealing with the existing electrical system by making observations and having discussions with people from Plant Services.

Next, we had to look at the various choices of mounting systems for the solar panels. For our installation, we considered two options: a ballast tray mount system and a beam mount system. The ballast tray mount system consists of mounting brackets attached to a large tray in which stones or bricks can be placed to hold the array in place. The beam mount system consists of two beams and a racking system that requires roof penetrations.

Solar Works expressed concern about the roof penetrations necessary for the beam mount system. Based on previous installations they recommended that we check to see if the Morgan Residence Hall roof is warranted by the manufacturer. They suggest that if a warranty does exist that we hire a technician that is certified by the manufacturer to maintain any warranties. We learned from Plant Services that the roof has no specific warranties, making the installation of a beam mount system much more feasible.

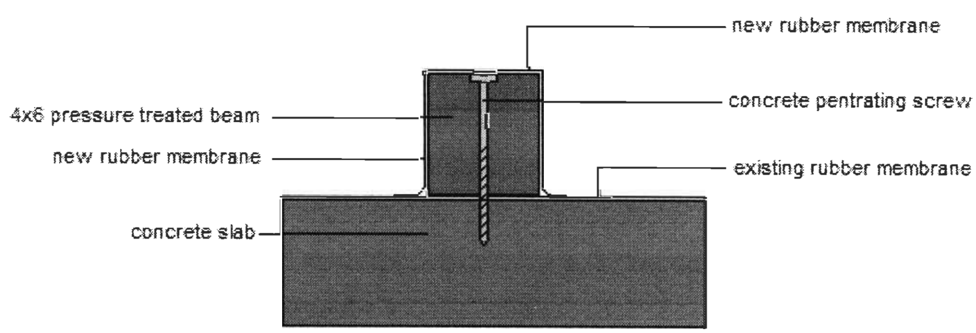


Figure 4-2: Beam mount diagram

The installation process and requirements of the beam mount system are stated below:

- **Materials**
    - Two parallel 25ft lengths of 6x4 pressure treated beams (could be supplied by Solar Works)
    - Lag bolts designed for cement penetration
- **Installation Procedures**
    - Scrape away existing stones on the roof until rubber membrane is exposed
    - Drill a hole through the beam and concrete slab
    - Insert lag bolt through beam and penetrate into concrete slab
    - Reinstall rubber membrane over the newly placed beams
    - Bolt the feet and arms of the racking system to the beams

We learned that the ballast tray system is easier to install but considerably more expensive. The beam mounting system requires more time from the installers, but is much more affordable and more of a permanent installation. Based on our discussions with Bob Fabian, Matthew Arner, and Chris Salter, an installation very similar to the beam mount system would be used. We learned that Plant Services will ultimately have authority over this part of the system installation. The remaining procedures involved in the installation of this project would be explained in detailed assembly instructions.

In an interview with John E. Miller, we were asked to confirm that everything that we were proposing would be approved by National Grid. This was his main concern. After contacting Massachusetts Electric (part of National Grid) to question the possibility for feeding back the generated power (from our proposed 1kW solar array) back to the electrical grid, we learned that for Mass Electric to permit the power feed back, they would need information as to the specific system components that are going to be used. Mr. John J. Bzura, a representative from Mass Electric provided us with a "Notice of Intent to Interconnect for NGUSA Retail Companies" form (this can be found in Appendix G to fill out, sign and mail it back to him at Mass Electric. This form will have to be filled out prior to the installation.

4.1.5. Required maintenance for the Solar Learning Lab

The power generation components of the Solar Learning Lab™ require minimal maintenance; a semi-annual visual inspection is suggested to check for any damage to the glass, the frame, and the electrical connections (specifically for loose connections and corrosion.) According to Evergreen Solar, "PV modules can operate effectively without ever being washed, although the removal of dirt from the front glass can increase output. The glass can be washed with a wet sponge or cloth, while wearing rubber gloves for electrical insulation."[6]

Matt Arner suggests that the output of the panels is recorded: once in the summer and once in the winter (e.g. July 15 and December 15 or a date close to these with optimal sunlight exposure) to compare the power being generated. Analyzing the data collected after the system has been working for even a few years can ensure that the panels are still producing a similar amount of electricity. The DAS needs no regular maintenance to operate properly; however, visual inspections of all of the data connections semi-annually are recommended. Repairs to the data acquisition system should be conducted as necessary.

4.2. Contributions offered by Stakeholders

This section describes the contributions that our stakeholders offered to our group. Every stakeholder offered a contribution on a fundamental level because they agreed to meet with us and discuss our project. In every case, our stakeholders have agreed to answer any further questions that any future groups working under our vision may have. In the following sections we discuss funding contributions, material contributions, and services offered by our stakeholders.

4.2.1. Funding Contributions

In May 2003, one of our advisors, Prof. Vaz, with the help of Matt Arner presented a proposal to the WPI class of 1975 and they were granted $10,000 for the project. This was the first big step towards making our project feasible. That gave us something to start with and to add to our proposal to WPI

[6] http://www.evergreensolar.com/egsolar1/pdf/Manual_ECv2.5.pdf

Solar Works Inc. also has a contract that could possibly help us with additional funding. The Massachusetts Technology Collaborative (MTC) is currently funding approximately $5.00 per kilowatt for installations that Solar Works Inc. is involved with. We are hoping that their contract will be reissued in 2004 without any changes so that we can help keep the project cost-free to WPI.

4.2.2. Material Contributions

We have received many material contributions from our stakeholders that played a major role in moving the project forward. Some of the contributions were already made and some were offered to us for when the Solar Learning Lab™ is going to be installed. Solar Now Inc. and the IT department at WPI offered contributions that will assist the project's installation of the Solar Learning Lab™ and its future academic programs.

Dr. Coleman from Solar Now Inc. donated materials to the project that consisted of eight solar panels (see receipt of donation in Appendix F). In order to test if the panels were operational, we set the panels in direct sunlight and read the open circuit voltage by using a multi-meter. We did not measure the corresponding short circuit currents to verify their functionality. The results from analyzing the panels are as follows:

- Panels are worn
- Only four of the eight panels are functional
- Protective weather coating is torn on some of the panels

These panels are not going to be used as part of the Solar Learning Lab™ permanent installation due to their age and capabilities. Instead, they will be used in future programs and projects for academic and outreach purposes. The functional panels will be used in future programs and projects for academic and outreach purposes specifically, while the non-functional panels can be used for display purposes.

In addition to the panels contributed by Solar Now Inc., the IT department at WPI offered to contribute materials during the installation process. During an interview with the Vice President of Information Technology Thomas Lynch and the Manager of Network Operations Sean O'Connor we discussed different possible contributions they can make to the project to better enhance the Solar Learning Lab™ experience. One idea that they expressed was displaying still images of the array and current energy production rates on a plasma screen. Sean O'Connor has offered to look for a PC to be used as a server to run the SunServer™ software. The computer requirements are as follows:

- At least 3 gigabytes of storage space
- Pentium 3, Pentium 4, Celeron or Athlon processor
- 32 MB of RAM
- A 10Mbps Ethernet/Network card
- Windows 2000 or later operating system

Sean. O'Connor offered to provide and setup the necessary networking components to connect the server to WPI's local area network. He also offered to look for available monitors and displays that can be used for the Solar Learning Lab™. Thomas Lynch presented different ideas and suggestions as to the type of displays we could use for the kiosk. The ideas presented were as follows:

1. Flat monitor
2. Touch screen flat monitor
3. Large plasma
4. Both options 2 and 3

Option 4 presents the possibility of having a touch screen display to interact directly with the SunViewer™ software, while a large plasma screen will display informational slide shows about the Solar Panels, its components, and the SunViewer™ software.

4.2.3. Services offered

Throughout the course of our project, we tried to solicit help and support from our stakeholders. Significant contributions came from the approval, installation, and maintenance as well as the academic stakeholder groups. In the academic stakeholder group, the director of K-12 outreach, Martha Cyr, has spread word of our project to educators in the Worcester Public Schools and informed outreach program coordinators about our project. She has offered to continue to make connections for us, and in doing so, has provided an invaluable service to this project, and others that may follow. The IT department agreed to offer the following services to this project:

- Help with installation
- Display in a high visibility area
- Maintain the DAS server and display

The manager of Network Operations, Sean O'Connor, has offered to help in the installation of the data acquisition system and server by running necessary data lines from the roof to the DAS. In addition the IT department has offered to run slides of the SunViewer™ software on a 32 inch plasma screen that now resides in the wedge (common area in front of Morgan dining hall between the Morgan and Daniels residence halls) for the public to see. This area has a high level of traffic move through it each week, and is visited by tour groups, so it serves as a good initial display if a kiosk cannot be obtained. Finally, the IT department offered to maintain the server and any potential kiosk after installation as necessary. The Department of Plant Services has agreed to provide the following services to our project:

- Provide accessibility to the roof
  The Director of Technical Trades Chris Salter offered to let us on the roof of the Morgan Residence Hall to do some analysis and measurements necessary for the installation.
- Help with installation of the array
  The department of Plant Services has offered to donate labor to our project for the purposes of installing the array. This includes drilling and sealing holes made in the roof for mounting purposes.
- Provide an electrician for connection to the utility grid
- Provide a roofer for the beam mount system

As we discussed previously, Solar Works Inc. has made a special exception for the purposes of our project in their quoting and evaluation phase of making a sale. They usually send a representative for some fee to the proposed site to evaluate it. Solar Works helped save us money by letting our group evaluate the site (the roof of Morgan) ourselves. Usually they have to send out their own technicians and workers to install the array, but once again, they have offered to let us do all of the labor, saving us hundreds of dollars.

Heliotronics has provided and offered many services to us. As our project sponsor, they have been the primary source of answers to questions regarding the solar industry and specific project questions. They put us in contact with Solar Works Inc. who can potentially cut our costs by $4000 – $5000 through grants from the MTC. Heliotronics has also offered to help with the installation when it occurs, and they have offered to help future groups as they continue work on this project.

4.3. Tangible Benefits to stakeholder groups

An important part of our project was determining the potential value of a Solar Learning Lab™ to all of our stakeholder groups on and off campus. This section describes the corresponding findings, with regards to marketing/publicity benefits, academic benefits, and financial benefits.

4.3.1. Marketing / Publicity Benefits

George Sinclair Flett, Director of University Marketing at WPI, met with us to discuss the possibility of using the Solar Learning Lab™ as a marketing tool. He is very interested in the project and sees many benefits that such an installation can provide to his department and to WPI. Kevin J. Wynn, Assistant Director of Media Relations, who was also in this meeting, sees possible uses dealing with educational outreach, specifically getting involved when students bring demonstrations and activities to Worcester elementary school students. At that point he would get newspapers outside of the Worcester area (such as the Boston Globe) involved to further promote WPI's academics, community involvement, educational outreach, and overall image of a WPI student. Among the possible uses and benefits, they mentioned that a Solar Learning Lab™ could:

- Help fulfill WPI's image of "The University of Science, Technology. And Life."
- Add an additional "mark" during campus tours to benefit enrolment

- Help present WPI's concern about the environment
- Use science and technology to teach students, faculty, staff, parents and visitors about the environment, energy usage, and photovoltaic technology
- Help the engineering pipeline by getting younger students involved in additional engineering activities and experiments

Finally, Heliotronics would gain publicity through all of the contacts that we make throughout the projects by the constant display of their SunViewer™ software on campus, and any articles that possibly make it in to newspapers.

4.3.2. Academic Benefits

The main purpose of the Solar Learning Lab, as stated on Heliotronics website www.heliotronics.com, is to help catalyze the environmental educational experience. Because of this fact and our vision, we thought that it was important to learn the value of a Solar Learning Lab™ to educators in the Worcester area. We learned of many educational programs that could benefit from a Solar Learning Lab, so we divided them up into the following categories to make analysis easier:

- WPI curriculum related
- WPI outreach programs
- Worcester K-12 schools
- Worcester K-12 educator enrichment programs

We learned through an interview with the Provost of Academic Affairs that our project could possibly benefit WPI. However, we did not learn much about how a Solar Learning Lab™ at WPI can benefit the existing courses. This would have required talking to department heads, which we chose not to do in the interest of the timely completion of our project.

We learned, in one key interview, that activities focused on a Solar Learning Lab™ could supplement existing outreach programs at WPI and would add value to them. The director of K-12 outreach, Martha Cyr, stated in an interview that our project could be beneficial to her department in many ways. Some of the possible ways in which projects utilizing a Solar Learning Lab™ could enhance outreach programs are listed below.

- Providing students with "hands on" experience with renewable energy
- Introducing students to geometric principles (learning how the angle of the array affects the power output)
- Introducing students to statistical analysis (extrapolation, averaging, interpreting the results)
- Making students aware of the relationship between the environment and energy
- Expanding environmental education into the student's homes

It was made clear in the interview with Martha Cyr that there are many more possible benefits, depending on the projects that are designed. This area of benefits is vast, and could not be covered completely in one interview. It may be left to future projects to determine the full potential of the Solar Learning Lab™ for outreach programs at WPI.

The potential benefits of a Solar Learning Lab™ to the Worcester Public School System were discussed throughout our interviews with stakeholders from the academic interest group. From what we learned, a Solar Learning Lab™ would provide some value to the school system. In an interview with the Science Curriculum Liaison to Worcester Public Schools, Joseph Buckley, he mentioned that he saw this holding the most value to middle school aged students, approximately grades 5 – 9. He stated that he believes that children usually learn of what they want to do for a career during that time, so they would be the best audience for projects oriented around the Solar Learning Lab. He also stated that inner city students, like most of those attending Worcester's public schools, need to do activities in which they can draw conclusions from abstract or raw data. He stated that activities designed around the Solar Learning Lab™ could provide this for Worcester's students. In all, a Solar Learning Lab™ at WPI could potentially have great value to Worcester Public Schools.

The idea that the Solar Learning Lab™ could be used for teacher workshops was introduced to us by one of our stakeholders in the course of the project. Public school teachers in the state of Massachusetts must accrue a certain number of hours in educator enrichment programs every four years in order to stay certified. Hours spent in the specially designed workshops are known as Professional Development Points. It was suggested to us by one stakeholder from Doherty High School, and later discussed with Martha Cyr, that the Solar Learning Lab™ could be used in designing some PDP programs. This potential wasn't investigated thoroughly, but we were able to determine that it could have great value to educators in Massachusetts and to our vision because it helps them meet requirements for their jobs, and helps us spread solar education to a broad area.

4.3.3. Financial Benefits

An economic analysis of the proposed solar array is an important aspect of feasibility and it is also important to building an argument either for support or funding. The economic analysis that we performed focused on how much WPI would save annually on its electricity bills credits received by installing a 1kW PV array. Annual revenue was defined as the product of the expected energy generated from the array, *E*, and the rate that WPI pays for energy, *R*. Funding spent on the array annually was estimated by multiplying an estimate of the hours spent annually on maintenance, T_l, by the estimated wage of a typical maintenance worker, *W*. The formula used was:

$$\textbf{\textit{Annual Revenue}} = (E \cdot R) - (T_l \cdot W) \qquad \textbf{Equation 4-1}$$

Some other costs may factor in if components of the system fail, but our analysis did not account for those potential costs. An estimate of the energy generated by the array annually was obtained by using a tool provided by NREL called PVWatts[7]. The rate that WPI pays for electricity and the labor rate were both obtained from the Vice President of Plant Services, John E. Miller. The annual amount of labor to maintain the array was estimated from the maintenance procedures discussed in Section 4.1.5. Table 4-3 shows the results of our economic calculations.

[7] More information about PVWatts and the assumptions involved can be viewed at http://rredc.nrel.gov/solar/calculators/PVWATTS/. Version 1 was used for the estimate.

Variable Names	Values
Electricity Rate♦	0.088
Annual Energy (kWh)	1,541.00
Energy Variance (percentage)	10.00%
Labor Rate	25.00
Annual Hours of Maintenance	2.00
Estimated Inflation Rate[8]	2.50%
Estimated Interest Rate[9]	6.79%
Estimated Read Interest Rate[10]	4.29%
Years	10
MTC Credit (dollars/kWh)	0.38
MTC Production Credit Cap♦	1,633

Calculated Values	
Annual Electricity Savings♦	85.608
Net Electricity Savings+	$1,041.75
Net MTC Credit+	$2,191.21
Total Expected Earnings	**$3,232.96**

Payback+	
Minimum Payback	$3,337.14
Maximum Payback	$3,128.79

Table 4-3: Projected Income for WPI (♦Current US dollars, +Future US dollars)

A baseline estimate for expected annual revenue was calculated to be $85.61. The PV Watts tool explains that the energy estimates that it produces can vary 10% annually, so this was used to calculate a low estimate and a high estimate for payback. Finally, inflation was taken into account by using Equation 4-2 with "years" being used as N, annual electricity savings being used as "investment," the inflation rate and interest rates being used for the similarly named variables:

$$\sum_{t=0}^{N-1} \mathit{investment} \cdot (1 + (\text{interest} - \text{inflation}))^{t}$$

Equation 4-2: Future value of a periodic investment

[8] This is the inflation rate based on past 5-year average.
[9] This is the interest rate based on past 5-year average of Moody's Seasoned Aaa Corporate Bond yield.
[10] This is the estimated interest rate – estimated inflation rate.

The inflation rate used was a trailing 5-year average while the interest rate was taken to be the trailing 5-year average of Moody's Seasoned Aaa Corporate Bond yield.

4.3.4. Environmental Benefits

One of the many benefits of using the Solar Learning Lab™ is its affect on the environment. Since burning fossil fuel produce major climate-change contributors such as sulfur dioxide (SO_2), nitrogen oxides (NO_X), and carbon dioxide (CO_2); reducing them by building the Solar Learning Lab™ will help improve the environment. To better quantify and evaluate the displaced emissions from our clean energy PV system, we need to calculate the Average Displaced Emission Rate (ADER) using Equation 4-3.

$$ADER = \frac{Displaced\ Emissions\ (lbs)}{Displayed\ Generation\ (MWh)}$$

Equation 4-3

Using the method[11] for applying ADER parameters to displaced generation and assuming that our solar array generates approximately 1KWh, the amount of CO_2 prevented from being displaced is approximately 1,221lbs annually. This may seem a small amount, however in the long run when about 1MWh of energy has been produced more than 600lbs of CO_2 is prevented from being displaced into the environment.

4.4. Feasibility Analysis

This section discusses the results of our analysis in terms, feasibility of the installation, feasibility of the Solar Learning Lab™ being used for educational purposes on and off campus, and the sustainability of a Solar Learning Lab™ at WPI.

4.4.1. Feasibility of Installing a Solar Learning Lab™ at WPI

The first step to our feasibility analysis deals with analyzing the physical installation of a Solar Learning Lab™ at WPI. We broke down the analysis into the following main topics:

[11] More information about EPA's Average Displacement Rate (ADER) approach and methodology can be viewed at http://www.epa.gov/ttnchie1/conference/ei11/poster/morgan.pdf. Northeast figures were used.

- Approval
- Installation
- Funding

We found that Plant Services is the entity at WPI who has the authority to approve or disapprove our installation. Therefore, the first step in determining the feasibility of the approval for the installation was to contact Plant Services. We found that representatives from Plant Services only needed the following three requirements met in order to approve the installation:

- The installation adheres to Mass Electric standards
- Roof penetrations must be performed by Plant Services staff
- A detailed list of materials and corresponding technical specifications must be submitted to Plant Services

The materials being supplied by Solar Works adhere to Mass Electric standards; however, Mass Electric needs documentation of what we connect to the grid. So, in order to properly adhere to Mass Electric standards, the grid connection worksheet in Appendix G must to be filled out prior to connecting the array to the grid.

In order to meet Plant Services' second requirement, we asked Solar Works to leave out all costs and materials related to roof mounting. We expressed to them that Plant Services would be performing much of the installation, so Solar Works was able to adjust its quote and list of materials for our installation.

In order to meet Plant Services third requirement, the lists of materials provided by Solar Works and Heliotronics must to be submitted to them. There are also other conditions that need to be met in order for it to happen successfully. They include:

- Detailed plan for the installation
- Sufficient funding

The conditions discussed above still need to be completed by future project groups.

The next step of the feasibility analysis is determining the financial aspects of the proposal. Knowing that the total costs of our materials will be approximately $13,527 and that we already have $10,000, there is an additional amount of funding required to make this project feasible from a financial perspective. By doing the installation ourselves and by hopefully receiving funds from the MTC, we are keeping our costs as low as possible. However, even in the best case, $3,527 of additional funding is required upfront for the installation to be feasible.

4.4.2. Feasibility of Incorporating a Solar Learning Lab™ into Educational Programs

Through the course of our project, we investigated the feasibility of the Solar Learning Lab™ being incorporated into educational programs, both on campus and off campus. This topic is extensive the educational programs that exist in Worcester are numerous. As discussed earlier we were able to categorize the programs and potential educational uses that we found in the following way, with separate feasibility criteria for each.

- WPI curriculum related
- WPI outreach programs
- Worcester K-12 schools
- Worcester K-12 educator enrichment programs

We discussed the possibility of the Solar Learning Lab™ being used in WPI's curriculum with Professor William Durgin, Associate Provost Vice President of Research. Though these discussions were brief, we learned that department heads of the academic departments within WPI may be the appropriate people to contact first. We did not pursue this option any further, as it was outside the scope of our project.

Through our discussions with the director of K-12 outreach at WPI, Martha Cyr, we learned that a Solar Learning Lab™ could have great potential for K-12 outreach programs. These programs deal with public schools, private schools, and also summer camps at WPI. However, in order for it to be feasibly used in outreach programs, a planned activity, such as an experiment utilizing the Solar Learning Lab™ must be developed first. Such an activity should fit within guidelines set forth by the Massachusetts Department of Education. If one were to develop an activity for a K-12 outreach program that utilizes the Solar Learning Lab, Mrs. Cyr should be the primary contact. More information and ideas about activities involving K-12 students can be found in Appendix D.

We discussed the potential uses of a Solar Learning Lab™ with many representatives from Worcester Public Schools [WPS]. We learned that there is great potential and there are many options to be pursued within the school system, ranging from field trips destined for WPI to statistical analysis of the data gathered at the Solar Learning Lab. In our project, we only briefly discussed the possibilities with representatives from the Worcester Public Schools. As a result, there should be further communication with WPS to fully explore the possibility of incorporating the Solar Learning Lab™ into its curriculum. We found that the best contact for further discussion would be Joseph Buckley, whose contact information can be found in Appendix I.

We also discussed the possibility of running educator workshops at WPI for Massachusetts's public teachers with representatives from WPS. We only discussed the possibility of this occurring, so the conditions necessary for feasibility aren't known yet. The best contact for this broad application is also the science curriculum liaison to WPS, Joseph Buckley.

4.4.3. Feasibility of Sustaining a Solar Learning Lab™ at WPI

We define sustainability of the Solar Learning Lab™ to be the degree to which the hardware and software of the Solar Learning Lab™ are maintained and the degree at which it is utilized. In order for this to be realistic, an established entity on campus must accept ownership of the Solar Learning Lab™ to ensure its sustainability. For the purposes of analysis, we divided the system into two subsystems: the power generation system and data acquisition system. The power generation subsystem includes the solar array, frame, inverter, and all the necessary electronic and the data acquisition system includes the data logger, data wiring, server, display, and the Epiphany™ series software. We believe that both subsystems lend themselves to different ownership, because one is intrinsically tied to the physical plant, and the other requires information technology to work properly.

Power Generation

The power generation subsystem is best to be maintained and owned by the Plant Services department. We will be proposing that Plant Services takes responsibility for ownership and maintenance of the Solar Learning Lab™ It is best to contact Chris Salter, Director of Technical Trades within Plant Services to further pursue this. Refer to Appendix I for contact information.

Data Acquisition

The data acquisition subsystem is best to be maintained and owned by the IT department. They will be handling all the hardware and software related to run, store and transmit the data over the WPI network. Similarly, this issue should be further pursued with the IT department. Sean M. O'Connor, the Manager of Network Operations within the IT department should be contacted to pursue ownership issues for the data acquisition system. His contact information can be found in Appendix I.

5. Conclusions and Recommendations

In this chapter, we make recommendations for future projects based on the conclusions from our own project. These recommendations are sorted into major categories, and represent what we believe to be helpful to the realization of our vision.

Location

- **We recommend that the Solar PV array be installed on the North Side of the Morgan Residence Hall roof at WPI.**

  Plant Services recommended that we install it on the roof of Morgan Residence Hall. From the two possible locations on that roof, we further narrowed it down to the Northern most location because of its convenient accessibility and high visibility.

- **We recommend that the next project group find a way to acknowledge our sponsors, Solar Now Inc, Heliotronics, and the WPI class of 1975 on or around the main kiosk display.**

  Be reminded that Solar Now Inc. specifically requested to be acknowledged somewhere on the final demonstration.

- **We recommend that the next project group contact the Information Technology (IT) department about obtaining a PC to run the SunServer™ software.**

  The costs of a PC for the SunServer™ software were not included in our economic analysis. This was because we assumed that obtaining an older PC from WPI would not be difficult. The Information Technology department is the entity at WPI that would be most likely to be able to provide such a donation. This donation has been discussed with the Manager of Network Operations, Sean O'Connor, but was never confirmed.

Education

- **We recommend that the next project group create one or more activities utilizing the Solar Learning Lab™ for a target audience of grades 6-8.**

  We suggest this because our educational stakeholders claimed that this would be the best way to incorporate the Solar Learning Lab™ into educational activities in Worcester. They also suggested that a middle school audience would be the most appropriate for these activities. We further recommend that the next project group work directly with the WPI director of K-12 outreach, Martha Cyr, and the Science Curriculum Liaison to the Worcester Public School System, Joseph Buckley while developing such activities.

- **We recommend that the next project group investigate the possibility of installing Solar Learning Labs at different WPI project centers across the globe.**

  Our stakeholders in the University Development and Relations Department presented this idea to us. It could further benefit our sponsor, Heliotronics, by helping them realize their corporate goals. This could also provide an interesting network of data that can be shared and analyzed globally. Furthermore, this brings our vision closer to reality.

- **We recommend that the next project group develop a mobile demonstration for the solar modules donated by Solar Now Inc. for outreach and educational purposes.**

  This was a direct recommendation from Joseph Buckley, the Science Curriculum Liaison to the Worcester Public School System. He suggested that this mobile demonstration could be useful for schools, which either cannot afford a field trip to WPI or cannot afford purchasing SunViewer.net™ licenses. We created drafts of the bracket style frame, which holds multiple panels. Machinists in the Washburn shops have offered to donate their services to machine the frame.

- **We recommend that the next project group speak with department heads at WPI to learn if the Solar Learning Lab™ has potential in any of the offered courses.**

  This was a direct recommendation from Professor William Durgin, Provost/Associate Vice President of Academic Affairs at WPI. We did not have enough time to pursue this task in our project.

- **We recommend that if a Solar Learning Lab™ is installed on the WPI campus that Professors Vaz and/or King generate interest amongst other faculty in it.**

  We have found that this may help ensure that the Solar Learning Lab™ will be sustained for years to come.

Economic

- **We recommend that the next project group continue pursuing funds with groups on campus that have not yet been contacted.**

  Our research indicated that the following student groups could be interested in supporting our project:

  - Student Government Association (SGA)
  - The Power of One
  - Global Awareness of Environmental Affairs (GAEA)

- **We recommend that Heliotronics help research alternative ways in which to make the project more economically feasible.**

  We have found that Heliotronics is in the best position to pursue more competitive quotes from different distributors.

Marketing

- **We recommend that the next project group organize a "ribbon cutting" ceremony for the Solar Learning Lab™ when it is installed and ready to operate.**
  We found through our project that this may beneficial in terms of marketing and raising awareness. It also would provide ample opportunity to acknowledge our sponsors and build a relationship with environmental groups on campus such as GAEA, Power of One, and any other groups that wish to involve themselves in environmental issues.

- **We recommend that the next project group contact the Department of University Development and Relations at WPI if their project reaches a point where students in Worcester Public Schools are utilizing the Solar Learning Lab at WPI.**
  This was a direct recommendation from our stakeholders in the University Development and Relations Department. They claimed that they would be interested in the project when it reaches a point where WPI students are bringing sustainable energy education to Worcester Public Schools.

Miscellaneous

- **We recommend that the next project group review our interview notes prior to contacting stakeholders.**
  We recommend this on the basis that most of our stakeholders are very busy. This will also aid our rapport by avoiding repeated questions.

- **We recommend that the next project group keep Solar Now Inc. up to date with the progress of their project and to consult with them for help with educational activities.**
  Solar Now Inc. donated several solar modules to our project and they requested to be updated with progress of the project as significant events occur. We also discovered that they are experienced in sustainable energy educational activities and thus may be a valuable resource when developing activities for the Solar Learning Lab™.

- **We recommend that the next project group contact and meet with the President of WPI, Edward Alton Parrish, explaining the purpose of our project.**
  Our group did not have the chance to interview with the president of WPI. He may be an important stakeholder to our project as he oversees all activities related to WPI.

- **We recommend that Professors Vaz and/or King continue to spread the word of this project to stakeholders at WPI.**
  We found that throughout our project, stakeholders whom Prof. Vaz had spoken to previously received us with more positive attitudes than those whom he did not speak to.

- **We recommend that the next project group contact Plant Services and Information Technology departments at WPI to pursue co-ownership of the Solar Learning Lab's™ power generation and data acquisition systems.**
  We learned that Plant Services would prefer having a co-owner with the Information Technology department to fully maintain the Solar Learning Lab™.

Our vision is to positively change attitudes towards sustainable energy throughout the world. We hope that our project was only the first of many towards attaining that vision. We hope that future projects will consider our recommendations; however, we are not in a position to say that they are complete. We look forward to seeing where future projects take our vision and we especially look forward to the day when our vision has been realized.

6. Bibliography

- Barron, K. (1998). I'm Greener than you. Forbes, 161(5). 45.

- Boyle, G. (1999). A Renewable Future. The Ecologist, 29(7). 430.

- Dohn Riley, M.(2001). Turning the Corner: Energy Solutions for the 21st Century: Alternate Energy Institute, Inc.

- EIA various publications from <http://www.eia.doe.gov/>

- Flavin, C., & Tunali, O. (1996). Climate of Hope: New Strategies for Stabilizing the World's Atmosphere. Ed Peterson:

- Flavin, Christopher, & O'Meara, M. (1998). Solar power markets boom. World Watch 11(5). 23.

- Fleming, J., & Knorr, B. (2003). Clean Air Act. History of the Clean Air Act. <http://www.ametsoc.org/sloan/cleanair/index.html> (2003, October 27).

- Gelbspan, R. (1997). The American Prospect. A Global Warming. <http://www.prospect.org/print/V8/31/gelbspan-r.html> (1997, October 20).

- Grigg, J., Flavin C., & Tunali, O. (1996, June). Climate of Hope: New Strategies for Stabilizing the World's Atmosphere Ed. Peterson,

- Grigg, J. (2002). [Review of the journal The health effects of fossil fuel derived particles]. Archives of Disease in Childhood, 79.

- Hornstein, MarkEngineering (1999) Design-A Day in the life of Four Engineers, Upper Saddle River NJ: Prentice-Hall Inc.

- Kennedy, M. (2002). UCR News: News Release Acid rain threatens forests in more ways than previously thought <http://www.info.ucr.edu/cgi-bin/display.cgi?id=257> (2003, Oct. 23).

- Koonts, M. (1998). Clean air and transportation: the facts may surprise you. Public Roads, 62(1). 42.

- Kuecken, J. (1979) How to Make Home Energy From Wind, Water & Sunshine. Blue Ridge Summit, PA: Tab Books.

- Kut, David & Hare., Gerald (1979) Applied Solar Energy. New York: Halsted Press.

- Mathews-Amos, A., & Berntson, E. (1999) Climate change harms ocean life. Earth Island Journal, 14(3), 20.
- Moore, T. (1987). EPRI Journal: Opening the Door for Utility Photovoltaics.
- Morrison, D. (2000). Industry Starts Building The Road To A Sun-Powered Future. Electronic Design, 48(16). 55.
- Nicholson, Nick; Harvest the Sun: Solar Construction in the Snowbelt; Ayer's Cliff, Quebec: Ayer's Cliff Centre for Solar Research; 1978
- "Passive Solar." Green Energy. p. 1-3. <http://greenenergy.org.uk/renewable_energy/solar_passive.htm> (2003, September 8).
- Retallack, S., & Bunyard, P. (1999). We're changing our climate! Who can doubt it?
- The health effects of fossil fuel derived particles. (2002) Archives of Disease in Childhood. 86(2). 79(5).
- Thomas, T. (1999). The New Future of Renewable Energy. World and I, 17(4). 152.
- Wilson, C. (1974). Energy for Survival: The Alternative to Extinction. Garden City, NY: Anchor Press.
- (2001). GreenBiz | News Center | Columns. Climate Wise - Nothing to Chance: An Argument for Distributed Systems. <http://www.greenbiz.com/news/columns_third.cfm?NewsID=17874> (2003, November 5).
- (2001). Online News Hour: President Bush -- June 11, 2001. Response to Global Warming. < http://www.pbs.org/newshour/bb/environment/energy/bush_6-11.html> (2003, September 4).
- (2002). Energy Information Administration: Annual Energy Review 2002. Annual Energy Review 2002. <http://www.eia.doe.gov/emeu/aer/contents.html> (2003, October 7).
- (2002). WEC - Annual Reports. WEC Annual Report 2002. <http://www.worldenergy.org/wecgeis/wec_info/annual_report/annual_report.asp> (2003, September 19).
- (2003). An Introduction to Solar Energy. An Introduction to Solar Energy. <http://www.ccs.neu.edu/home/feneric/solar.html > (2003, November 18).

- (2003). Distributed Resources: Frequently Asked Questions. National Conference of State Legislatures - Energy Project: The Distributed Resources Series. <http://www.ncsl.org/programs/esnr/drfaqs.htm> (2003, September 28).

- (2003). EUROPA - Research - Energy - Energy Supply and Demand. Energy Supply and Demand. <http://europa.eu.int/comm/research/energy/gp/gp_imp_esd_en.html#1> (2003, October 1).

- (2003). Massachusetts Electric Company - GreenUp Energy Options. GreenUp Energy Options. <http://www.masselectric.com/res/newchoices/greenup.html> (2003, September 23).

- (2003). Million Solar Roofs. About the Million Solar Roofs Initiative. <http://www.millionsolarroofs.org/about/> (2003, September 11).

- (2003). Missouri Department of Natural Resources - Outreach and Assistance Center - Energy Center. Missouri's Solar Energy Resource What is it, how much is there, and how can we use it? <http://www.dnr.state.mo.us/energy/renewables/solardata.htm> (2003, November 2).

- (2003). National Center for Photovoltaics (NCPV). PV Watts A Performance Calculator for Grid-Connected PV Systems. <http://www.nrel.gov/ncpv/> (2003, September 3).

- (2003). NaturalGas.org. Overview of Natural Gas. <http://www.naturalgas.org/overview/overview.asp> (2003, September 2).

- (2003). NREL: Solar Research Home Page. National Renewable Energy Labratory-Solar Research & Photo Voltaics for Buildings. <http://www.nrel.gov/solar/> (2003, September 14).

- (2003). Photovoltaics – Slow on the Uptake? Photovoltaics – Slow on the Uptake? <http://www.seraph.demon.co.uk/PVuptake.htm> (2003, October 12).

- (2003). POPClocks - Java version. US Census Bureu Reports. <http://www.census.gov/ipc/www/clock.html > (2003, September 20).

- (2003). Pros and Cons of Distributed Photovoltaics. EPRI Journal (online edition) - Pros and Cons of Distributed Photovoltaics. <http://www.brianfies.com/ejbipv> (2003, September 20).

- (2003). Prospects for Distributed Electricity Generation. Prospects for Distributed Electricity Generation. <http://www.cbo.gov/showdoc.cfm?index=4552&sequence=1> (2003, October 15).

- (2003). Selected Publications and Reference Material. Renewable Energy Information on Markets, Policy, Investment, and Future. <http://www.martinot.info/reference.htm> (2003, October 15).

- (2003). SESCI. Solar Energy for your Home. <http://www.solarenergysociety.ca/home.htm> (2003, November 15).

- (2003). The Conversion From Fossil Fuels. The Conversion From Fossil Fuels.<http://mesun4.wustl.edu/ME/courses/me404a/StudProjSP00/Ulmer/The_Conversion_From_Fossil_Fuels.htm > (2003, November 20).

- (2003). The Northeast Sustainable Energy Association works to bring clean electricity, green transportation, and healthy, efficient buildings into everyday use. NESEA - Northeast Sustainable Energy Association Energy and National Security. <http://www.nesea.org/publications/NESun/national_security.html> (2003, November 3).

- (2003). UCR News. Acid rain threatens forests in more ways than previously thought. <http://www.info.ucr.edu/cgi-bin/display.cgi?id=257>. (2003, October 23).

- (2003). World Nuclear Association | Information | Chernobyl. World Nuclear Association. <http://www.world-nuclear.org/info/chernobyl/inf07.htm> (2003, October 25).

- (2003) WPI: Organization of the University. WPI Organization of the University. <http://www.wpi.edu/Admin/Org/> (2003, September 2).

Appendix A. Draft Proposal: Installing and Sustaining a Solar Learning Lab™ at WPI

Monday, December 22, 2003

Proposal to Worcester Polytechnic Institute

Installing and Sustaining a Solar Learning Lab™ at WPI

Solar Team 1 (solar1students@wpi.edu)
Haitham Al-Beik, Joseph Chapman, Joseph Ledue, Jason Wailgum

Advisors
Professor Richard F. Vaz (vaz@wpi.edu)
Professor Kankana Mukherjee (kmukher@wpi.edu)

Sponsor
Heliotronics (http://www.heliotronics.com)

Introduction

Conventional energy sources today pollute the environment and adversely affect public health. Every year, the U.S emits over six billion tons of carbon dioxide and over one million tons of nitrous oxides into the Earth's atmosphere. These gases and other byproducts of fossil fuels have been linked to acid rain, increased mortality rates in infants, and global warming. In the short term, these effects are often overlooked and disregarded by the public; however, they could grow to potentially devastating problems threatening the global environment in the long term. Furthermore, conventional energy sources use limited fuels that will be depleted if current consumption rates are to continue. Because of these problems, many scientists around the world have concluded that the development and use of other non-conventional energy sources is essential if the world is to continue to rely on energy as it does today.

Sustainable energy when compared to conventional energy is not cost-effective, which many believe is the reason that it accounts for less than one percent of energy produced in the world today. However, awareness also plays a big role in its widespread use and adoption. If the public is not aware of the need for and the benefits of sustainable energy, then the technology will not likely be adopted.

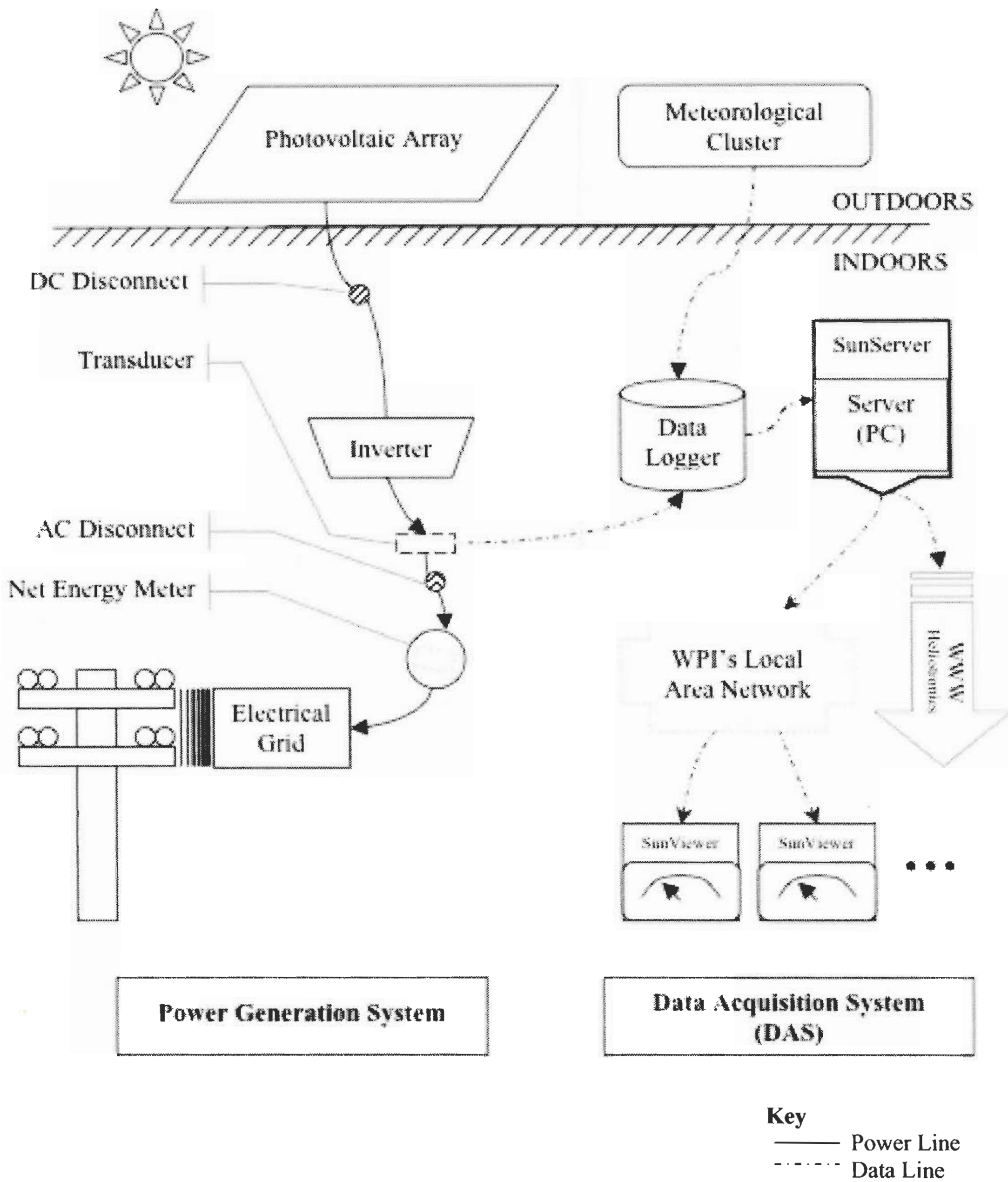
Our goal

Since we envision a world that primarily uses sustainable energy and since we cannot bring down its costs directly, we have decided to focus on raising awareness of it. Worcester public schools currently offer minimal sustainable energy education and WPI lacks any formal courses or programs that teach it. We believe that it is reasonable to assume that WPI, being "The University of Science and Technology. And Life," should offer such programs to its students to increase their awareness of sustainable energy. We decided that an educational solar photovoltaic (PV) demonstration would be a good way to establish such a program at WPI. Our project sponsor, Heliotronics, develops and distributes products that help educators and energy consumers learn about the potential of solar PV energy. They have developed a concept called the Solar Learning Lab™, which is a tool that helps promote solar energy education in a unique way.

The Solar Learning Lab™

The Solar Learning Lab™ concept is the combination of a solar PV array, a data acquisition system (DAS), and an educational software package called the SunViewer™ that displays data collected by the DAS and educational information about solar energy in general.

A diagram describing the relationships of the components of the Solar Learning Lab™ can be seen below. In addition, snapshots of the SunViewer™ software have been attached at the end of this document.



Solar Learning Lab™ diagram

Environmental benefits of the Solar Learning Lab™

By using some conservative estimates, we were able to determine that the energy generated from the solar PV array in the Solar Learning Lab™ could displace over 1,000 pounds of carbon dioxide emitted into the atmosphere annually. Though this benefit may not seem to have any direct value to WPI, we can reasonably say that it could leave a good impression on individuals who are concerned with the environment.

Educational benefits of the Solar Learning Lab™

We have learned through interviews with educators on and off campus that a Solar Learning Lab™ could enrich WPI's educational programs. We learned that future IQP groups could help ensure the use of the Solar Learning Lab™ by developing educational activities that utilize it. Some of the possible ways in which activities utilizing a Solar Learning Lab™ could enhance these programs are listed below:

- Providing students with "hands on" experience with sustainable energy
- Introducing students to geometric principles (learning how the angle of the array affects the power output)
- Introducing students to statistical analysis (extrapolation, averaging, interpreting the results)
- Making students aware of the relationship between the environment and energy
- Expanding environmental education into student's homes

It was made clear in our interviews that there are many more possible benefits, depending on the projects that are designed. It may be left to future projects to determine the full potential of the Solar Learning Lab™ for outreach programs at WPI, but even now, the potential seems to be immense.

Costs of the Solar Learning Lab™ and current funding

As with most items of value, the benefits mentioned above come at a cost. Currently, that cost is $3,160. However, we determined that this investment could be returned in roughly ten years due to credits and electricity savings. A more detailed cost analysis is listed in the table below.

Heliotronics	Data Acquisition System (DAS)	$4,697
Solar Works Inc.	Power Generation System: 1kW PV Array & Inverter	$12,274
Total costs of combined systems		**$16,971**
Class of 1975 donation		– $10,000
Estimated MTC installation credit		– $3,811
Initial costs / funding required		**$3,160**

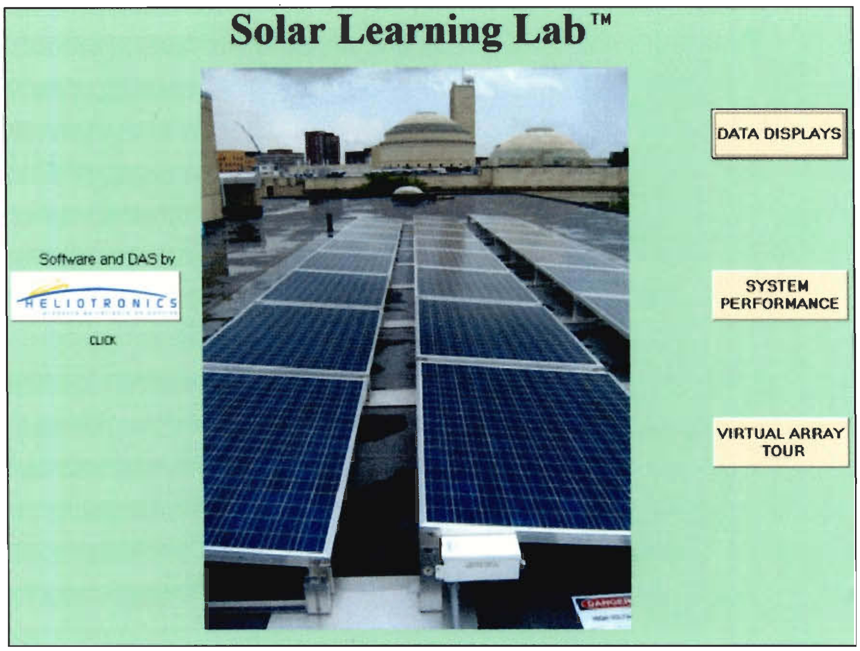
Financial status of the Solar Learning Lab™

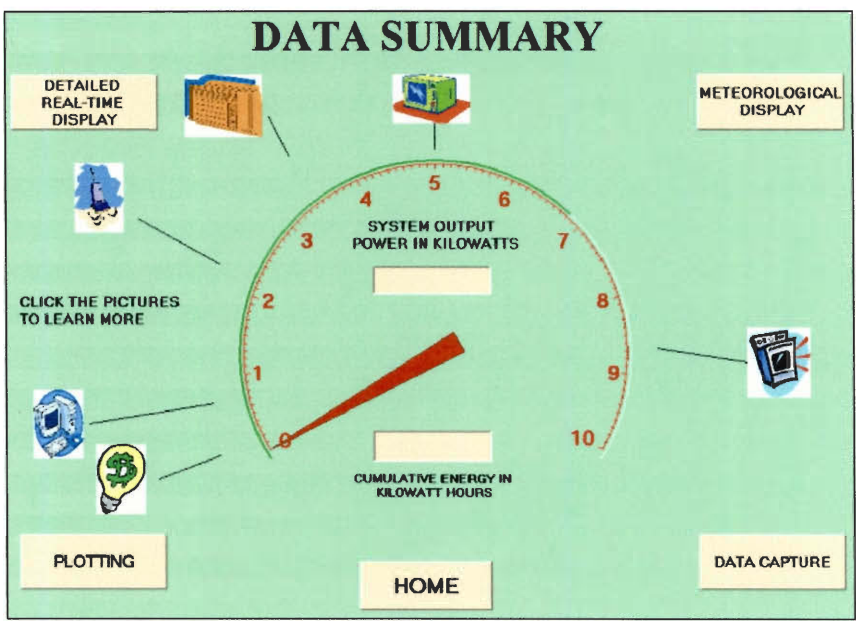
As can be seen in the table, we have already obtained $10,000 from the Class of 1975 towards achieving our goal. In addition, the distributor of our power generation components has credited us $3,811 from a Massachusetts Technology Collaborative (MTC) grant.

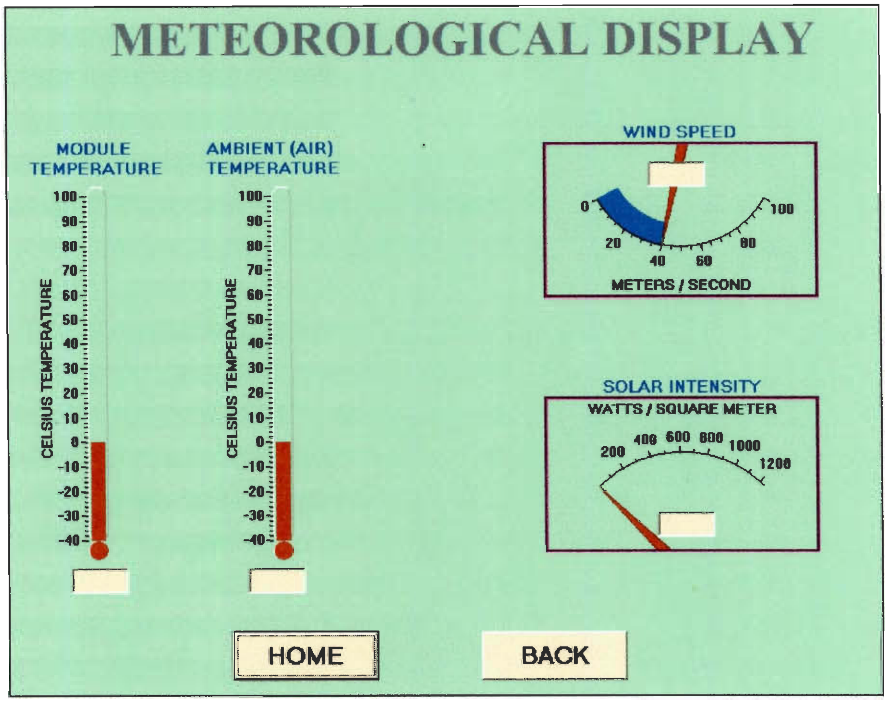
Ownership and maintenance

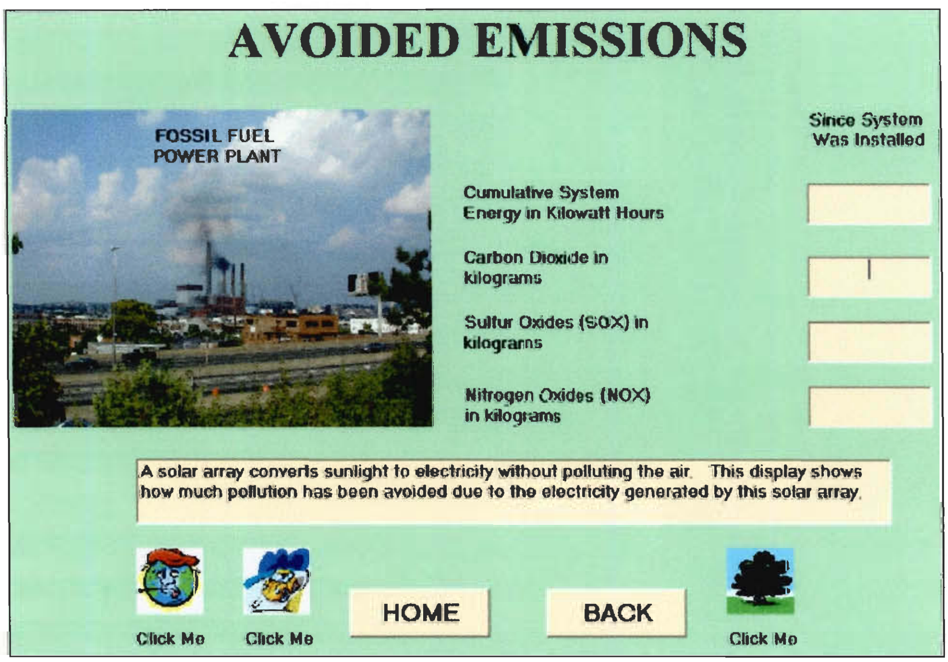
In addition to requiring funding, this project also requires an entity or combination of entities at WPI to take ownership of the Solar Learning Lab™. The owner does not necessarily have to meet the additional funds required, but they would be expected to properly maintain the Solar Learning Lab™. Maintenance required for the physical components of the Solar Learning Lab™ is minimal, consisting of semi-annual visual inspections and cleanings. There is no regular maintenance required for the software of the Solar Learning Lab™, but the owner should be ready for any general networking or software problems that may occur. Without ownership, the Solar Learning Lab™ at WPI could reasonably fall into disrepair.

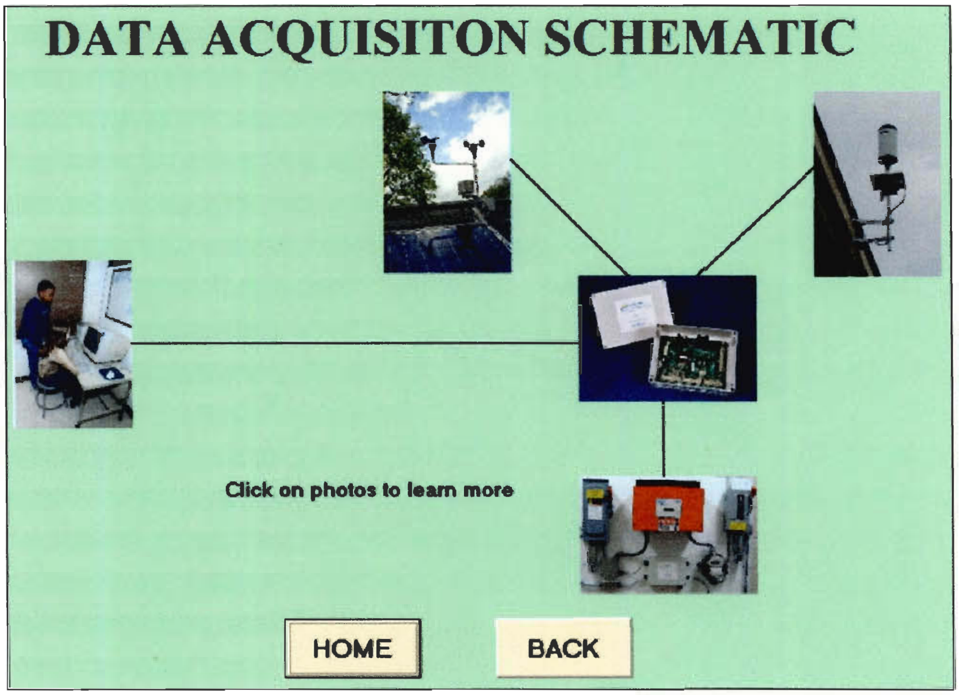
Snapshots of the SunViewer™ software

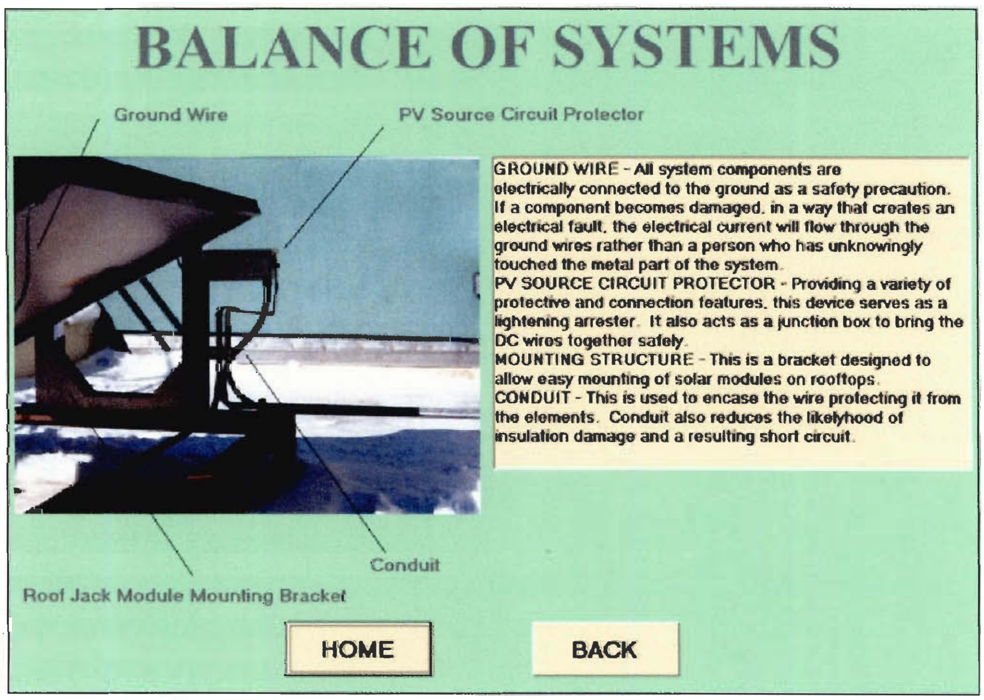





METEOROLOGICAL DISPLAY
MODULE TEMPERATURE
AMBIENT (AIR) TEMPERATURE
CELSIUS TEMPERATURE
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
WIND SPEED
0
20
40
60
80
100
METERS / SECOND
SOLAR INTENSITY
WATTS / SQUARE METER
200
400
600
800
1000
1200
HOME
BACK


AVOIDED EMISSIONS
FOSSIL FUEL POWER PLANT
Since System Was Installed
Cumulative System Energy in Kilowatt Hours
Carbon Dioxide in kilograms
Sulfur Oxides (SOX) in kilograms
Nitrogen Oxides (NOX) in kilograms
A solar array converts sunlight to electricity without polluting the air. This display shows how much pollution has been avoided due to the electricity generated by this solar array.
Click Me
Click Me
HOME
BACK
Click Me


DATA ACQUISITON SCHEMATIC
Click on photos to learn more
HOME
BACK


BALANCE OF SYSTEMS
Ground Wire
PV Source Circuit Protector
GROUND WIRE - All system components are electrically connected to the ground as a safety precaution. If a component becomes damaged, in a way that creates an electrical fault, the electrical current will flow through the ground wires rather than a person who has unknowingly touched the metal part of the system.
PV SOURCE CIRCUIT PROTECTOR - Providing a variety of protective and connection features, this device serves as a lightening arrester. It also acts as a junction box to bring the DC wires together safely.
MOUNTING STRUCTURE - This is a bracket designed to allow easy mounting of solar modules on rooftops.
CONDUIT - This is used to encase the wire protecting it from the elements. Conduit also reduces the likelyhood of insulation damage and a resulting short circuit.
Conduit
Roof Jack Module Mounting Bracket
HOME
BACK

Appendix B. Heliotronics

Heliotronics is a company that was founded in April of 1999 as an engineering consulting firm, and since, has expanded to become a retailer of solar related systems for the purpose of solar energy education. They have developed a concept called The Solar Learning Lab™, a combination of a solar PV array, and a data acquisition system, for the purposes of education. The Solar Learning Lab™ offers students with hands on opportunities that they could not possibly get from studying text books alone. It includes the SunViewer™ software, which enables students to view the data collected from the array in many levels of detail and complexity. Heliotronics was recently awarded a contract to install Solar Learning Labs at 22 schools throughout New York State. An installation at WPI would further compliment their list of achievements for the past five years.

Appendix C. Solar Now Inc.

In Massachusetts, there currently exist substantial efforts to educate the public about sustainable energy. For example, the largest single photovoltaic array in all New England is located in Beverly, and overseen by a non-profit organization known as Solar Now Inc. According to its website, "Solar Now is an international non-profit organization dedicated to promoting education about renewable energy and the environment" (Solar Now 1999). Solar Now has actively participated in solar education in Massachusetts for over a decade, while hosting teacher workshops, setting up internships, developing environmental curriculum, hosting solar vehicle races, and generally publicizing and promoting renewable energy (Solar Now inc. 1999). As quoted in a press release from the Massachusetts Division of Energy Resources (DOER), Mayor Scanlon of Beverly comments on the success of Solar Now, saying "Beverly citizens have always been proud of Solar Now and its photovoltaic facility…" (DOER 1997). Solar Now Inc. has been a significant resource for renewable energy educators, and also for our project. They donated eight solar modules from the solar power corporation to our project, which have already been put to educational use for undergraduates. Their contribution will be a significant resource for any future projects dealing with solar education.

Appendix D. Documented Interviews

Interview w/ John L. Heyl

ATTENDANCE

Interview Date:	Friday, October 17th, 2003	
Interviewee(s):	John L. Heyl	VP, Dev & University Relations
Interviewer(s):	Haitham Al-Beik Joseph Chapman	

We had the intentions of learning what Mr. Heyl thought were good candidates for locations for the array, we wanted to learn what value the project had to WPI from his perspective, and we wanted to learn if there was anybody else that we should talk to. We also wanted to get him excited about the idea of our project.

Mr. Heyl suggested that displays for the array go in the new admissions building or the campus center. He thought that they might help portray what goes on at WPI, which is valuable to the school, because it gives a stronger impression to admissions visitors.

He thought that our project would be useful for on campus marketing more than off campus marketing. By this, he meant that he didn't see it as something that WPI would incorporate into commercials necessarily; rather, he saw it as being more useful to show to people who are visiting campus.

He expanded this idea, suggesting that it could be very useful to bring younger kids on campus perhaps for a half-day program. He mentioned the K-12 engineering pipeline, which has been shrinking recently. He believed that our project could help the pipeline stay full in Worcester by spurring interest in engineering at an early age. He stressed that whatever we have in the end should not end up becoming a museum exhibit; instead it should be interactive. He believed that this project has a lot of value to the school's outreach programs.

In conclusion, Mr. Heyl was excited about our project, stating that our project was "fascinating" and "exciting." He offered to help us in the future should we need any further assistance.

Interview w/ John E. Miller

ATTENDANCE

Interview Date:	Friday, October 27th, 2003	
Interviewee(s):	John E. Miller	Director of Physical Plant
Interviewer(s):	Haitham Al-Beik Joseph Ledue	

We wanted to meet with John Miller to discuss the installation aspect of the project. This included the physical installation and the electrical requirements. He stated that we must meet with Massachusetts Electric to see that everything can be approved and that we must follow the guidelines that they give us.

He told us to contact Aleta Fazzone of National Grid to get their approval for connecting our solar panels to the electrical grid.

Aleta Fazzone, National Grid, Accounting Office

Phone: (508) 860 6386, Email: aleta.fazzone@us.ngrid.com

John E. Miller wanted us to provide him with a list of all materials needed for installation We pointed out that we wanted a permanent installation, which means that the system will need ownership and continuous maintenance.

Interview w/ William W. Durgin

ATTENDANCE

Interview Date:	Wednesday, October 29th, 2003	
Interviewee(s):	William W. Durgin	Associate Provost/VP Research
Interviewer(s):	Haitham Al-Beik Joseph Ledue	

We started the interview by explaining and providing the necessary information to better describe our IQP project in general and our current and future goals. This includes giving him a hard copy of the overview document.

This interview focused on how to take advantage of the Solar Learning Lab academically. The academics we discussed targeted high school and college research level education.

Academic areas that could benefit:

- Statistics,
- Physics,
- Mathematics,
- Electrical and Computer Engineering,
- Thermo-related engineering,

Have the second group possibly create experiments for each of the above subjects.

Mr. Durgin recommended that we contact:

Denise Rodino:	To help & guiding us to learn about ways to get additional funding
Dave Olinger:	For demonstration Projects& getting it on the web
John Blandino:	Because he deals with mechanical and electrical engineering research

He stated that we are going to need a custodian for this (possibly first year ECE students).

He discussed possibly working with different energy storage possibilities which could include:

- Flywheels
- Fuel cells
- Water pumps

The interview ended with ideas and possible future projects for WPI and Solar Team 2 to think about and further analyze.

Interview w/ Thomas Lynch, Christopher Salter, and Sean O'Connor

ATTENDANCE

Interview Date:	Thursday, October 30th, 2003	
Interviewee(s):	Bernard Brown	VP of Student Affairs
	Thomas Lynch	VP of Information Technology
	Sean M. O'Connor	Manager of Network Operations
	Chris Salter	Director of Techanical Trades
Interviewer(s):	Haitham Al-Beik	
	Joseph Chapman	

The meeting essentially was scheduled to be an interview with Vice President Bernard Brown and Vice President of Information Technology Thomas Lynch. However, they invited Sean O'Conner the Manager of Network Operations and Chris Salter the Director of Technical Trades and introduced them to us before the meeting started.

We started by explaining and providing the necessary information to better describe our IQP project in general and our current and future goals. All of them had a positive opinion towards the idea of the project. This initial support was then followed with questions to better understand what equipments are going to be used and needed for the installation to happen. At this point the meeting shifted to a logistical and technical discussion.

Note: VP Brown helped getting all the necessary people together in one meeting, which better helped us to communicate and discuss many of the different opinions and issues of the project. He left the meeting early to attend another meeting he scheduled.

The following categories will better summarize the rest of the meeting regarding each of the technical issues that came up and their outcomes.

Heliotronics Solar Learning Lab™ Software

Lynch and O'Connor presented questions and concerns regarding the server software that will be installed and running on WPI's local area network. He made it clear that we have to make sure that the software follows WPI's rules, guidelines, and especially security regulations.

Server PC

Lynch presented questions regarding the server PC that will store and analyze the data retrieved from the data acquisition system.

- How much information is it storing/processing per period of time?
- How many times do we need to have access to the PC?
- Do we need/require wireless access to send/receive the data?
- How much does individual licenses cost?

O'Connor expressed that providing us with a simple PC for the server would not be an issue and would even help us in the setup and installation of the server to be part of WPI's LAN.

Kiosk Display and Location

Lynch presented different ideas and suggestions as to the type of displays we could use for our kiosk:

1. Flat Monitor Display
2. Touch Screen Flat Monitor Display
3. Large Plasma Display
4. Both options 2 and 3

The fourth option will have the touch screen as the user interface while the plasma display (on top of the kiosk) will be displaying slide shows of information about the installation, status and/or renewable energy facts. *The plasma can switch to display the current screen on the kiosk when active, but that is a more complicated setup.*

Lynch and O'Connor presented different opinions as to the possible locations for the kiosk. The main decisive kiosk-location-selection factor was the student traffic associated at that location. The following is a list of locations ordered in most probable:

- Wedge
- Campus Center
- Admissions Building

The Campus Center already has its own kiosk and may not be possible to add a new one or add to the current one.

Logistics, Materials and Installation

We presented the following information:

1. What type of equipments, materials and devices we will be installing and using?
2. Who will be in charge of the installation?
3. Are the panels installed for short or long term purposes?
4. Who will be in charge of its maintenance?

Chris requested more information regarding the mounting equipment that we are going to use for the installation. In addition, knowing that the generated power from our panels will be fed back to the electrical grid, we informed him that we are working on getting permission from Massachusetts Electric and/or National Grid.

Chris informed us that Plant Services would help in the installation of the solar panels and the mounting brackets. Moreover, O'Connor presented us with a web-cam idea. He is willing to install a web-cam on top of Morgan (see next category) to record the installation and view weather and panel conditions.

Selecting an Ideal Location for the Solar Array

In this category everyone contributed to discuss each location and discuss its pros and cons. The locations we discussed are as follows:

Location \ Major Issues	Safety	Spacious	Accessibility	Security	Connectivity
Higgins Lab	✓				
Goddard Hall			✓	✓	
Fuller Building	✓	✓			✓
Stratton Hall		✓		✓	
Campus Center	✓	✓			✓
Daniels	✓	✓	✓	✓	✓
Morgan	✓	✓	✓	✓	✓

Each of the major issues relate to a question as follows:

Safety: Does the location provide safe access for people installing, maintaining and visiting the panels?

Spacious: Does the location provide sufficient space for the solar array and the interconnected devices?

Accessibility: Does the location provide easy access for people installing, maintaining and visiting the panels?

Security: Does WPI have any security restrictions to that location?

Connectivity: Does the location provide easy power and data wiring for all required connections?

We were able to narrow down the location to Morgan. Morgan was selected over Daniels mainly due to the already ongoing projects on that building and the available conduits for connectivity purposes.

Interview w/ Pietrewicz

ATTENDANCE

Interview Date:	Friday, October 31st, 2003	
Interviewee(s):	Mrs. Pietrewicz	Science Dept. Head at Doherty Memorial High School
Interviewer(s):	Joseph Chapman Jason Wailgum	

Inspired ideas and angles to obtain one of our goals for a K-12 outreach came up during this meeting: Mrs. Pietrewicz noted that we contact next along with Martha Cyr, Joseph Buckley; the Science Curriculum Liaison of WPS .

It was noted to us that throughout the City of Worcester, each public high school such as Burncoat High and Doherty are each segregated upon a theme. By this, she explained that Doherty was the "engineering" high school, which does include the study of chemical make up of the PV's within chemistry class, etc. Meanwhile Burncoats' theme is "arts."

Mrs. Pietrewicz pointed out a great idea to include on our future *Solar Day*. Within every four years, teachers *MUST* be recertified by the state in order to maintain an up-to date teaching certificate. Within those four years, every teacher is required to learn a new understanding in an area by credit hours. In other words, she pointed out that our IQP could have the potential of giving valid credit to the teachers towards there required hours, and can be guaranteed to them by then teaching the information learned to their students.

As far as the idea of Heliotronics selling Doherty High School the software to connect to WPI's array server; this would have to be passed by the school board and possibly by Mr. Buckley. It was also noted that Mr. Buckley teaches classes at South High, near the Worcester Airport.

Interview w/ Martha Cyr

ATTENDANCE

Interview Date:	Monday, October 10^{th}, 2003	
Interviewee(s):	Martha Nevin Cyr	Director, K-12 Outreach
Interviewer(s):	Joseph Ledue	
	Jason Wailgum	

The interview with Martha Cyr was very easy going yet professional. We have gained Martha Cyr's attention and support to help complete our IQP vision. Martha Cyr was very enthusiastic about an outreach program and prompted new ideas to us.

We started the meeting by explaining and providing the necessary information to better describe our IQP project in general and our current and future goals. She pointed out that Joe Buckley was a very good source to interview and gain more information heaving to deal with K-12 outreach programs.

She said that $200 is a lot of money for Worcester public schools to pay for an access fee to the data acquired by Heliotronics from our PV system. Most schools wouldn't be able to find the funds for this. Think of ways to make outreach available to students whose school can't afford this fee.

Here are some of the ideas she gave us for creating activates:

- She recommended using snapshots of the computer screen when the software is showing the data during different power rates, and building an in class demonstration this way. Possibly showing 3-4 scenarios and have kids extrapolate and interpret an additional scenario where they have to solve for the unknown information.
- She recommended creating an activity where students could try plotting energy production fluctuation over months and years based on information that they could extrapolate from.

- She recommended creating an activity where students could try to estimating the size of a panel needed to support 10% of WPI's energy, based on information that they could extrapolate from.
- She recommended creating an activity where students could take home examples of sustainable energy and energy consumption and make a connection through everyday work.
- She recommended that we explain the downfalls of solar in any activity created.
- She recommended using Solar Lego™ kits as demonstration tools.
- She recommended creating an activity dealing with solar radiance & temp vs. energy production.
- She recommended creating an activity for that would interest students in one or more of the following: electrical, mechanical, and chemical engineering.
- She recommended keeping in mind how does theory relate to 4th grade students? (She can explain this idea in more detail to new student groups)
- She recommended creating an activity for a summer camp program where there could be 35 minutes of background information & a one hour activity or an open exploration of the SunViewer™ software.
- She recommended creating an activity which would compare to total amount of energy that WPI uses to the actual amount of energy being supplied through the 1kW array.

Gear Professional Developments Points (PDP) towards Center for Industrial Mathematics and Statistics (CIMS). Professor Heinricker and Professor Goulet have both been involved in teaching teachers which fulfill their PDP requirements.

She brought WPI Summer programs to our attention. She said that various programs are constantly being run it he summer and they include day and overnight camps. Some of the mentioned programs include:

- **Frontier** is a 2-week, on-campus research and learning experience that challenges high school junior and seniors to explore the outer limits of knowledge in science, mathematics and engineering. Students live on campus and learn from outstanding WPI professors, use state-of-the-art experimental, analytical and computer technology, and get assistance from WPI students in the lab and in study groups.

- **GEMS** (Girls in Engineering, Math and Science) is a 1-week, on-campus program for girls entering grades 10-12. GEMS offers participants the opportunity to explore various fields in science and engineering through hands-on activities.
- **GEMS Jr.** is a 4-day commuter program for African American, Latino and American Indian students, Strive Jr. offers students in the 7th - 9th grades the opportunity to explore various fields in science and engineering through hands-on activities.
- **Strive** is a 1-week, on-campus program for African American, Latino, and Native American students. 9th - 12th grades the chance to explore various fields in science and engineering through hands-on activities.
- **Camp Reach** is a two week overnight camp for girls in middle school. Further information can be received from Office of Diversity and Women's Programs Stephanie Blaisdell and Minority Affairs

This information was obtained from WPI's Summer Programs website located at www.wpi.edu/Academics/Summer/middleschool.html.

These camps offer an educational background and plenty of academic activities throughout the day. The basis of each camp is like a giant science project / fair with block scheduling consisting of multiple workshops in a day.

She noted that in order for our IQP and or Solar Day to become beneficial to local area high schools we *must* meet the Massachusetts state curriculum framework. Otherwise, the teachers will be wasting there time and not fulfilling their standards.
For more information visit: http://www.doe.mass.edu/frameworks/current.html)

We mentioned that the solar student group to follow us would be more involved with creating an activity. We ensured her that we would we would provide them with enough information and recommendations to ensure a smooth transition & furthermore, the sustainability of the project for years to come.

There was great interest by Martha Cyr to have a copy of our report. She noted that a thorough methodology of the process, of our project would be valuable to her. She noted that a methodology formatted for younger students to easily understand would also be valuable to her, so that more audiences can experience and appreciate the work put into the IQP.

Martha Cyr made aware to us that currently, she has employed student(s) to consolidate information of outreach programs and K-12 based IQPs looking for appropriate projects and activities for K-12 students during the summer camps to work on. She did note that our IQP would not only be very appropriate for this age bracket, but very beneficial to the outreach programs here at WPI.

She is also creating a database of schools in the area that like to do science, math and engineering activities. This information may be available to additional solar student groups in the future. She told us that she would be more than willing to help with additional projects in the future and would like to be in contact with the team that follows our project.

Interview w/ Denise Rodino

ATTENDANCE

Interview Date:	Monday, December 1st, 2003	
Interviewee(s):	Denise Rowe Rodino	Exec Director C+F Relations
Interviewer(s):	Joseph Ledue	

This meeting was scheduled with recommendations from Prof. Durgin with the hope to find additional funding for the installation of a Solar Learning Lab on the WPI campus.

Prior to the interview she wrote me the following:

Hi Joe, I'm happy to help and especially happy to talk to you, but cannot offer tremendous encouragement.... these gifts are hard for us (the university) to secure; typically, unless we can find a good connection, they are even harder for students. That is not, however, meant as discouragement!

> *I will look forward to meeting with you.*
> *In the meantime, if you could be compiling lists of "who" might benefit from this technology and how that benefit might be turned into a corporate request (why they should fund), it would be helpful. Alternately, perhaps your solar PV would benefit underserved populations and be a prospect for foundation money (harder to get in terms of taking longer...)*

I went to the meeting with a brainstormed list of benefits and ideas for corporate requests (some of which had already been put into use), and benefits to companies who might be willing to donate money or products.

I started the meeting by explaining and providing the necessary information to better describe our IQP project in general and our current and future goals. She had a positive opinion towards the idea of the project.

She informed me that she has seen very few cases where students have received funding from corporations and even more rarely from foundations.

I told her what we have done already to search for donations of money or products, which included calling manufactures of solar PV products and a number of distributors. I told her that none as of yet have been successful.

She was impressed with the work and contacts that we made, and the fact that we asked for PV related products from companies and distributors instead of direct monetary donations.

Some key comments that she made were:

- The time that's required to get the kind of funds that we are looking for would take much longer than the two terms that we spent working on the project.
- Organizations donating to a project like this don't donate to students very much. Seldom has she seen funding go to student groups.

She said possibly try additional manufacturers or alumni involved in PV technology (We are working with the only WPI working in PV that we know of.)

She told us to look at companies giving away second-generation equipment. I responded by saying that we have already done this and we had used panels donated to us, but for our installation we need new equipment so that it will last for a few decades.

She wondered if Mass Electric would donate money to our project and what reasons might cause them to do so. She told us that we might want to see if they have some sort of "giving arm" or possibly tap into their marketing budget. She told us that we really wouldn't have much luck with foundations.

She mentioned a group that she thought the name was the Energy Research Collaborative, which funded a portion of a project that Prof. Clark worked on with the Penobscot Indians of Maine in the 70's. She also noted that this group is dated and may no longer exist. (We researched this possibility and concluded that they no longer exist, or the name provided was inaccurate)
She informed us that if additional solar student groups get to a point where we are writing a proposal for funds to a company or organization, she would help us revise our work.

Interview w/ Bob Fabian and Mathew Arner

ATTENDANCE

Conference Call

Interview Date:	Thursday, December 4th, 2003	
Interviewee(s):	Bob Fabian	Solar Works Inc.
	Mathew Arner	Heliotronics
Interviewer(s):	Haitham Al-Beik	
	Joseph Chapman	
	Joseph Ledue	

This meeting was a conference call, and was scheduled to discuss logistics in order to receive project estimates from both Solar Works Inc. and Heliotronics

We learned about the aspects of a beam mount system:

System Requirements

- Beam Mount System
- Two parallel 25ft lengths of 6x4 pressure treated beams (could be supplied by Solar Works)
- **Installation Procedures**
    - Scrape away existing stones on the roof until rubber membrane is exposed
    - Drill a hole through the beam and roof joist
    - Insert lag bolt through both
    - Secure the lag possibly using a nut for steel joists
    - Reinstall rubber membrane over the newly placed beams
    - Bolt the feet and arms of the racking system to the beams

Roofer Information

- If the roof is under warranty by its manufacturer, we have to bring a certified worker from the manufacturer to complete the installation of the rubber membrane
- Typical re-roofing of the beams would cost ~$200.00

Solar PV System Specs

- **Modules:** 11EC110 Evergreen Solar Modules, ~1210W DC → ~1KW AC
- **Inverter:** Sunnyboy 1800 (Single Phase)
- **Weight:** Beam Mount System Weight: 4 pounds per square foot

Inverter Information (for the National Grid worksheet)

- Manufacturer: SMA
- Model#: SMA-1800, 120V AC

For MTC subsidies, Solar Works needs to play role of Project Manager

- Solar Works Insurance Coverage: Everyone on the job
- **Solar Works Contract**
    - Will read as they are the people in charge of the installation
    - Pay 30% down (after the MTC Subsidy) at the time of signing the contract
    - 60% needs to be paid when installation is complete
    - Remaining balance (10%) is paid two weeks after completion
- **Estimates**
    - Total cost with Solar Works before any subsidies: $11,500 (tentative)
    - MTC incentive reductions/subsidies: [Depends on the turn of the year] ~$4/W

We learned that we needed to complete the following tasks for Bob Fabian:

- Contact Chris Salter regarding the connection of a single phase (120V) inverter to a 3 phase (240 V) system
- Email all contact/phone numbers of solar1students@wpi.edu to Bob Fabian.
- Create a scaled drawing (preferably in a CAD program) to show Bob Fabian the exact dimensions of the roof and any obstacles that could pose a problem to installation or sunlight exposure
- Learn if there are rafters or is there is a concrete slab below the rubber membrane and stones on the roof

The Conclusions to our conference call were as follows:

- We are not in a position to sign a contract with Solar Works during our project.
- We will be taking a risk regarding MTC subsidies for next year.
- We need specific financial information from the contract for our proposal.

Interview w/ Joseph Buckley

ATTENDANCE

Interview Date:	Wednesday, December 10th, 2003	
Interviewee(s):	Joseph Buckley	Worcester Public Schools Science Curriculum Liaison
Interviewer(s):	Joseph Chapman Joseph Ledue	

This meeting was scheduled with hope to find what is currently being done in the Worcester public school system for renewable energy education, specifically dealing with solar panel systems. We also wanted to make an initial contact in the Worcester public school system for the second team to be able to work with to create an activity or experiment involving solar panels.

We started by explaining and providing the necessary information to better describe our IQP project in general and our current and future goals. This included giving him a hard copy of our project overview document.

Mr. Buckley began by explaining that he worked with a consultant over the summer Solar Now, and visited them at their head quarters. He recommended to many teachers in the WPS system that they go along with him to learn more about solar energy. He wanted to try to get teachers involved in this technology, hoping that they may bring some of what they learned over the day back to the class room to teach to their students. We told him that Solar Now donated 4 working panels to us, and they would be used for demonstrations and educational purposes.

He said one great way to bring solar into the school is to create an activity based at a middle school level so that you could add or subtract material and easily develop it into a 5-6 grade or high school lever program. He suggested that when the second group goes ahead to develop an activity that they use the state frameworks for technology and engineering and uses the Massachusetts Dept of Education. (*also suggested by Martha Cyr*)

He mentioned that a small portion Worcester schools build mini solar powered cars at the middle school level and race them, but that this activity is not directly involved with the Junior Solar Sprint. This project is funded through the National Science Foundation.

He also said that the Alden Academy, a Worcester vocational school, bases a lot of its curriculum around material science and engineering design. And that they are looking to develop a large-scale solar vehicle.

He noted that at the Elm Park Community School and the Midland School currently have graduates from WPI working with teachers and faculty members to help bring more engineering related programs into their curriculum.

He said that he is always looking for new "educational consultants" to offer their knowledge and see how they can work their expertise into the WPS curriculum.

He said that a current problem with the students of Worcester is that they don't play they stay inside all day long either in front of a computer or a television. He informed us that most people learn as much about engineering while playing as a child, as they do in school. However, most of the kids in the city don't have this opportunity to "play". They are spoon-fed information and they develop poor problem solving skills. They are given information (i.e. x, x, x, x, and the final answer is z). All they need to know is how to get to z and that is all they care about. He is currently working to mend this weak point by modifying and adding to their curriculum. The SunViewer™ Software or activates involving the collection of data from our DAS could provide to be a helpful tool in solving the issue of poor data collection, interpretation, and analysis skills of WPS students.

He informed us that engineering collaborative between the Boston Museum of science and Doherty High school is in the process. Recently member of the board and MIT Dean visited the school and said the there is no program like this one in eastern Massachusetts. (additional for students using this appendices as a resource: the marketing department at WPI showed a specific interest in creating an connection between a Solar Learning Lab™ and the Boston Museum of Science.)

When creating an activity for WPS students keep in mind that they learn with much more ease by interpreting short down to earth pieces of information. He said, "Think of spoon-feeding a baby when creating the activity or experiment."

He mentioned the City Worcester benchmarks which are available on line to parents so they can see and understand what students should be learning about at certain grade and age levels. This maybe an helpful tool while creating an activity

He offered his services and said he would happily advise students during the process of creating an activity. He also said that he would review, and comment on an activity created by WPI students, and then find a place where it can be developed and modified for optimal implementation. Once an activity is created and any kinks have been worked out, guaranteed that he would find a place in the WPS curriculum where it could be put into use.

Appendix E. Solar Works Inc. Evaluation Form

SOLAR WORKS PV SITE EVALUATION FORM

Customer Name ____________________ Date Nov. 19

Customer Code ____________________ Evaluator ____________________

Site Address: 100 Institute Rd Tel: (H) ____________________

Worcester, MA 01609-2208 Tel: (W) ____________________

Fax: ____________________

County Site is in: Worcester E Mail: solar1@wpi.edu

Utility Company ____________________ Utility Acc't # ____________________

Does the customer have Day/Night or Time of Use metering? If yes, see p. 4) ____________________

Directions to the site: Take MA PIKE (I-90) to Exit 11A. Proceed North to I-290 then west into Worcester. Take exit 18 (Lincoln Sq. Rt 9) turn right at end of ramp then an immediate right before next traffic light. At next right proceed straight through bearing to the right on Salisbury St. At the WPI sign turn left onto Boynton St. then right onto Institute Rd. Take your first right (Private Way)

Permissions Visitor Parking is under the foot bridge & in the main Parking lot

	Yes	No
1. Is property in a historical district?	☐	☒
2. Are there any local restrictions on putting solar panels on the roof or in the yard?	☐	☒
3. Are there considerations on how the installation will look to neighbors?	☐	☒

>> i.e. while choosing a location for array or ground mount, talk with client about visual impact considerations to neighbors. Customer may want to consult with neighbors prior to choosing location.<<

	Yes	No
3. Will an electrical permit be required?	☒	☐
4. Does the customer have an electrician that works on their house, or that they request we work with?	☐	☒

Name: ____________________

Customer Electrician Contact info: ____________________

	Yes	No
5. Is a building permit, or are any other local permits required?	☐	☒

Where to obtain these: ____________________

Permits to be obtained by whom?: ____________________

	Yes	No
6. Does the customer understand a utility interconnection agreement will be required (for all grid-tie systems)	☒	☐
7. Will the owner allow us to use a job sign on the site?	☒	☐

8. What's the preferred timeframe for this installation? (IE: specific dates, ASAP, spring, etc.)
>> typical: minimum 4 weeks from signed contract <<

ASAP

	Yes	No
9. Does client have specific concerns about array location, the installation, roof penetrations, shading, etc., etc. If so, list below under #11 Comments.	☒	☐
10. Is permission granted for the utility to monitor the equipment?	☐	☐

11. Comments: We prefer no roof penetration ie ballast tray mounting

12. Commitments made to customer at time of site evaluation by site evaluator (IE: dates, materials, location of installed equipment, follow-up materials, etc.

Type of System:
UPS ☐ Grid Intertie ☒ Hybrid ☐ Other ☐

Generators: Customer has ☐ doesn't have ☐ wants ☐ doesn't want a generator ☒
Customer has been informed (if they want/have a generator) that we'll add a transfer switch to disable PV system on non-battery grid-tied systems Yes___ Not Yet___

Array Location:	Yes	No
1. Clear southern access to the sun between 9:00 AM and 3:00 PM?..........	☒	☐
2. Site has been evaluated with a Solar Pathfinder?	☐	☒
3. Was a "shade-tracing" done using the Solar Pathfinder?	☐	☒
4. Are there any trees that will shade the array now or in the future?.........	☐	☒
5. Are there other objects (e.g. chimneys, roof vents) that will shade the array?	☐	☒

6. List hours of the day, and in which months, shading will occur, and over what percentage of the array No shading

7. Has the customer been told about any shading issues, and what is their acceptance or stated actions to eliminate shading? ______

Roof Mounted Arrays:
Array will mount Flush to Roof ☐ OR Inclined relative to Roof ☒ OR TBD ☐
If significant loss due to a low roof pitch, customer accepts inclined array Yes__ No__,
or customer prefers lower system output ☐ to keep array flush to roof.
What % output loss has the customer accepted by not inclining the array ________%

Panels will mount in Landscape ☐ or Portrait ☐ (ex., 4 AstroPower modules make 1 panel)

Site Evaluator has been on roof to determine proposed array location works (IE: taken accurate measurements, determined shading issues, etc.)
Yes ✓ **No___ Needs to be done ____ Not Needed Because** ______

Ground Mounted Arrays:
This will be a ground mounted array ☐ because: ______
Standard ground mount ☐ (post and beam construction), or tracker ☐ or pole mount ☐
________ # feet of trench required between array and house (or other building)
Will inverter be mounted at array ☐ or at the house ☐
Who is responsible for providing trench: Solar Works ☐ Customer ☐ TBD ☐
Has ground mount and trench path been marked on ground w/ flags/marker? Y___ N___
>> Dig Safe must be contacted and will need to see markings.<<

Customer is flexible with precise array location ☒ or very concerned with layout ☐

Mounting Comments (Particularly if mounting questions remain TBD, list considerations)
considering ballast tray and all other mounting options

For Roof Mounts:

1. Roof Age ? Newest on Campus 2. Roof Material Rubber/Tar Roof w/ 3/4" stone
3. Roof Pitch 0 ° 4. Roof faces ________ ° (bearing on compass, in degrees)
4. Solar South for site location is ________ °.
5. Roof faces ________ ° to the East ☐, or West ☐ of Solar South. (within 30° OK)
6. Drip Edge Height Above Ground________ Ridge Height Above Ground ________
7. Dimensions of available roof space ≈ 40 ft. X 40 ft. or 25 x 28
8. Rafter dimensions 2"x4" ☐ 2"x6" ☐ 2"x8" ☐ 2"x10" ☐ Other ☒
9. Are ladders, scaffolding, harnesses, mechanical hoists etc. needed?...Yes ☐ No ☒
Describe:________

Wiring Pathway (Array to Inverter):

>> 2002 NEC codes require exterior conduit runs, and that the inverter or DC disconnect be located immediately upon the conduit entering the building! <<

1. Total distance (sum of vertical and horizontal) from array to inverter ≈ 166 or 177 or 40 ft ft.
2. Describe/estimate the conduit run from the roof to the inverter, in as much detail as you can.
(IE: from array, 25' along ridge to West edge, sweep over west edge at NW corner, 18' down west wall, 90 deg. sweep north <about 18" off ground>. LB through clapboard <6" wall>, 90 sweep down 3', LB into inverter.)

Option 1 from array ≈ 140 ft 90° turn to ground (12 ft) through brick & cement blocks 90° down (8 ft), 90° turn to storage room (8 ft)

Option 2 from array ≈ 140 ft 90° turn to ground (30 ft) through brick & cement blocks 90° down (8 ft) 90° turn to storage room (8 ft)

Option 3 from array ≈ 10 feet 90° down to ground 12 ft + 8 + 8

3. Cathedral ceiling below array location? Y N ✓
4. Attic access below array location? Y N
5. Materials to cut through Cement, brick

Electrical Service / BOS Locations:

1. Name brand of main service panel:________
2. What voltage is the electric service to the house? 120/240 ☑ 120 ☐ 240 ☐
3. Does the main service panel have a circuit breaker to shut off all power? Yes ☑ No ☐
4. Amperage of main service disconnect:________ Circuit breakers ☑ Fuses ☐
5. If there's unused circuit breakers we can use, list specs:_____amps, 120V ☑ or 240V ☑
If no unused breakers are available in the AC load center, list # of open spaces for additional circuit breakers of each voltage: 120_____ 240_____ (i.e.: could fit how many of each)
6. If there is not an empty slot in AC panel, has homeowner been notified that they will need to upgrade existing AC service? Yes ☐ No ☐
7. Is there room for the inverter to be located near the main service panel? Yes ☑ No ☐
How much (horizontal) wall space is available? 4 x 8 or 4 x 4
8. Distance between the power control center/inverter and the service panel? ≈ 8 ft
9. What will the inverter/power control center be mounted to: sheetrock over studs ☑ plywood over studs ☐ cement (poured) ☐ cement block ☑ wood ☐ (either one depending on location)
Will a backerboard (piece of painted plywood) be needed for inverter/monitor? Yes ☐ No ☑

Specific Location where will Outside Disconnect be mounted? No opinion (TBD)

Electric Metering Equipment::

If customer has Time-of-Use or Day/Night rates a second meter will be required.

1. Is there room for a second meter beside the existing electric meter? Yes ☐ No ☐
2. Does the customer have a digital electric meter ☐ or old-fashioned kind (w/ spinning disk) ☐

Data Monitoring Equipment:

1. What is the location of the customer monitor-to-monitor PV production? (standard location is at the inverter. Xantrex/Trace ST's series it's built in. XR series and Advanced Energy GC series inverters it is remote, SMA is built in.):

Heliotronics Data aquisition system will be installed If monitor location is anyplace other than at the inverter, do a complete write up of the path signal wiring will route, estimated time and difficulty to run wire, and mounting surface of monitor.

* What is the Customer's specific preference for monitoring – e.g., do they want monitor linked to a computer? Yes

2. What is the length of the wiring run from the inverter/control center to the monitor?________

Batteries (for UPS systems):

Is there space for the battery box near where the inverter will be? Yes ☐ No ☐

(Standard battery box for flooded batteries is 2' deep x 2' high x 5' wide. Sealed batteries require a 1~ less width, 1' more height)

If Yes, how much floor space is available? ________

Vented batteries require a battery box vent. (Sealed batteries require no venting.) Is there easy access to the outside for the vent pipe? Distance from battery box to outside in feet ________

Circuit Breaker and Circuit Loads Info for UPS Systems Only

CB#	Equipment Description	CB Amps	Volts-Watts-HP	Items on circuit
	Refrigerator			
	Freezer			
	Smoke/CO2 Alarms			
	Lighting Circuit1			
	Lighting Circuit2			
	Lighting Circuit3			
	Well Pump			
	Septic Pump			
	Computer			

Additional Tools Needed:

List any special tools needed to complete this installation: We will be doing installation

SW Equipment: (revised as necessary from original proposal)

1. Modules: Manufacturer/model________ #of modules________
2. Batteries: Manufacturer/model________ # of batteries________
3. Inverter: Manufacturer/model________
4. Power Center: Manufacturer/model________
5. Will there be a transformer? Yes ☐ No ☐ Size? ______
6. Will there be a generator? Yes ☐ No ☑ Size? ______
7. Other equipment:________

could we please have a detailed cost description w/ out the installation

Labor: it is needed for our written proposal to WPI.

Labor Estimates in Hours (and/or dollars if known): we will be doing installation w/ Helio

Estimated labor hours to complete installation: ?

Staging/Prep Work Plant Services Install Modules: IQP teams

AC Electrician: Plant Services All Other IQP teams

Additions to Budget:

Travel_______ Trenching________ Ground Mount_________

Equipment Rental ___________________ Staging___________ Crane________

Draw a (1) PLAN view and (2) SIDE view of the proposed array location. Include specific measured dimensions, chimneys, skylights, heights. (see next page)

Draw a diagram of balance of system components: Include measured distances between the: array, inverter, battery box, power control center, electrical service panel and outside disconnect. Show specific location of battery box vent and the system monitor, when necessary.

Photo List:

Bold face are "must haves". Check-off the views you've taken photos of.

- ___East side of house, straight on
- ___SE corner from far enough back to show entire house
- ___South side of house and roof, straight-on, - showing entire house
- ___SW corner - showing entire house
- ___West side of house, straight on
- ___Collector location close-ups as needed
- ___Potential solar-window obstacles (trees, chimneys, etc.)
- ___conduit path: PV array to power control center (may include close-ups)
- ___Battery box location(s) (UPS PV) or tank location (DHW)
- ___AC Service panel with surroundings (all PV systems) or existing water heater (DHW)
- ___Outside Disconnect proposed location
- ___UPS load center/Inverter proposed location (show in relation to AC panel if nearby)
- ___Ground mount location - in relation to house

Check-List before leaving site:

1. Have you discussed placement of all hardware with customer, including:
Array, conduit run, inverter, second meter, outside disconnect?
2. Do you have the essential photos?
3. Have you reviewed the site visit form for completeness of specific items that can only be answered on-site (Electrical Service/BOS locations, electric meter type, etc.)

We can email Photos!

Drawing

Appendix F.   Solar Now Inc. Receipt

Solar Demo Interactive Qualifying Project (IQP)

Team #1
Email: solar1students@wpi.edu

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA, 01609

Professor Richard Vaz
Solar Demo IQP Team 1 Project Advisor
ECE Department, Atwater Kent 225
Phone: +1 508-831-5344
Email: vaz@wpi.edu

Receipt

RE: Materials **donated** by Solar Now Inc. to Worcester Polytechnic Institute on Wednesday, October 29, 2003

Donated by:

Dr. Coleman, Science Director
Solar Now Inc.
100 Sohier Road
Beverly, MA 01915

Picked Up by:

Joseph Chapman and Jason Wailgum
Solar Demo IQP Team 1
Worcester Polytechnic Institute

Receipt #: **01**
Delivery Date: **10.29.2003**
Receipt Date: **11.12.2003**

Quantity	Item	Description
6	EM3610	Solar Power Corporation Solar Power Generator
1	G12-361CT	Solar Power Corporation Solar Power Generator
1	G361	Solar Power Corporation Solar Power Generator
1	Frame	Frame for 6 of EM3610
Nine (9) Items in Total		

Professor Richard Vaz

Appendix G. Notice of Intent to Interconnect

NOTICE of INTENT to INTERCONNECT for NGUSA RETAIL COMPANIES

PURSUANT TO 220 CMR 8.03 (4) (f) (2), APPLICANT HEREBY NOTIFIES UTILITY OF INTENT TO INSTALL AND OPERATE A GENERATING FACILITY.

APPLICANT	TELEPHONE #	DATE

STREET (MAILING) ADDRESS	CITY, STATE & ZIP CODE
FACILITY LOCATION, IF NOT ADDRESS ABOVE	CITY, STATE & ZIP CODE
UTILITY PROVIDING SERVICE	ACCOUNT NUMBER

DESCRIPTION OF GENERATING FACILITY

ENERGY SOURCE	PEAK POWER RATING-KW	INVERTER TYPE [1] (if applicable)	GENERATOR TYPE [2] (if applicable)

1. Only inverters meeting IEEE Standard 929-2000 and UL Standard 1741 are qualified for interconnection. The Company will determine from this application if your inverter is qualified and contact you.

2. Any rotating generator requires protective equipment at the point of interconnection. If you have this type of generator, the Company will contact you regarding required equipment based upon this application.

If an ownership connection exists between the applicant and this utility or National Grid USA, please provide details on the back of this form.

ESTIMATED INSTALLATION DATE	ESTIMATED OPERATION DATE

If your generating facility is rated at (A) 60 KW or less in Massachusetts, or (B) 25 KW or less in Rhode Island or New Hampshire, you are eligible for monthly net energy billing. If eligible, do you request single-meter net energy billing/sales? YES ___ NO ___

NOII-NGC-9-02.DOC

I hereby certify that, to the best of my knowledge, all of the information provided in this Notice is true.

Signature of Applicant ______________________

THIS NOTICE SHOULD BE COMPLETED, SIGNED AND RETURNED TO: R&D-ENGINEERING, NATIONAL GRID USA SERVICE COMPANY, 55 BEARFOOT ROAD, NORTHBOROUGH, MA 01532

Appendix H. Stakeholder Matrix

** WPI Employed*

Position	Stakeholders	Logistical Considerations for a Solar Learning Lab	Costs, Required Services, and Resources	Tangible Benefits to Stakeholder Group
Relations and Marketing				
*VP of Development and University Relations	John Heyl			4.3.2
*Associate VP, Marketing	George Sinclair Flett			4.3.2
*Exec Director Corporate & Foundation Relations	- Prof. Denise Rodino			4.3.2
Approval, Materials, Costs and Installation				
*VP of Physical Plant	John E. Miller	4.1.1	4.2.2	4.3.3
*Director of Technical Trades	- Mr. Chris Salter	4.1.2	4.2.2	
*VP of Information Technology	Thomas Lynch	4.1.1	4.2.3	
*Manager of Network Operations	- Sean M. O'Connor	4.1.3	4.2.3	
Mass Electric (National Grid)	John Bzura	4.1.4		
Suppliers / Sponsors				
Solar Works Inc. Project Manager	Bob Fabian	4.1.4	4.2.1	
Heliotronics Business Development	Mathew Arner	4.1.1	4.2.1	4.3.2
Solar Now Inc. Science Director	Dr. Coleman		4.2.3	
Academia, Education, and Outreach				
*Associate Provost/VP Research	Prof. William Durgin			4.4.4
*Director, K-12 Outreach	Martha Cyr		4.2.3	4.4.4
Worcester Schools Science Curriculum Liaison	Joseph W. Buckley, Jr.			
Doherty High School	Steven Platt			4.3.4
Science Dept Head of Doherty High School	Mrs. Pietrewicz			4.3.4

Appendix I. Stakeholder Contact Information

** WPI Employed*

Relations and Marketing

John Heyl*
Vice President of Development and University Relations
Email: jlheyl@wpi.edu
Telephone: 508-831-5874
Office: Boynton Hall, 3rd Fl

George Sinclair Flett*
Associate VP, Marketing
Email: gflett@wpi.edu
Telephone: 508-831-6029
Office: Boynton Hall, 3rd Fl

Denise Rodino*
Exec Director Corporate and Foundation Relations
Email: drrodino@wpi.edu
Telephone: 508-831-5607
Office: 20 Trowbridge Rd

Approval, Materials, Costs and Installation

John E. Miller*
Vice President of Physical Plant
Email: jemiller@wpi.edu
Telephone: 508-831-5500 / 5130
Office: 27 Hackfeld Road

Christopher Salter*
Director of Mechanical Trades
Email: csalter@wpi.edu
Telephone: 508-831-6060
Office: Daniels Hall 012

Thomas J. Lynch*
Vice President of Information Technology
Email: tlynch@wpi.edu
Telephone: 508-831-6075
Office: Fuller Labs 214

Sean M. O'Connor*
Manager of Network Operations
Email: soconnor@wpi.edu
Telephone: 508-831-5115
Office: Fuller Labs B26

John Bzura
National Grid USA
55 Bearfoot Road
Northborough, MA 01532
Email: John.Bzura@us.ngrid.com
Telephone: 508-421-7642

Suppliers / Sponsors

Bob Fabian
Solar Works Inc.
Project Manager
Arlington, MA 02474
Email: bfabian@solar-works.com
Telephone: 1-800-339-7804 ext. 314

Matthew Arner
Heliotronics
Business Development
Email: marner@heliotronics.com
Telephone: 617-730-5436

Dr. John Coleman
Solar Now Inc.
Science Director
Email: solarnow@comcast.net

Academic, Education, and Outreach

William Durgin*
Associate Provost/Vice President Research
Email: wwdurgin@wpi.edu
Telephone: 508-831-5404 / 5065
Office: Boynton Hall, 2nd Fl

Martha Nevin Cyr*
Director, K-12 Outreach
Email: mcyr@wpi.edu
Telephone: 508-831-6709
Office: Boynton Hall, 3rd Fl

Joseph W. Buckley, Jr.
Worcester Public Schools
Science Curriculum Liaison
Main Building
20 Irving Street
Downtown Worcester
Email: buckleyjw@worc.k12.ma.us
Telephone: 508-799-3205
Office: School Department, #205

Steven Platt
Doherty High School
Email: stevenplatt82@msn.com

Mrs. Pietrewicz
Doherty High School
Science Department Head
Email: pietrewiczl@worc.k12.ma.us

Appendix J. Price Quote from Heliotronics

Appendix K. Price Quote from Solar Works Inc

SOLAR WORKS INC

Massachusetts Regional Office
13 Palmer St. Arlington, MA 02474
Tel: 781-316-5625 Fax: 781-643-6494

Corporate Headquarters
64 Main St. Montpelier, VT 05602, USA
Tel: 802-223-7804 Fax: 802-223-8980
www.solar-works.com

12/12/03

Hi Joe,

I have prepared your proposal for an SP-12 Photovoltaic system. This system includes 11 EC110 12 volt modules from Evergreen Solar in Marlboro, MA, and a Sunny Boy 1800 inverter from SMA of Germany. I have specified a Unirac Tilt Leg mounting system, and all balance of system components are included with the exception or wire and conduit, which will be supplied by the school, and a meter, which Heliotronics will supply. WPI will provide all labor, including a master electrician.

The project costs and MTC incentives are outlined below according to the current incentive plan. The MTC Installation credit of $3,811 reduces your cost immediately so that the contract price is $8,463.. The Production credit is paid quarterly for three years, based on $0.38 per kWh generated by your system. The total Production credit cannot exceed the figure of $1,633 for this system. The final cost after all credits would be $6,830.

When you are ready to go ahead with the project, let us know and we will appraise you of the best path forward to optimize your grant from the MTC. Solar Works prices are only guaranteed for 30 days, but I do not foresee any major changes over the next months.

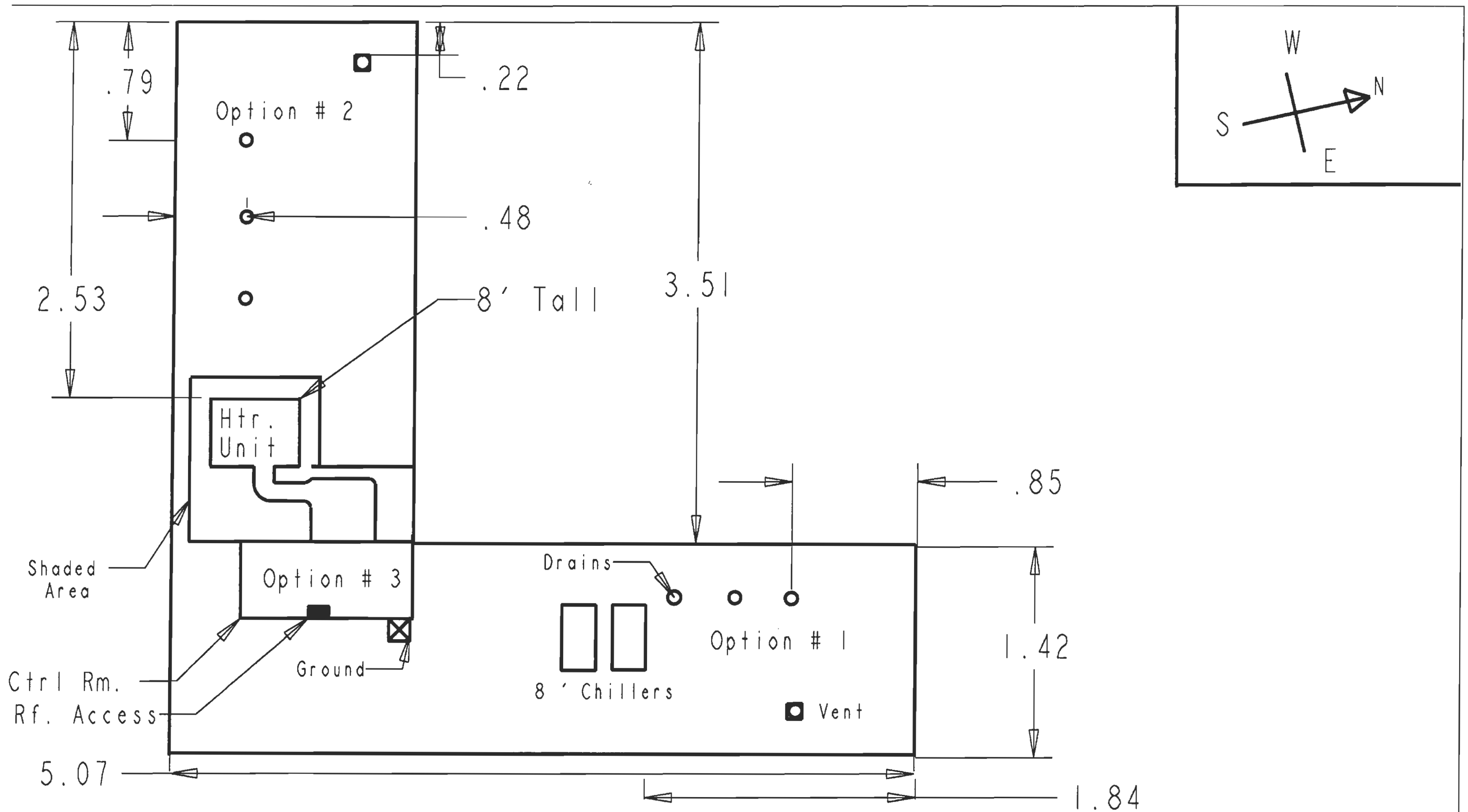
After you have familiarized yourself with this information, please call me. You may have some questions and I will be happy to answer them. I look forward to working with you on this project.

Sincerely,

Bob Fabian

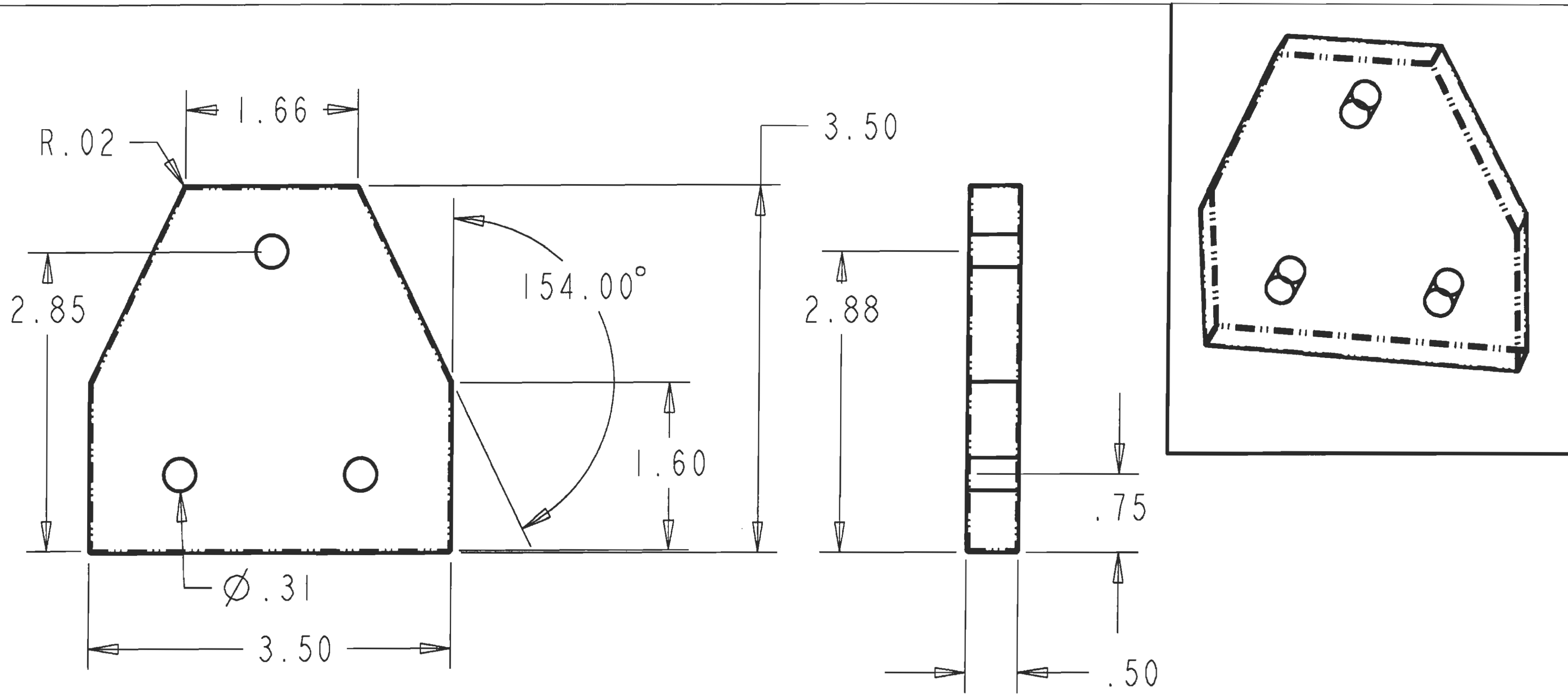
Bob Fabian

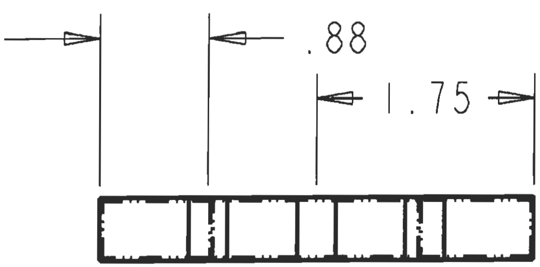
Appendix L. Drafts of Proposed Location Roof



Solar Students	Ft.	WPI DEPARTMENT OF MECHANICAL ENGINEERING WORCESTER POLYTECHNIC INSTITUTE
		TITLE Morgan Roof Top
		SIZE A | CAGE CODE 81359 | DWG NO
		SCALE .031 | SHEET 1 of 1

Appendix M. Drafts of Mounting Frames





Solar I Students

In.

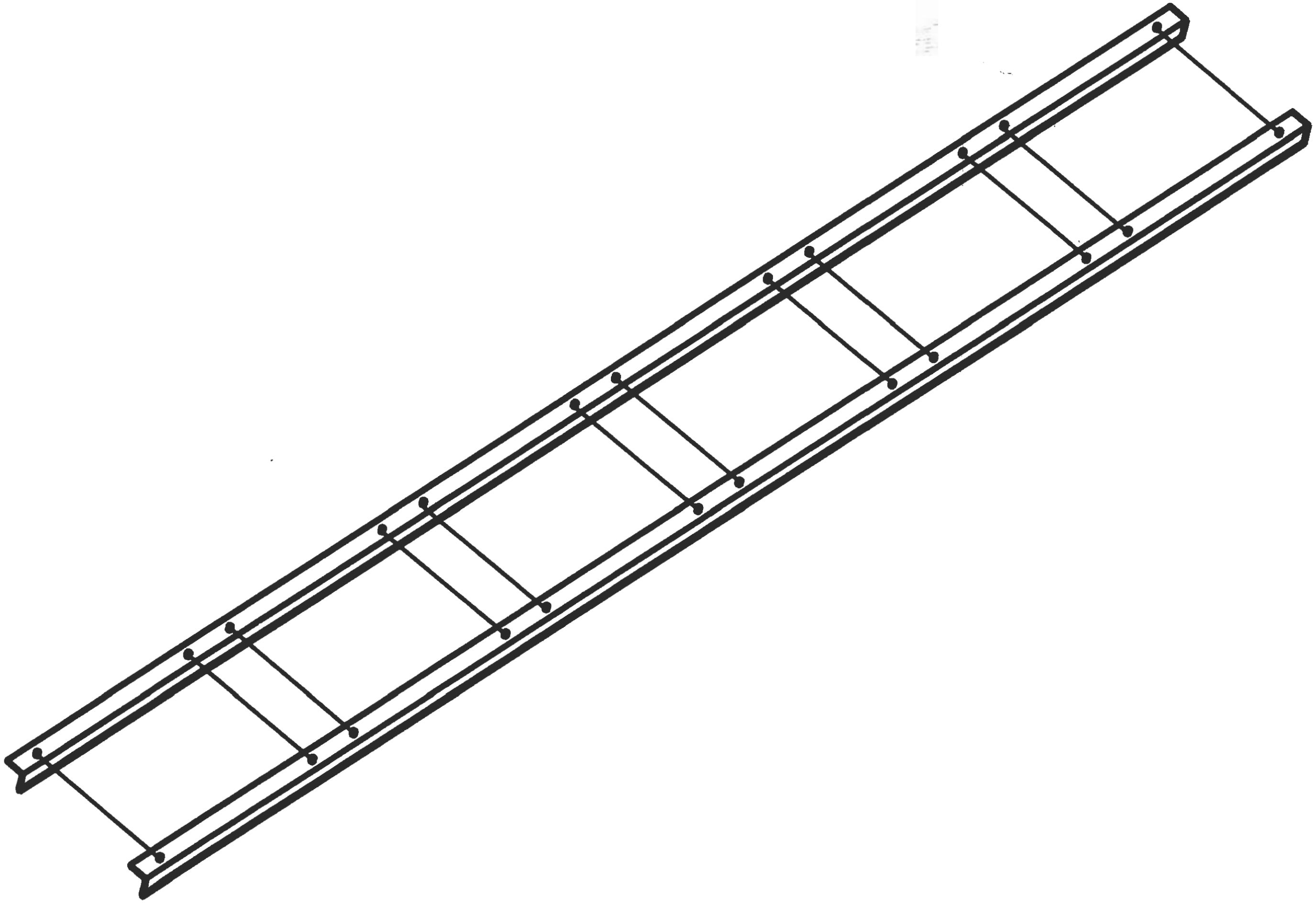
WPI DEPARTMENT OF MECHANICAL ENGINEERING WORCESTER POLYTECHNIC INSTITUTE

TITLE

Frame Bracket

SIZE	CAGE CODE	DWG NO
A	81359	

SCALE .650		SHEET 1 of 1



SolarIStudents		**WPI** DEPARTMENT OF MECHANICAL ENGINEERING WORCESTER POLYTECHNIC INSTITUTE
		TITLE Solar Panel Frame
		SIZE A · CAGE CODE 81359 · DWG NO
		SCALE 0.1 · SHEET 1 of 1

Appendix N. Morgan Residence Hall Roof Pictures

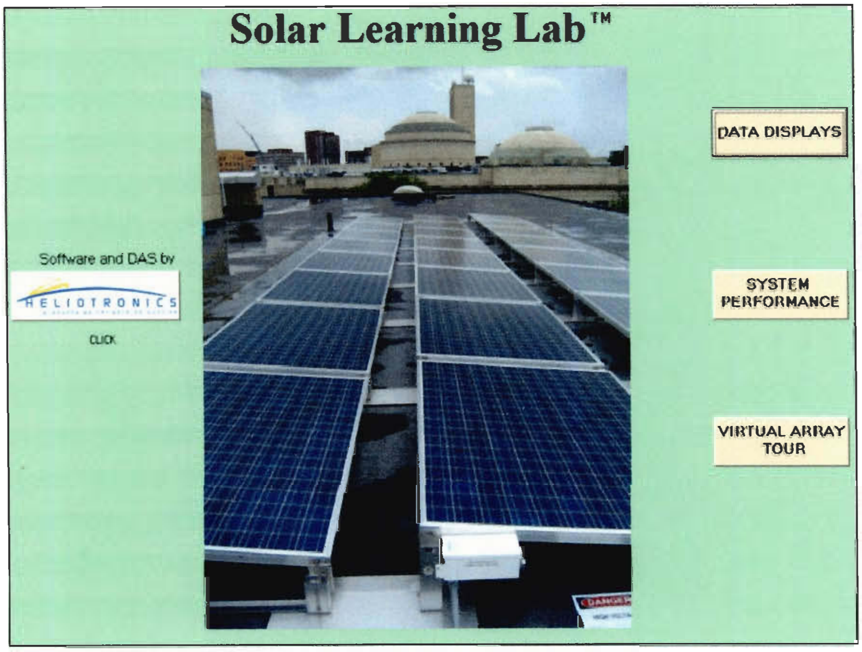
Option #1 facing South as labeled in Appendix L.

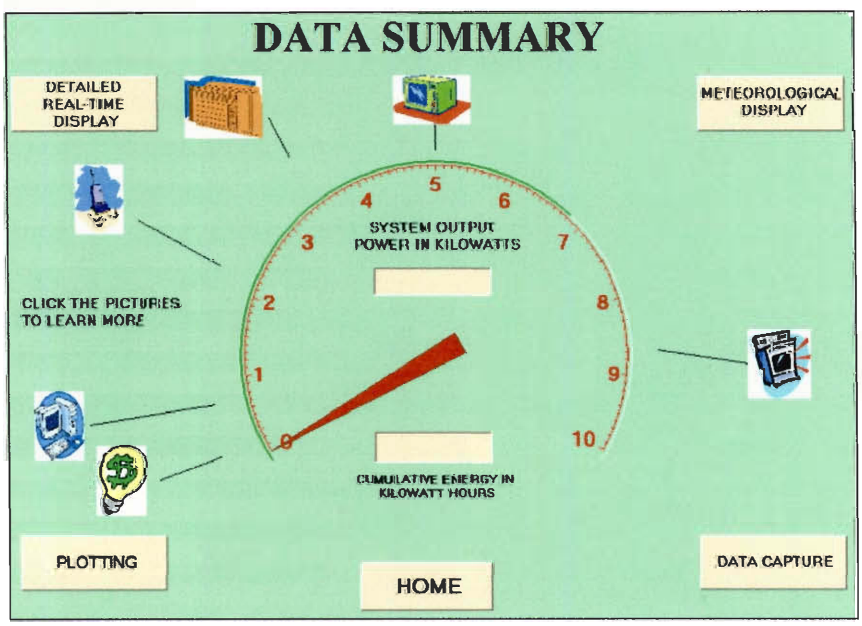
Option #1 facing North as labeled in Appendix L.

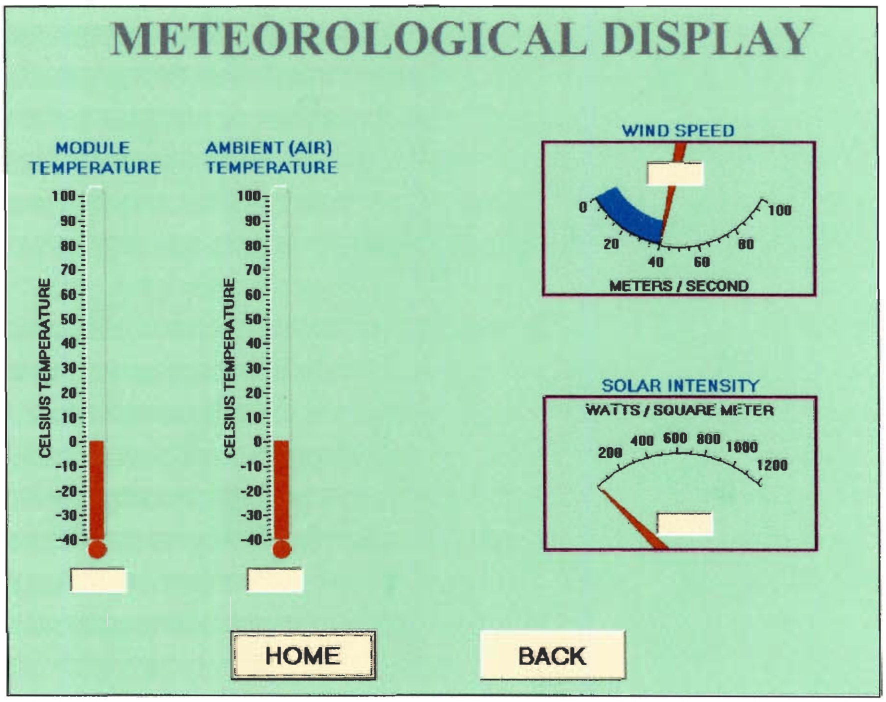
Option #2 facing East as labeled in Appendix L.

Option #2 facing West as labeled in Appendix L.

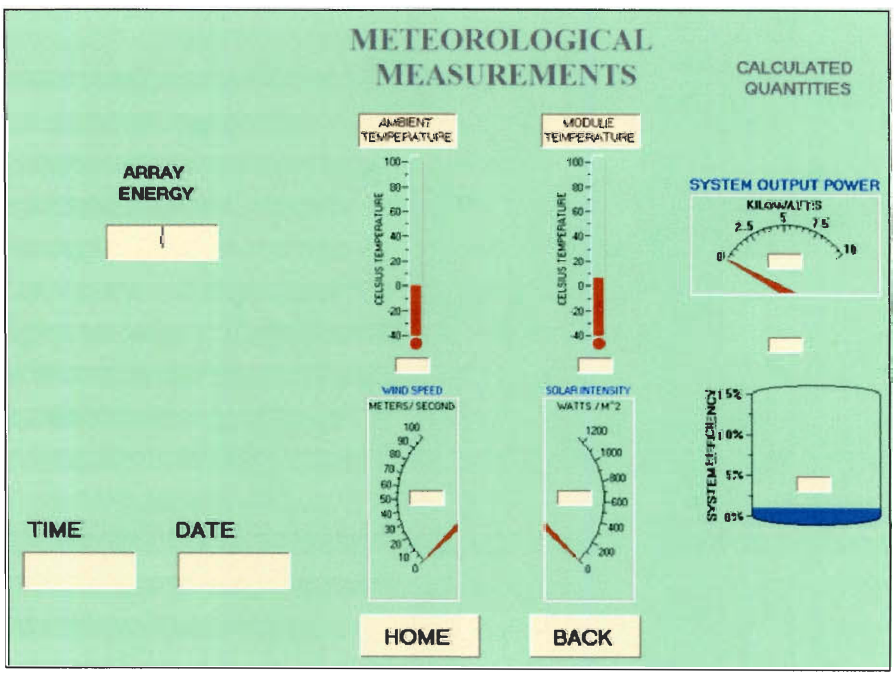
Appendix O. SunViewer™ Software Snapshots



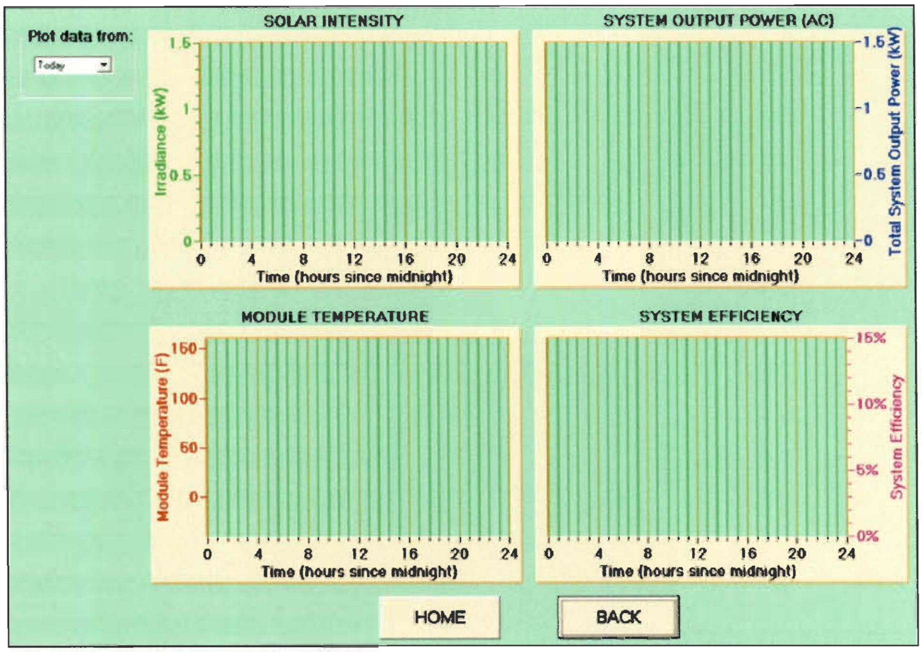


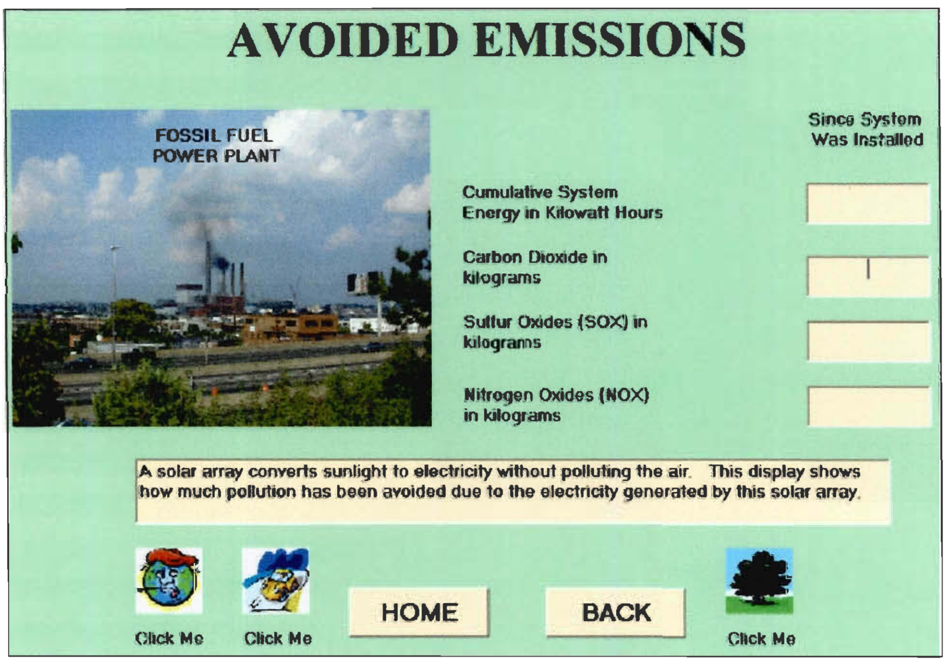


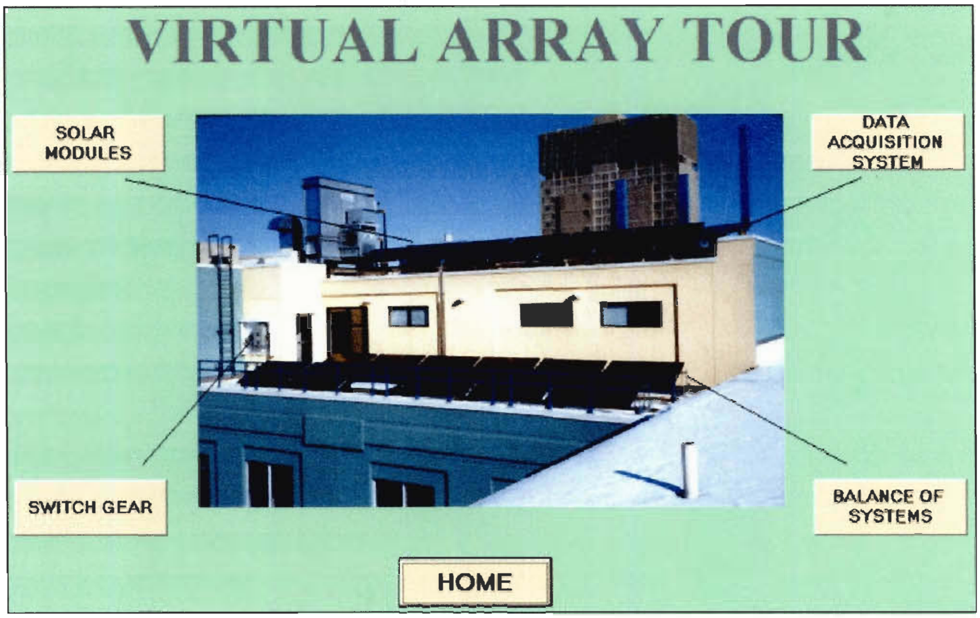
METEOROLOGICAL DISPLAY
MODULE TEMPERATURE
AMBIENT (AIR) TEMPERATURE
CELSIUS TEMPERATURE
WIND SPEED
METERS / SECOND
SOLAR INTENSITY
WATTS / SQUARE METER
HOME
BACK

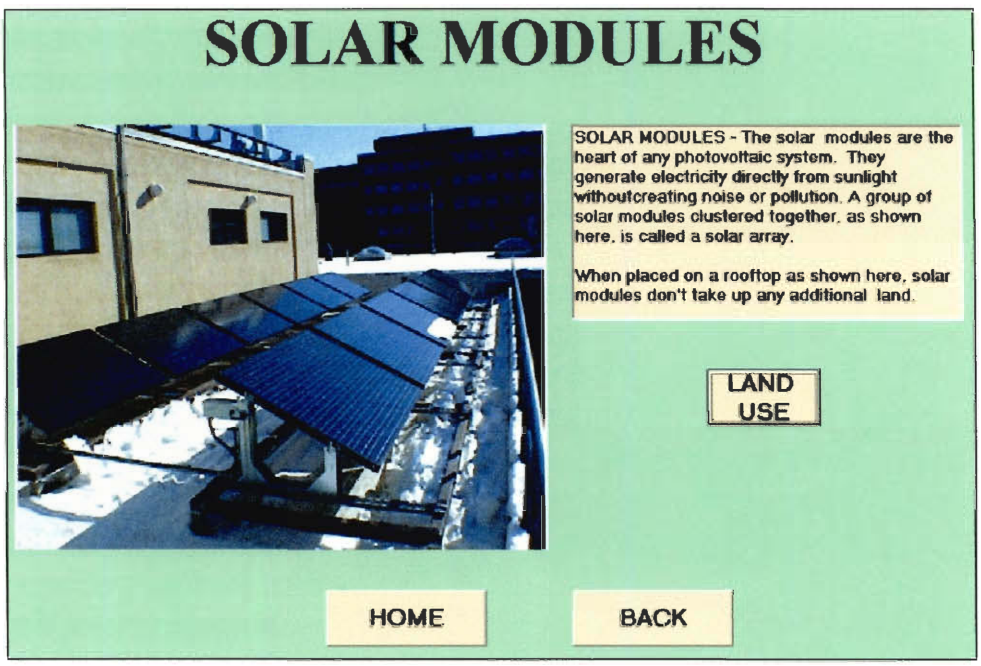


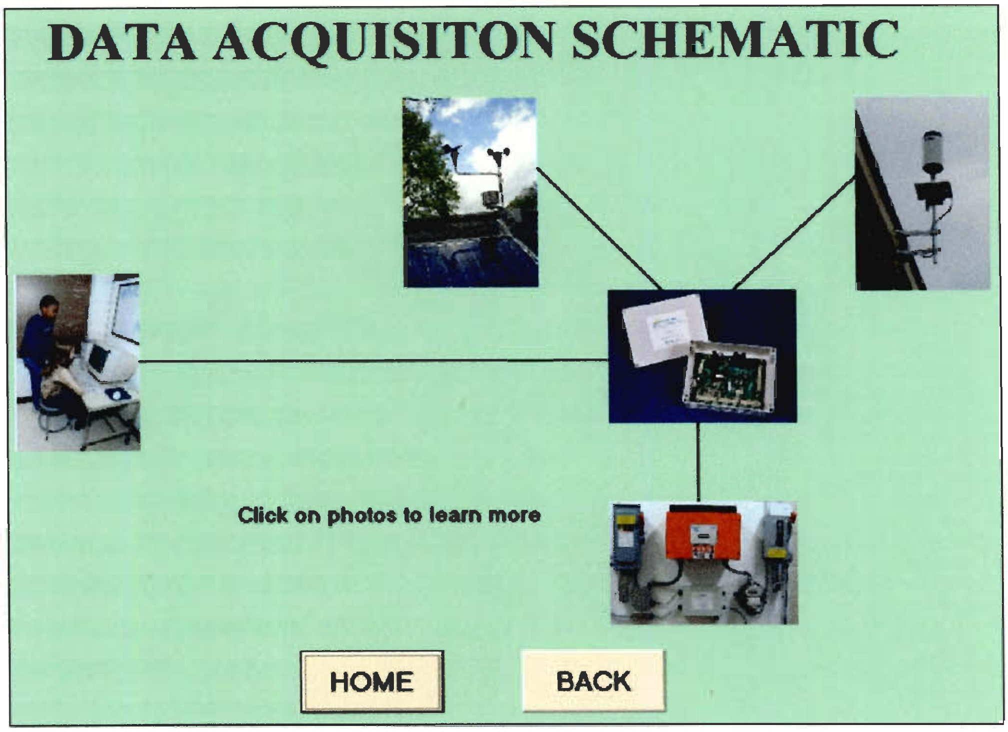
METEOROLOGICAL MEASUREMENTS
CALCULATED QUANTITIES
ARRAY ENERGY
AMBIENT TEMPERATURE
MODULE TEMPERATURE
SYSTEM OUTPUT POWER
KILOWATTS
WIND SPEED
METERS/ SECOND
SOLAR INTENSITY
WATTS / M^2
TIME
DATE
HOME
BACK

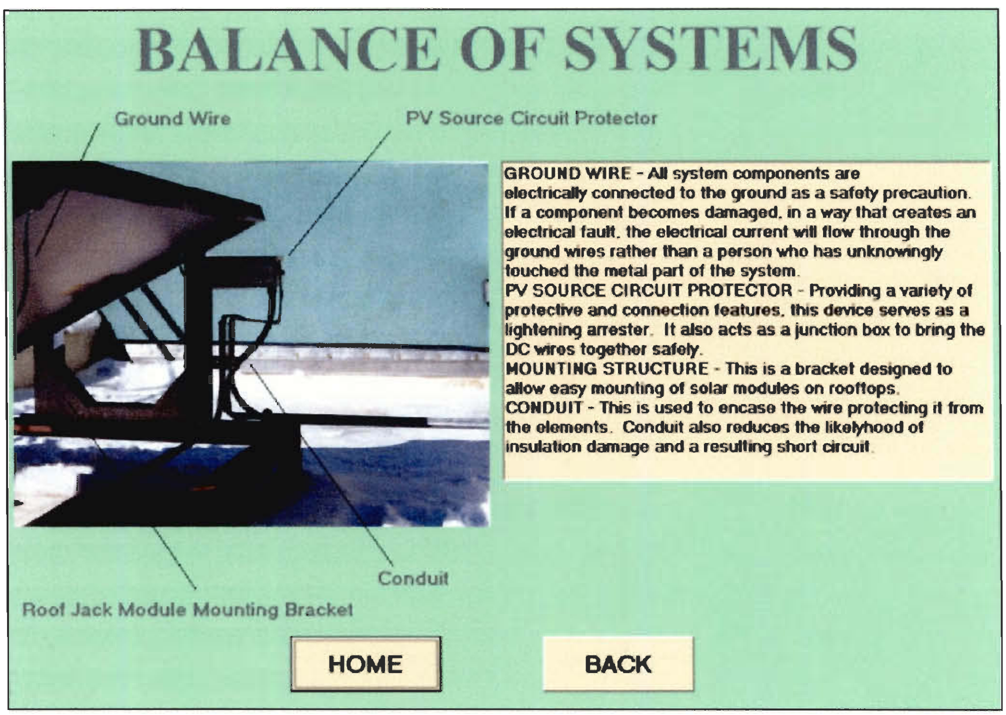

Plot data from:
Today
SOLAR INTENSITY
Irradiance (kW)
Time (hours since midnight)
SYSTEM OUTPUT POWER (AC)
Total System Output Power (kW)
Time (hours since midnight)
MODULE TEMPERATURE
Module Temperature (F)
Time (hours since midnight)
SYSTEM EFFICIENCY
System Efficiency
Time (hours since midnight)
HOME
BACK

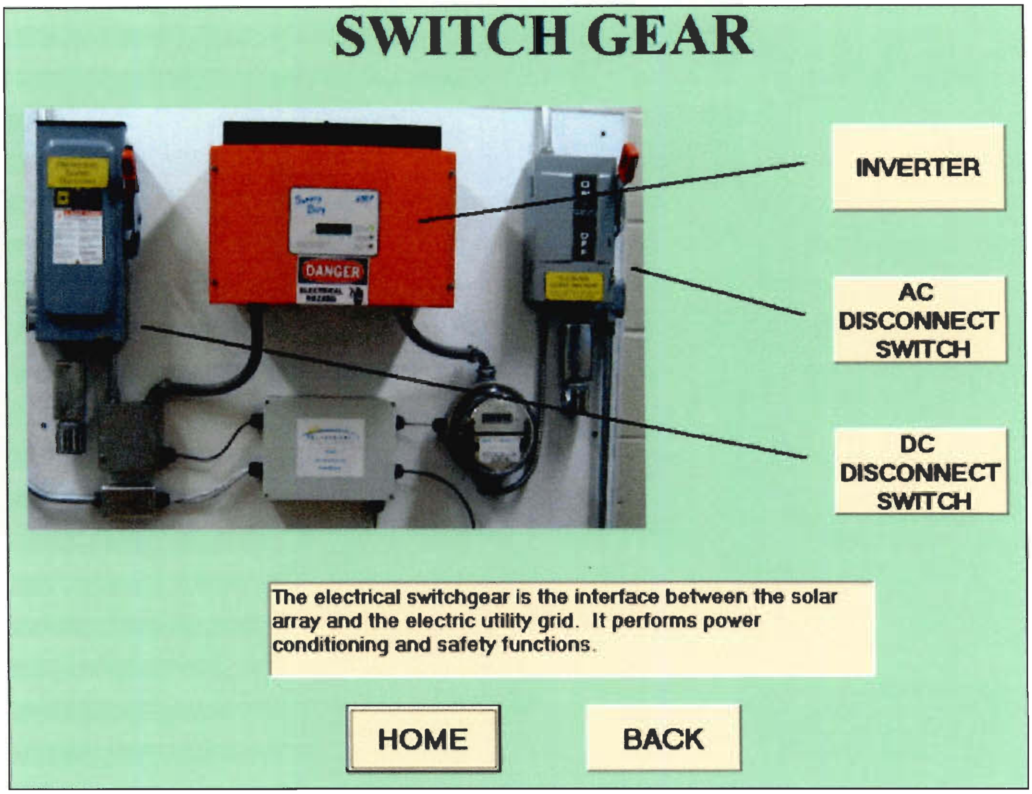

AVOIDED EMISSIONS
FOSSIL FUEL
POWER PLANT
Since System
Was Installed
Cumulative System
Energy in Kilowatt Hours
Carbon Dioxide in
kilograms
Sulfur Oxides (SOX) in
kilograms
Nitrogen Oxides (NOX)
in kilograms
A solar array converts sunlight to electricity without polluting the air. This display shows how much pollution has been avoided due to the electricity generated by this solar array.
Click Me
Click Me
HOME
BACK
Click Me


VIRTUAL ARRAY TOUR
SOLAR MODULES
DATA ACQUISITION SYSTEM
SWITCH GEAR
BALANCE OF SYSTEMS
HOME


SOLAR MODULES
SOLAR MODULES - The solar modules are the heart of any photovoltaic system. They generate electricity directly from sunlight withoutcreating noise or pollution. A group of solar modules clustered together, as shown here, is called a solar array.
When placed on a rooftop as shown here, solar modules don't take up any additional land.
LAND USE
HOME
BACK


DATA ACQUISITON SCHEMATIC
Click on photos to learn more
HOME
BACK


BALANCE OF SYSTEMS
Ground Wire
PV Source Circuit Protector
GROUND WIRE - All system components are electrically connected to the ground as a safety precaution. If a component becomes damaged, in a way that creates an electrical fault, the electrical current will flow through the ground wires rather than a person who has unknowingly touched the metal part of the system.
PV SOURCE CIRCUIT PROTECTOR - Providing a variety of protective and connection features, this device serves as a lightening arrester. It also acts as a junction box to bring the DC wires together safely.
MOUNTING STRUCTURE - This is a bracket designed to allow easy mounting of solar modules on rooftops.
CONDUIT - This is used to encase the wire protecting it from the elements. Conduit also reduces the likelyhood of insulation damage and a resulting short circuit.
Conduit
Roof Jack Module Mounting Bracket
HOME
BACK


SWITCH GEAR
INVERTER
AC DISCONNECT SWITCH
DC DISCONNECT SWITCH
DANGER
The electrical switchgear is the interface between the solar array and the electric utility grid. It performs power conditioning and safety functions.
HOME
BACK


HELIOTRONICS, INC.
HELIOTRONICS
www.heliotronics.com
Heliotronics, Inc. develops software and electronic products to educate the public about solar energy. Our company's mission is to move society more rapidly to the day when environmentally friendly solar energy will be a mainstream power source. Learn more about Heliotronics at www.heliotronics.com.
CLOSE