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SOLAR ENERGY AND PHOTOVOLTAICS EDUCATION IN WORCESTER

An Interactive Qualifying Project: submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

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Abstract

The goal of this project was to promote awareness and education of sustainable energy on a local scale. To achieve this goal we implemented a solar photovoltaic array at WPI, including a data acquisition and display system. Further, we developed an educational program, for both students and educators, to promote sustainable and solar energy education in schools. Finally, we attempted to ensure the long term viability of this project by promoting it at WPI and in the local community.

Authorship

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Executive Summary	*Rupani, Wang*
Introduction	*Brande*
Background	*Brande, Rupani*
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Results and Analysis	*Brande, Rupani, Wang*
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Appendix Q: Professional Development Program Guide	*LaBossiere*

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In addition, we would like to thank the Class of 1975 for their generous donation of $10,000 that was crucial to our project.

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We are greatly appreciative of Martha Cyr's help through providing us with the information and guidance that made it possible for us to create the educational programs for our report. She also gave us the opportunity to implement our educational programs in the real world.

We would like to thank Mike Dorsey and Kevin Wynn for helping us spread awareness of our project to the community, both within WPI and in the Worcester area.

Finally, we would like to thank Solar Now for providing us with eight solar panels for future use in educational programs.

Executive Summary

Introduction

The use of many conventional energy sources, such as fossil fuels, depletes natural resources, damages the environment, and threatens public health. These energy sources are therefore considered not sustainable. A common definition of sustainability is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainable energy sources, such as wind and solar energy, pollute minimally and do not risk depletion of natural resources at the same rate as fossil fuels. Therefore they can meet the needs of the present without compromising the future.

However, as it stands, sustainable energy accounts for less than one percent of global power production for a variety of reasons. Some reasons for not adopting sustainable energy include implementation cost and installation space (finding a large enough area for a high output wind or solar farm). Additionally, there is a lack of fundamental education regarding sustainable energy at the K-12 and post secondary levels in this country and elsewhere. Therefore, while many people may be familiar with the idea of sustainable energy, young people are not necessarily fully educated about the issue. Finally, there is a general lack of awareness of sustainable energy in society.

Project Scope

In an attempt to address the lack of awareness of sustainable energy, two consecutive projects were started in order to promote the awareness of sustainable energy in the 2003 – 2004 academic year. Heliotronics, a business with a similar goal of promoting solar energy, sponsored these projects. The WPI class of 1975 also supported these projects through a $10,000 donation. The first project team defined the goal of promoting solar energy awareness through establishing a Heliotronics Solar Learning Lab™ on the WPI campus and creating educational programs for Worcester public schools and WPI outreach programs. The first project team built the foundation of our project by conducting a feasibility study of the project goals. They conducted interviews with key stakeholders and obtained administrative approval for the Solar Learning Lab™ installation. The first project team also acquired price quotes from several material suppliers, Heliotronics and Solar Works Inc.

The Solar Learning Lab™ is a product promoted by and partially supplied by the project sponsor, Heliotronics. It consists of a data acquisition system, supplied by Heliotronics, which is coupled a power generating photovoltaic array. The photovoltaic array was purchased separately from RWE Schott Solar Inc. The educational value of the Solar Learning Lab™ comes from its interactive software. The Heliotronics SunServer™ software runs on a PC that communicates with the data acquisition module and broadcasts information over the local area network. This information can be accessed from the local area network with Heliotronics' SunViewer™ software. Also, Heliotronics' SunViewer.net™ software is a web-portal, allowing access of the information from SunServer™ through a web page.

This is the report of the second project team. We worked to establish a photovoltaic installation on the WPI campus. This installation included the Solar Learning Lab™. We also set out to develop educational programs that promote solar energy. These educational programs include a weeklong lesson about sustainable energy for 8th/9th grade students and a workshop for a professional development program for high school and middle school educators.

Project Goals

The overall vision of our project is to positively change attitudes toward solar energy at WPI, Worcester public schools, and the general Worcester area. The main goals that we established in order to work toward our vision are:

- Establish a solar installation at WPI
- Market and promote solar energy at WPI
- Create solar energy oriented educational activities

The solar installation consists of the photovoltaic array and the Solar Learning Lab™ data acquisition system. Establishing the installation is an essential goal to our project because it serves as a tool for promoting awareness and education of solar power. The key purpose of this physical installation is not only the "green" power that it generates, but also the "green" education that it has to potential to generate. Marketing the attractiveness of solar power at WPI supports the survival of the installation and works toward our vision of promoting solar energy awareness. The solar energy oriented educational activities support our efforts to make K-12 students aware of the benefits of sustainable energy.

Methodology

The work of the first project team provided a solid foundation for us to establish the photovoltaic array and Solar Learning Lab™. They met with several key members of the WPI administration, including John Miller (Director of Physical Plant), Chris Salter (Manager of Technical Trades), Sean O'Connor (Director of Network Operations), and Thomas Lynch (VP of Information Technology), and obtained their approval for the project. Also, the first team examined the logistical issues of the installation, such as array placement and utility interconnection, and secured price quotes from material suppliers Heliotronics and Solar Works.

Our project team continued the work of the first team by first reestablishing contact with key stakeholders from the first team and securing their support. The main WPI organizations that we worked with to establish the installation were Plant Services and Network Operations. We also located a different, less expensive supplier, RWE Schott Solar Inc., for the power generating components. Purchase of materials from this supplier was arranged by the Massachusetts Energy Consumers Alliance, a non-profit organization. Our installation participates in the Mass Energy program to establish 100 kW of solar installations in the greater Boston area. By participating in this program we obtained bulk prices for the RWE Schott components and we received funding from the Massachusetts Technology Collaborative (MTC). This funding allowed us to stay within our $10,000 budget.

The installation of the Solar Learning Lab™ will be performed under the supervision and with the assistance of WPI Plant Services and WPI Network Operations. The eight students that were involved in the two projects will contribute physical labor, but Plant Services will provide all professional work, such as electrical and roofing work. Network Operations will primarily help with the setup of the PC for the Solar Learning Lab™ software, which will include connecting it the local network. These organizations have also agreed to oversee and maintain the Solar Learning Lab™ installation for its full operating lifetime.

The educational material that we developed was created under the guidance of Martha Cyr, a qualified educational expert and the director of K-12 outreach at WPI. Mrs. Cyr helped us develop our objectives for education programs. With her advice, we decided on creating an educational module for 8th/9th grade students and developed a portion of a workshop for a professional development program for high school and middle school educators. We also discussed the possibility of adapting the educational module into the WPI outreach programs with Mrs. Cyr. Further, we contacted Joseph Buckley, the science liaison for Worcester Public Schools about the possibility of integrating these activities into the Worcester public schools.

We approached our goal of marketing the installation mostly through contact with Kevin Wynn (Assistant Director of Media Relations) and Mike Dorsey (Director of Communications).

Results

The grid-connected solar installation will reside on the roof of Morgan Residence Hall, providing roughly 1 kW of clean, renewable power. The installation is part of the Solar Learning Lab, an educational product of our sponsor Heliotronics. The SunViewer™ software will be output to plasma display screens on the first floor of Morgan residence hall.

To fulfill our educational goals, we created a week long set of activities designed for 8th/9th grade students. These activities were primarily modified and adapted from similar education activities and programs, developed by professional educators, designed specifically for education relating to energy use and alternative energy sources. The educational program is very flexible, educators can choose whether to do the full week or use only a couple of activities as standalone lessons. These educational activities can also be easily adapted to fit into the WPI summer outreach programs, where middle school students come to WPI to participate in summer educational workshops.

As another part of the educational contribution of our project, we designed a portion of a workshop for a professional development program for high school and middle school educators. The workshop is a nine day session designed to teach educators about the engineering design process and about solar energy. Our portion of the workshop consists of an hour every day for eight days. Its focus is solving a design problem through the use of solar power. This workshop will promote understanding of solar power and stimulate interest in the subject for these educators, which may lead to them educating their students about sustainable energy. Also, at the end of the workshop, participants will be given a copy our educational module that they can choose to integrate into the curriculum at their schools.

We also enjoyed success in generating publicity for the project and marketing the project to WPI. Virtually all of the WPI administrators that the two project teams met with, such as the heads of Plant Services and Network Operations, along with Vice Presidents Steven Hebert and Thomas Lynch, approved of our project. Through contact with representatives from WPI University Relations and Media Relations, Kevin Wynn and Mike Dorsey, we also received support in generating publicity for the installation. Kevin Wynn helped schedule press coverage of the installation with media. Mike Dorsey will be able to have articles on our project placed in several of WPI's publications, including Transformations, a prominent magazine sent to tens of thousands alumni, faculty and staff, relatives of students, members of the community, and other individuals affiliated with the university.

Recommendations

This section presents our team's recommendations for the future of the Solar Demonstration project and Solar Learning Lab™ installation, along with the conclusions we have drawn regarding these recommendations. Our recommendations are broken down according to recommendations relating to the installation, to education, and to marketing.

Recommendations Regarding the Physical Installation

> We recommend that WPI's Manager of Network Operations pursue an interactive terminal for the SunViewer^{TM} software, possibly using the touch screen plasma display to be installed in the Campus Center
>
> We recommend that Network Operations maintain the SunServer^{TM} PC terminal and strive to achieve maximum uptime for the server.
>
> We recommend that Plant Services and Network Operations collaborate to install a visual display feed from the rooftop installation.
>
> We recommend that Plant Services provide upkeep and maintenance for the installation.
>
> We recommend that GAEA and Plant Services collaborate to arrange periodic minor maintenance of the installation.
>
> We recommend that Plant Services investigate the feasibility of allowing interested parties to view the rooftop installation in person.
>
> We recommend that the Web Development Office create a website for the installation on official WPI web space.
>
> We recommend that WPI's Manager of Technical Trades submit the monthly PTS data figure online.

Recommendations Regarding Educational Material

> We recommend that the Science Curriculum Liaison for Worcester Public Schools work actively to implement our educational programs in Worcester area school classrooms.
>
> We recommend that WPI's Director of K-12 Outreach pursue developing educational modules for grades beyond the ones targeted by our educational program (8th and 9th).
>
> We recommend that WPI's Director of K-12 Outreach and the director of WPI's summer programs pursue integrating our classroom education modules into summer educational programs hosted by WPI.
>
> We recommend that WPI's faculty investigate the possibility of integrating the installation into WPI curriculum, possibly by considering a major or minor in Renewable Energy engineering.

Recommendations Regarding Marketing

We recommend that WPI's Director of Marketing & Communications and Assistant Director of Media Relations undertake a long term effort to market and publicize the project in addition to their current roles.

We recommend that GAEA consider sponsoring events on the topics of sustainable and solar energy.

We recommend that Tech News publicize the project.

We recommend that the Committee on Student Life Issues of the Student Government Association design a question about solar and renewable energy, specifically containing references to the installation, to be put on myWPI as a survey question early in the next academic year.

We recommend that the WPI Admissions Office take an active interest in our project by including a mention of the installation on campus tours and featuring the installation in admissions literature.

Recommendations to the Advisors

We recommend that the current Solar Demonstration project advisors establish future, related projects.

We recommend that the project continue to be promoted to the WPI vice presidents and to the incoming WPI president by the project advisors.

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1 Introduction

Energy production, including its history, future, and drawbacks, has become a major modern issue reaching into science, politics, and education. Energy production holds a place as part of the foundation of our modern society, and therefore has been the subject of a great deal of scrutiny. While certain topics surrounding energy production are more hotly debated than others, unquestionably one of the most prominent issues is energy sustainability. A common international definition of sustainability is, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [54] In other words, sustainability represents the ability to provide energy from sources that are plentiful such as wind and solar, without harmful side effects such as damage to the environment, damage to society, and damage to public health.

Under the umbrella of sustainability, pollution has continued to be a popular topic of discussion in recent years as scientists continue to gather more evidence that human influence is having a large and likely adverse impact on the global environment. While many sources are cited as the causes of this pollution, there is no doubt that energy production relying on conventional fuels (including fossil and nuclear fuels) is a fundamental source of pollution.

Furthermore, energy production currently relies almost exclusively on non-sustainable fuels. These include traditional fossil fuels, such as coal and petroleum, in addition to nuclear fuels. While these fuels offer a favorable short-term solution in terms of cost and implementation they are also representative of what is non-sustainable. As of 1993 fossil fuels such as coal, oil, and natural gas were being consumed at a rate about 100,000 times faster than they were being created [55] There are varying reports concerning the quantity of fossil fuels remaining at our disposal, but there is no doubt that at the current rate of consumption our fossil fuel supplies will be depleted, perhaps as early as this century.

One possible solution to the problem of pollution and sustainability in energy production is in low or non-polluting sustainable energy sources. More specifically, non-polluting, sustainable energy sources, such as wind and solar, present an attractive solution for decreasing pollution and dependence on conventional fuels as they can provide large amounts of power with no chemical emissions from sources that are readily available and will never be depleted.

However, as it stands, sustainable energy accounts for less than one percent of global power production for a variety of reasons. Obvious reasons for not adopting sustainable energy include implementation cost and installation space (finding a large enough area for a high output wind or solar farm). At the same time there is a lack of fundamental education regarding sustainable energy at the K-12 and post secondary levels in this country and elsewhere. Therefore, while many people may be familiar with the idea of sustainable energy, young people are not necessarily fully educated about the issue. Furthermore, there is a general lack of awareness of sustainable energy in society.

The vision of this project is to promote awareness and education of sustainable energy in the greater Worcester area in the hopes of promoting sustainable energy as a viable solution for long-term power production and pollution reduction. Our goal for moving towards this vision is to implement a solar energy installation on the WPI campus and to create education and learning programs about sustainable energy. Our sponsor, Heliotronics, shares this goal on a broader scale, and works to promote sustainable energy through solar photovoltaics (PV) and more specifically through their Solar Learning Lab^{TM} system. By implementing a Solar Learning

Lab^{TM} installation on the WPI campus and generating educational outreach programs we will try to promote awareness through education about sustainable energy.

2 Background

This chapter presents information in three major areas. The first area covered is the fundamentals of how the hardware in solar panels and solar installations works. The second area is how technology and engineering are currently being integrated into schools both statewide and nationally. The final area is how companies and organizations are currently marketing solar energy and how it can be marketed as a viable sustainable energy source. The information presented provides insights into and a context for renewable energy technologies in today's world.

2.1 Renewable Energy – Implementation, Potential and Demand

This section presents an overview of the state of renewable energy technologies in terms of their current implementation, latent potential and consumer demand. The reliance of the United States on conventional energy resources is examined, followed by a demonstration of the potential of renewable energy technologies. Finally it is presented that there is a sizeable consumer demand for a move towards these renewable energy producing technologies.

2.1.1 The Current State of Conventional Energy

America's energy system is dominated by fossil fuels; according to the U.S. Energy Information Administration (EIA), 89 percent of our electricity, a component of energy demand, is generated from fossil fuels and nuclear power [1] (Figure 2.1). Research in fossil fuels suggests that they endanger the environment through mining, refining, waste disposal, and vulnerable delivery systems. Similar research has also linked fossil fuels to increased mortality rates, acid rain, and global warning. [2, 3, 4] These energy sources are considered non-sustainable, part of which means that they have finite reserves, which is a topic of much debate and speculation. Scientists have known for over half a century that conventional energy supplies cannot sustain the globe indefinitely in light of diminishing reserves and increasing global energy demands. [5] Estimates made by the U.S Geological Survey in 2000 and analyses based on those estimates and consumption rates done by David Deming, an experienced earth scientist, predict that the world oil supplies will be depleted by 2056. [6, 7] Many scientists share the position that alternative sources of energy to fossil fuels must be developed if the world is to continue to meet its energy needs. [5, 8]

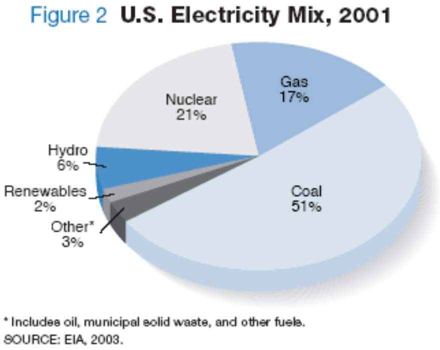
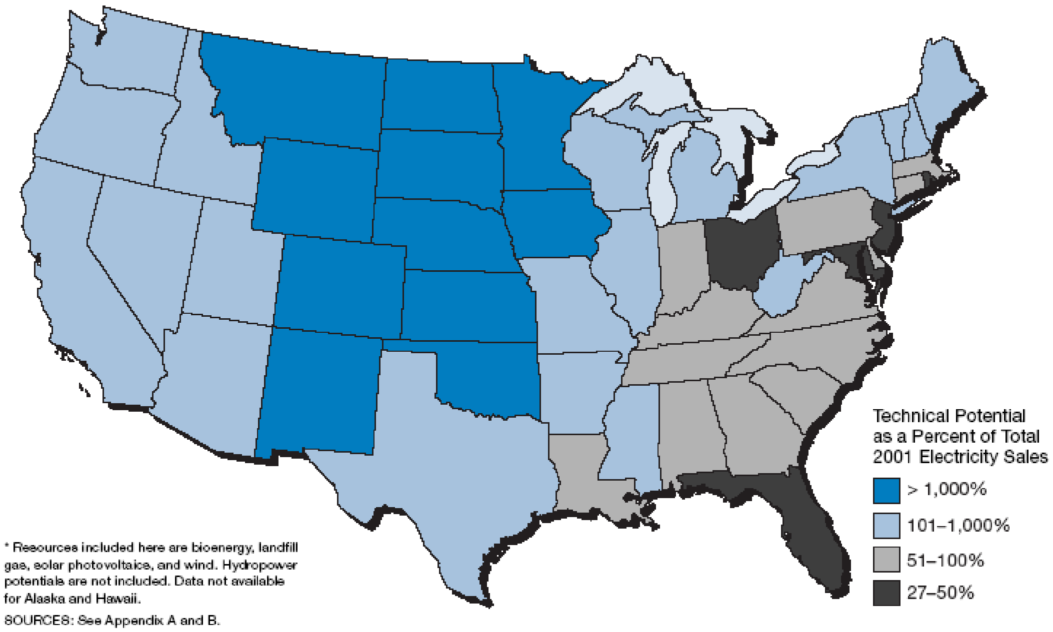


Figure 2.1: US Electricity Mix, 2001

2.1.2 The Case for Sustainable/Renewable Energy

One suggestion by private organizations, such as the Union of Concerned Scientists (UCS), is that the growing reliance on fossil fuels and nuclear power can be reduced by using clean, renewable energy sources such as solar, wind, geothermal, landfill gas, and bio-energy (fuel from organic materials including wood and agricultural wastes or crops grown specifically to produce energy). The UCS asserts that these are safe energy sources that rely on hardware and raw materials that are available in many parts of globe and, through efforts to raise awareness and acceptance, are becoming increasingly cost-effective. They further state that solar, wind, bio-energy, geothermal, and landfill gas represent some of the major non-hydroelectric renewable energy technologies with significant technical potential. Figure 2.1, from the UCS, portrays the technical potential of states to generate their electricity from renewable sources. According to the figure, thirty states have the potential to generate all of their electricity from renewable sources and even have a surplus of renewable electricity that could be exported to other states.



* Resources included here are bioenergy, landfill gas, solar photovoltaics, and wind. Hydropower potentials are not included. Data not available for Alaska and Hawaii.

SOURCES: See Appendix A and B.

Figure 2.2: Renewable Energy Technical Potential of States in the U.S[9]

Several recent studies by government agencies and nonprofit organizations, such as the UCS, have shown that increasing the use of renewable technologies in the United States would create an energy system that

- Is more diverse;
- Safer;
- Pollutes less;
- Reduces the emissions causing global warming;
- Creates jobs;
- Saves consumers money;
- And stimulates rural economies [10, 11, 12, 13, 14, 15, 16]

The EIA suggests that, despite the claimed benefits of renewable over traditional energy, there is a "clean energy gap" in this country, in that renewable energy sources, excluding hydropower, account for only two percent of electricity generation. [1]

2.1.3 Consumer and Industry Interest in Sustainable/Renewable Energy

In addition to enthusiasm from groups such as the UCS, polls and studies also show that there is consumer interest in renewable energy. Consumer polls taken by the Mellman Group and Gallup Organization make it clear that consumers want more renewable energy. When asked recently whether power companies should be required to generate 20 percent of their electricity from sustainable sources, thereby reducing our dependence on fossil fuels, 70 percent of respondents said "yes." [17] These responses indicate that consumers feel that these energy sources are cleaner and more secure than oil, gas, coal, and nuclear power. Other polls show 80 to 95 percent support for increased development of renewable energy sources. [18, 19, 20]

According to the UCS, one oft-stated reason for resistance to adoption of sustainable or renewable energy sources is a high initial cost. However, the UCS states that in reality the costs of renewable energy have come down significantly in recent years and that studies show increasing economies of scale and improved performance can continue to decrease the costs. According to the Photovoltaic Insider's Report generating costs for photovoltaic systems have declined about 15% every year from 1971 to 1993. [21] These trends would seem to indicate that the solar industry has entered a positive feedback loop, where demand creates lower prices and then in turn lower prices increase demand.

Consumer surveys make it clear many that consumers are also willing to pay more for sustainable energy. A survey conducted by the Mellman Group in February 2002 found that 65 to 72 percent of consumers would be willing to pay two or three dollars more on their monthly electricity bills as a result of utilities being required to obtain 20 percent of their electricity from renewable sources by 2020.[17]

Further surveys have also noticed a strong domestic demand for sustainable energy from consumers concerned about the environmental impact of their energy sources. A survey conducted by Research Strategy Management Inc. polled consumers on what energy sources they preferred. It showed that Americans favored renewable energy the most, followed in a close second by energy efficient technologies. Natural gas was favored slightly, but other fossil fuels and nuclear energy were not favored. According to this survey three of every four respondants are willing to pay more for energy from renewable sources. About 23% would pay up to 2% more, 26% would pay between 2% to 5% more, and 26% would pay between 5% and 10% more.[22]

According to the Utility Photovoltaic Group (UPVG), a consortium of utilities striving for the commercialization of photovoltaics, both foreign and domestic demand for photovoltaic systems has risen. The UPVG further mentions that photovoltaic systems are presented as attractive energy sources in developing nations where connecting to a main power grid would be unfeasible due to cost, availability, and/or reliability issues. India is becoming one of the world's largest manufacturers of photovoltaic cells and the government is planning to power 100,000 villages and install solar powered phones in all 500,000 of the nation's villages. Mexico plans to power 60,000 villages with solar power and some of Zaire's major hospitals rely entirely on solar power. Solar power has the ability to bring electricity to people in developing nations where conventional power sources, such as grid interconnection to main power plants, is unfeasible due cost or practicability. [23]

In the United States, according to the Photovoltaic Roadmap (PV Roadmap) presented by Sandia National Laboratories, the photovoltaic industry is very optimistic about the future of photovoltaic electricity. The U.S. PV industry represented by the PV roadmap states one of its goals is to provide 10% of the United States' supply of electricity by 2030. The PV Roadmap outlines the necessary steps by the government and the photovoltaic industry to achieve this goal. This roadmap calls for various activities to occur over the course of twenty years, such as policy change that promote the use of sustainable energy, reinvestment of profit into marketing and publicity for photovoltaic technology, and creation of public awareness programs for solar power. [24]

The research and information presented by a wide variety of government and private groups, such as the EIA, the UCS, and the UPVG, asserts that there are growing real, negative effects from conventional energy sources. Furthermore, this research and information along with polls of consumers such as those by the Mellman Group and the Gallup Organization suggests the trend that sustainable energy is becoming viable both technologically and commercially.

2.2 Photovoltaic Technology

One of the more mature forms of sustainable energy is solar energy. While solar energy can be used in various ways, one of major applications is photovoltaic electricity. Photovoltaic technology, despite having its origins in the 1830s [25] has only in the last thirty years begun to receive the same sort of attention that more mature technologies have enjoyed. Despite the slow start of photovoltaics, the technology has received a good deal of funding and governmental support in the last quarter century; a large part of this support has come from the U.S. [26] The rapid expansion of the space program in the 1960s (the "space race") along with the oil crisis in the late 1970s both played roles in encouraging the growth of solar energy and garnering support in both government and civilian circles. This section presents a brief description of the technology behind photovoltaic electricity including the photovoltaic effect, photovoltaic hardware, and photovoltaic installations.

2.2.1 Description of Photovoltaic Hardware

The fundamental basis for photovoltaic electricity is the photovoltaic effect which converts sunlight into electricity and can be used for power generation. Sunlight is comprised of photons which have different amounts of energy based on different wavelengths of light. These photons can be absorbed by the photovoltaic (PV) panels and can subsequently energize electrons, freeing them from their normal bonds. These electrons will then flow in a certain direction while the "holes" left by the electrons will flow in the opposite direction as a result of an opposite charge, thus creating an electric current. [27]

The construction of a PV panel is, however a somewhat complex task. PV panels are comprised of PV solar cells which are P-N junction photodiodes. These PV cells are made of two semiconductors layers (P and N type semiconductors) sandwiched between two conductor layers (usually made of metal) which serve to collect the current generated by the cells. [28]

Crystalline silicon (c-Si), in a variety of forms, is the primary material used for the semiconductor layers in solar cells. C-Si cells have existed for about 45 years and although somewhat mature continue to be researched and improved. Thin film solar cells, which use layers of semiconductor material only a few micrometers thick are also available at a lower cost than traditional c-Si cells as there is a much lower amount of semiconductor material required. Dye-sensitized solar cells, which use a dye-impregnated layer of titanium dioxide as opposed to semiconductor material, and polymer solar cells are also being researched as lower cost alternatives to solar cells using semiconductor material. [28]

In addition to the material used in PV cells there are a variety of other options in their construction. The semiconductor material used in PV cells can be "doped" with substances such as boron or phosphorous to change the properties of the semiconductor, allowing it to respond to different light frequencies. Furthermore, several layers of different semiconductor cells can be used to create a multijuntion device. Each PV cell layer in the device responds to a different frequency of light, which allows the device to capture a larger portion of the energy contained in sunlight. Other considerations in the construction of a PV panel include the use of anti-reflective coatings which allow a larger portion of the sunlight to strike the semiconductor layers instead of being bounced away by a glass or plastic covering. [28]

Another technique to increase the output of PV cells without greatly increasing the cost is concentrating the sunlight falling on the panels. Mirrors, mirrored dishes, Fresnel lenses, and other devices can be used to concentrate or focus sunlight to either maximize the efficiency of the panels or to allow the use of a smaller amount of semiconductor material. [28]

The output of PV cells is frequently condensed into an efficiency percentage. This percentage figure depicts how much solar energy striking the PV cell is actually being converted into energy. According to the U.S. Department of Energy (DOE) factors affecting efficiency can include the operating temperature of the PV cell, the reflectivity of the PV cell, the wavelength of light being converted, and the natural resistance of electron flow in the PV cell, among other factors.[49] A collection of solar cell efficiency tables published by the Key Centre for Photovoltaic Engineering at the University of New South Wales in 2001 provides a list of highest measured efficiencies of a variety of PV cells and modules using different materials and construction techniques. According to the tables, although there are confirmed efficiency measurements as high as approximately 30%, most PV cells are currently operating in the 16-25% efficiency range.[50]

2.2.2 Description of Small Scale Solar Energy Installations

In addition to the PV panels themselves there is also a variety of additional hardware that is involved in generating solar energy. The most important piece of additional hardware is the power inverter. Because PV panels supply direct current (DC) power while most everyday devices are designed to use alternating current (AC) power an inverter is required to take the DC power coming from the PV panels and change it into AC power to be used by fixtures and appliances. However, the process of changing DC power to AC power suffers from inefficiency. Therefore designers strive to create inverters that output the best possible power with the least possible power loss. As a result of these design choices there are two basic types of inverters, sine wave output and modified sine wave output. The major difference between the two is that modified sine wave inverters are more efficient however, modified sine wave inverters output power that can cause certain devices, such as motors and power supplies, to run less efficiently. The issue of efficiency therefore plays a role in inverter choice. Inverters can also be used with a transformer to output both standard 120VAC and 240VAC power to permit using a wider range of devices. [29]

In many consumer applications a charge controller along with a bank of batteries is used to allow for safe, continuous power production. Since PV panels are only producing electricity when exposed to sunlight batteries are employed to store this electricity during periods of low or no sunlight, such as cloudy days or at night. A charge controller is also used to ensure that the batteries are always properly charged and not overcharged or damaged. [29]

In a solar installation designed for educational purposes as well as in home systems a data acquisition system (DAS) can also be installed to monitor the installation. A DAS usually consists of a hardware system attached to the PV array that measures a variety of signals such as weather conditions and power output from the panels. This collection hardware can then send its data to a software code that allows for display of all the gathered data. A DAS can be useful for monitoring changing power output with seasons and weather conditions, maintaining maximum efficiency of the solar installation, and can be helpful as a dynamic display tool in educating about solar energy.

2.3 Renewable Energy Education

While Section 2.1 presented discussion on the overall importance of renewable energy, there still remains the issue of bringing about the adoption of renewable energy. The belief in the renewable energy community is that education is an important first step in making the transition from conventional to renewable energy. In their manual, "Renewables are Ready" the UCS states that renewable energy technologies are ready to be implemented, and renewable energy is an ideal topic for middle and high school classrooms. They assert that an educational unit on renewable energy can be used not only to teach basic scientific principles to schoolchildren but also to provide an indirect path to increased public confidence which is needed for development of these resources and to make large-scale use of renewable energy a reality. [30]

Initially this section argues that there is a place for renewable energy technologies in middle and high school science and technology curricula today by examining existing science and technology education standards and curriculum frameworks. In addition, these standards and frameworks provide a set of guidelines that any science or technology educational program for middle and high schools can be designed around, along with intended outcomes for the programs. Following this, a list of resources that contain information and examples on designing educational programs based either on solar energy specifically or science and technology as a whole are presented. These can be used as references and templates to design educational activities. Once it is demonstrated that educational activities based on renewable energy technologies can be fit into high school curricula and existing programs and activity examples have been examined, the Schools Going Solar program is presented. This program is an initiative with numerous examples of schools across the country that have not only integrated renewable energy (specifically solar energy) activities into their curricula, but also have installed working solar energy facilities in their schools, and use them for educational purposes. Schools Going Solar provides a large store of information that can be drawn on either to establish similar small-scale solar installations for educational purposes or to design educational activities centered on solar energy.

We then move from the K-12 level to the university level, and examine how renewable energy technologies have been integrated into university curricula. This discussion is centered on one particularly striking example, the University of New South Wales (UNSW) in Australia. UNSW has established a center dedicated entirely to renewable energy education and provides two undergraduate majors in renewable energy engineering and photovoltaic engineering respectively, along with masters programs and research in these fields. UNSW can be looked at as an example for how to successfully integrate renewable energy into university curricula.

2.3.1 Science and Technology/Engineering Curriculum Frameworks and Standards

Below we present information on a number of curriculum frameworks and standards that provide guidelines for educational programs in science and technology that can be implemented in schools. The standards examined range from the district level to the international level. Particular attention is paid to the Massachusetts Curriculum Frameworks.

Standards/Frameworks at the National Level

The National Science Education Standards (NSES) were drawn up by the National Committee on Science Education Standards and Assessment, and are an outline for what students need to know, understand, and be able to do to be scientifically literate at different grade levels. They describe an entire educational system at a national level. They are broken into six strands, or core topics, to enable organization of content. The NSES have the following strands that apply to teaching a unit on renewable energy technologies:

- Science and Technology
- Science in Personal and Social Perspectives [33]

The International Society for Technology in Education (ISTE) has created the National Educational Technology Standards (NETS) project initiative to help develop national standards for education of and with technology. The ISTE breaks down its standards for students into six main categories: basic operations and concepts; social, ethical, and human issues; technology productivity tools; technology communications tools; technology research tools; and technology problem-solving and decision-making tools. Thus we see that the NETS also have various categories into which a program on renewable energy technologies could fit. [34]

Massachusetts Science and Technology/Engineering Curriculum Frameworks

In May, 2001, the Massachusetts Department of Education issued a new Curriculum Framework in the area of science and technology/engineering. The purpose of the framework is to guide teachers and curriculum coordinators through what content to teach from kindergarten through high school in the fields of science and technology, through how to teach the content, and through the intended outcomes.[31]

The curriculum is designed around a set of ten guiding principles about effective K-12 programs and instruction in science and technology/engineering. The guiding principles present the ideals of teaching, learning, assessing, and administering science and technology/engineering programs.[31]

The core concept behind the frameworks, as stated in the frameworks themselves, is that if students are to become familiar with and feel ownership of questions pertaining to science and technology, then they need to engage with them in the way that scientists and technologists do. The Massachusetts Department of Education board asserts that students "…need to wrestle with contradiction, puzzle through paradoxes, evaluate evidence, and search for connections." The frameworks are designed to provide pursuits that will require students to deal with the "real world." The frameworks suggest that all educational programs in science and technology should be firmly grounded in the belief that asking questions and evaluating evidence are central to the core concept of science education.[31]

The frameworks are divided into separate strands that organize the content areas. The four strands are: earth and space science, life science (biology), physical science (physics and chemistry), and technology/engineering. Each strand details the essential knowledge and skills that students should acquire through the grades. Within each strand the learning standards are further organized by grade span and grouped by subject area topics. The standards outline in detail what students should know and be able to accomplish at the end of each grade span. One of the subsections in the Science and Technology strand (section 5, Grades 9-10) is: *Energy and Power Technologies– Electrical Systems:* Electrical systems generate, transfer, and distribute electricity. Programs based on photovoltaics and the electricity produced by solar panels would fall under this subsection in the strands.[31]

The frameworks also provide complete examples of successful and meaningful instances of actual classroom science and technology activities that have been designed and implemented based on the guidelines in the frameworks. These examples are accompanied with specific explanations of how different sections of the activities are linked to the frameworks. [31]

Wachusett Regional School District (WRSD) Framework Revision

A revision of the Massachusetts Engineering Frameworks undertaken by the Wachusett Regional School District (WRSD) presents modified strands that are compatible with teaching renewable energy technologies. A description of these specific strands is provided below.

Strand 4: Science Applications

The science applications standards in the Wachusett District revision establish connections between the natural and designed worlds. These standards emphasize a fundamental understanding about the links between science and technology. These standards require students to develop abilities to identify and state a problem, design a solution including a cost and risk-and-benefit analysis, and to implement and evaluate the solution. [32]

Strand 5: Science in personal and social perspectives

The Wachusett District Revision also includes this strand that describes the ideal essential to the use and implementation of renewable energy. The Wachusett District Revision states that an important purpose of science education is to give students a means to understand and act on personal and social issues. The Revision goes on to describe that the strand is intended to help students evaluate science in personal and social perspectives and develop decision-making skills. In addition, it says that the understanding associated with the concepts in these standards give students a foundation on which to base decisions they will face as citizens.[32]

2.3.2 Resources to design curricula on Renewable Energy Technologies

In this section we present descriptions of a number of existing resources that can easily be used to teach science and technology, particularly renewable energy technologies, in middle and high schools. The information from these resources is mostly in the form of final deliverables and ready activities that can be implemented in classrooms.

Renewables Are Ready: A Guide to Teaching Renewable Energy in Junior and Senior High School Classrooms

This manual, created by the Union of Concerned Scientists (UCS), is a teacher's guide and is intended to help teachers introduce their students to renewable energy technologies and the political and economic conditions necessary for their implementation. It contains a set of classroom activities with detailed instructions, an expanded list of project suggestions, ideas for student-led education and action campaigns, and a bibliography of resources for further investigation. [30]

The manual includes detailed descriptions of activities that can be designed and explains their educational value. The activities included are multidisciplinary and investigatory. Most of the projects emphasize group work and cooperative learning. The activities can be taught independently or as a unit. The manual suggests that teachers use them in the context of a comprehensive unit on energy and energy-related environmental issues. Several resources on energy and the environment are listed in the bibliography.

To quote the preface of the manual, "…[it] is intended to help school teachers provide their students with an understanding of the technologies and the political and economic systems that must be understood to work towards a clean, sustainable energy future."[30]

Pre K-12 Engineering

Pre K-12 Engineering is a website that is a free resource for educators and administrators looking to integrate engineering concepts and activities into Pre K – 12 classrooms. The website was developed by the Center for Engineering Educational Outreach (CEE) as a result of changes to the Massachusetts Science and Technology/Engineering Curriculum Frameworks to include concepts from engineering including materials, design, development, etc. It provides classroom activities that fulfill the frameworks by teaching key engineering concepts and principles. It has an activities section that contains activities for all grade levels. The activities available on the site are linked to the new Massachusetts Science and Technology/Engineering Curriculum Frameworks. Many of the standards in these frameworks are closely related to the nationally recommended standards for technological literacy by the International Technology Education Association (ITEA). A quote on the website from a teacher reads, "This site will be extremely beneficial to teachers as they add engineering activities that support the state curriculum frameworks into their own curricula." [35]

The website presents the engineering activities and projects as providing a forum for planning, hands-on building, and testing activities within a set of design criteria. The website lists some of the benefits that come from using engineering based projects as:

1. Increase the technological literacy of all students
2. Strong motivator for mathematics and science learning
3. Excellent platform for problem/project based learning
4. Catalyst for integrating knowledge from all disciplines

The website also provides numerous examples of engineering activities with specifics and detailed information. These can be used as templates to design other activities in related areas. [35]

Energy for Keeps: Electricity from Renewable Energy

Energy For Keeps: Electricity from Renewable Energy is a school textbook currently being used in California's public school system with the aim to educate children in grades 6-12 about renewable energy technologies like solar, wind, geothermal, hydroelectric, ocean energy, and hydrogen.[36]

The publication of the 233-page book was prompted by a competitive grant from the state's Energy Commission. The book is published by the group Educators for the Environment (EE). To insure objectivity and accuracy, the publishing house consulted over 75 technical and educational experts from all over the U.S. The CEO of the EE group says that the "…next step is to publish a shorter version – one without the extra information for teachers – as a sort of handbook for everyone who uses electricity; then we'd like to publish a version that includes energy data for all 50 states". The group cites positive reviews of the book, and it is currently being looked at for integration into curricula in other states, specifically Hawaii. [36]

2.3.3 Schools Going Solar

Many schools across the country are already equipped with solar energy systems which they feel provide the benefits of sustainable energy to the school building and also to help the students augment their math and science studies. There currently exists a program called Schools Going Solar that considers bringing solar energy to schools an important first step to increasing the overall use of solar energy. The rationale cited on the website is as follows: "Schools make excellent showcases for displaying the benefits of solar energy. Students learn about solar energy, and then can educate their parents and other adult member of the community about these technologies." [39]

Schools Going Solar states that many of these projects in schools came about through the interest and impetus of a student and/or a teacher in the school. The Schools Going Solar movement and their website are intended to build a network – a community of people who can share experiences with solar energy in schools. Their hope is that teachers, students, community officials, and the general public should find the information contained in their website helpful in establishing a project.

The website is owned by the Interstate Renewable Energy Council (IREC**)**. The IREC is a non-profit organization whose mission is to "…accelerate the sustainable utilization of renewable energy sources and technologies in and through state and local government and community activities." Members of the IREC include state energy offices, city energy offices, other municipal and state agencies, national laboratories, renewable energy organizations, and individual members.

The Schools Going Solar website has a database of schools in Massachusetts where solar energy installations have been successfully integrated into curricula. The teachers and other personnel associated with the solar installations from these schools present a valuable resource for information and feedback. Using this resource of experience with literally hundreds of school projects the Schools Going Solar website presents a collection of tips to help establish educational solar facilities at a school. These tips are presented below:

"*Overall*

- Find at least one enthusiastic 'champion.'
- Obtain buy-in up front
- Be sure the school's custodial and maintenance staff are engaged and educated.
- Establish partnerships with business.
- Even with many participants, make sure that a single office or individual has project responsibility.
- Create community ownership.

Hardware Hints

- Choose an established, reliable solar contractor.
- Make sure the roof is not due to be replaced in the next few years.
- To get the most out of PV, be sure the school uses electricity as efficiency as possible.

Inside the School

- Provide teachers with a curriculum, lesson plans, and/or experiments.
- Make it easy for the teachers to teach solar energy.
- Be sure materials meet standards.
- Computer hook-ups and real-time date are great learning tools.
- An educational display brings the project to many." [39]

These tips are the product of numerous experiences, and can be looked to as guidelines for the establishment of similar facilities elsewhere. The schools listed in the database can also be contacted to get firsthand advice and suggestions on establishing and generating educational programs based on these facilities.

2.3.4 Integrating Renewable Energy technology into University Curricula

Education on renewable energy technologies and their applications does not have to stop at the K-12 level. Several colleges and universities have already proposed that there is a real market for people with the skills necessary for researching and developing new and better renewable energy resources as well as people who can make use of related current technologies. We will take a look at one example, striking in that it includes two undergraduate degrees in the field.

The University of New South Wales (UNSW) in Sydney, Australia, has created an entire center for photovoltaic engineering and renewable energy. The UNSW Key Centre for Photovoltaic Engineering offers two Bachelor's degree programs; a Bachelor of Engineering (BE) in Photovoltaics and Solar Energy, and a BE in Renewable Energy Engineering. The photovoltaics degree focuses specifically on solar power, while the renewable energy degree branches out into other forms of renewable energy. [37]

Both degrees include training in many aspects of renewable energy. First, they include research and development skills required to develop new renewable energy systems. The UNSW proposes that research and development will lead to better and less expensive renewable energy systems. Second, the degree programs include training in the manufacturing, quality control, and reliability studies of renewable energy systems as a way for the students to take their research and development skills and apply them to building better, more practical systems. Third, students receive training in business related aspects of renewable energy. They learn about policy, financing, marketing, management, consulting, training, and education relating to renewable energy. With these three aspects, the UNSW believes they receive a complete education that can be used in the real world to promote and develop renewable energy. [37]

It is worthwhile to note that these programs at the UNSW are already beginning to graduate students with degrees in photovoltaics and renewable energy. Other colleges, such as San Juan College in New Mexico, have begun offering degree programs in photovoltaics and renewable energy as well based on very similar principles and course offerings. [38]

2.3.5 Solar Energy in Competitions

As evidenced by the success of programs like FIRST robotics and the FSAE collegiate design competition, competitions are a popular way to engage students in productive learning activity. This can be specifically applied to activities related to solar energy as most experts agree that competitions serve to spread awareness in an atmosphere that is exciting and conducive to self motivated learning.[51, 52] There are various competitions for college and high school student teams built around the use of solar energy. These programs were created to help promote and educate the usefulness of renewable energy technology. These competitions are intended to provide a greater understanding of solar energy technology, its environmental benefits and its promise for the future and, a "hands-on" opportunity for students and engineers to develop and demonstrate their technical and creative abilities. Some examples of such events are discussed below. [40]

American Solar Challenge

The US Department of Energy (DOE) sponsors the American Solar Challenge, a 10-day solar powered car race from Chicago to Claremont, California; the longest solar powered car race in the world. Teams from universities must construct vehicles that can travel the 2,300 miles that are powered solely be the sun. Secretary of Energy Spencer Abraham states that, "The American Solar Challenge will advance renewable energy and electric vehicle technologies, promote educational and engineering excellence, and encourage environmental consciousness and teach teamwork." [41]

Solar Decathlon

The US Department of Energy, through its National Renewable Energy Laboratory (NREL) and Energy Efficiency Renewable Energy Network (EREN), has also created the Solar Decathlon contest for teams of college students. The purpose of the contest is to promote public awareness and future consideration of renewable energy in the design of homes. The goal of the Solar Decathlon is to design and build an entire house, which will be powered by only solar power, in eight days. These solar houses will not only provide a working demonstration of the possibilities of solar power but may also spawn design innovations. This contest also integrates the schools of architecture and engineering and promotes the thought of solar power integration in common homes. [42]

These competitions are examples of how solar and renewable energy is being brought to students nationwide. They provide an insight into the current view of renewable energy and an example of a successful method of bringing renewable energy into education at various levels.

2.4 Marketing Solar Energy

Education is not, however, the only issue of importance in promoting sustainable energy. This section presents information on marketing solar energy as a viable solution to energy needs and as a positive symbol of sustainability. Promising applications for promoting sustainable energy along with the barriers that are faced with the adoption of these applications are presented as a study of implementing sustainable energy technology. Further, a case study of the Palo Alto Green program is used as an example of a sustainable energy initiative that has been successful in promoting community program participation and recognition. Finally, examples of other universities that currently have solar installations are presented as a demonstration of the ability of successful marketing for and of installations to stimulate recognition and funding.

2.4.1 Neighborhood Renewables

Neighborhood renewable energy technologies, according to the UCS, "…are small, flexible power systems that use naturally replenishable resources, such as sunlight and wind, which also have little or no environmental impact." Another term they use for these technologies, which include solar water heaters, photovoltaic panels, wind turbines, and biomass-fueled electricity generators, is distributed renewables, meaning they can be distributed to roofs and other areas throughout a utility region. The argument of the UCS for the advantages of distributed renewables is that by distributing the energy generation sites you can decrease the energy transmission and distribution costs associated with central power plants. Distributed renewables are considered demand-side management renewables because placing the renewable technologies where the electricity is used reduces the demand for more power from a central power plant. Energy-efficiency measures, another type of demand-side energy management, have a similar effect.[44]

According to the UCS many ongoing government and industry programs to improve the marketability of clean energy systems are based on the concept that a small, growing commitment to renewable energy technologies will lead to sustained, orderly development. They state this as "…a process based on identifying and implementing technologies first in niche markets where they are most cost-effective, then achieving economies of scale, reducing production costs, enabling penetration of new markets, and so on." Examining opportunities for neighborhood renewables is presented as a strategy to support this process. [44]

2.4.2 The City of Palo Alto: Palo Alto Green Program

The city of Palo Alto, California has implemented a renewable energy program called Palo Alto Green. Participants of this program receive all of their energy from renewable sources: wind power and solar power. Nearly 2,000 households have signed up for this program and they are nearing their goal of being the largest community renewable energy program in the country. The city considers effective marketing to the community as a key element to their success. They make the case that the average household that participates in this program prevents the release of 4.75 tons of carbon dioxide per year, which is equivalent to planting 624 trees or not driving 11,762 miles a year. They also argue in favor of the other benefits of the program such as; clean air, reduction of carbon dioxide that contributes to global warming, and the creation of jobs in the field of sustainable energy.[43]

2.4.3 Solar Installations at Universities

There is also an effort at some universities in this country to promote sustainability through implementing solar energy installations. Several universities throughout the country, including California State University Northridge (CSUN), Loyola Marymount University (LMU), and Oakland University (OU), have both large and interesting solar installations. CSUN and LMU have two of the largest university solar installations in the country, with outputs of 225kW and 723kW, respectively.[45] OU has recently implemented a more modest yet interesting 10kW system that uses PV shingles as opposed to the more commonly seen panels as the PV elements in the system.[46]

The common threads among these installations are the high costs of setting up the installations and the benefits of the installations suggested by the institutions and their sponsors. The smallest of the systems, at OU, was implemented with $130,000 in state and university funding. The largest of the installations, at LMU, had an estimated cost of $4.3 million with funding being received from utility rebates and university contributions. While these installations represent a large investment of capital, statements from the universities and their sponsors suggest that they see a value not only in the savings generated by the installations but also in image of being more environmentally friendly. Essentially the institutions and organizations associated with these projects suggest that the installations will save them money, promote sustainability, and also help positively promote their images.[45, 46, 47, 48]

2.4.4 Market Barriers

Although groups such as the UCS see the advantages of sustainable/renewable energy sources, including distributed renewables, they also concede that numerous barriers exist in society and in the energy market. The UCS presents the following list of market barriers:

- The price of solar electricity is higher than the price of electricity from conventional sources.
- Today's electricity market has been dominated for many decades by technologies and thinking geared towards large central generating stations coupled to long-distance distribution systems. The concept of local, neighborhood resources, such as photovoltaic panels, competing with large scale power plants is still little-known and untried by many planners and decision makers today. Developments in neighborhood utility technologies are just beginning to be incorporated into the industry's decision-making and will require extra consideration in the design of a restructured electricity industry
- Limited understanding of and experience with these neighborhood systems along with challenges delivering large numbers of relatively small systems efficiently and inexpensively to appropriate customers.

Although these barriers relate primarily to distributed renewables, the lack of knowledge and marketing about sustainable energy is a theme that carries through. [44]

The UCS, among other groups, presents a variety of tasks that can be undertaken to bring the full benefits of sustainable energy, namely distributed renewables, to neighborhoods. One of the most significant tasks presented is the suggestion to “undertake pilot and demonstration projects for promising technologies.” This corresponds to the theory of having a small yet growing commitment to sustainable energy that will promote the growth of sustainable energy presence and technology in a region. [44]

3 Methodology

Our vision and the goals that we set out to accomplish are based on the work of the WPI student project team that completed a feasibility study on our project in the fall of 2003. They established a solid foundation on which our project rests. They conducted interviews with various stakeholders on and off campus, getting their support for the project and making it easier for our team to approach the various administrative and logistical issues. They also obtained price quotes from some material suppliers, Heliotronics and Solar Works.

The overall vision of our project is to positively change attitudes toward solar energy at WPI, Worcester public schools, and the general Worcester area. We have established the main goals of our project that work toward our vision. These are:

- Establish a solar installation at WPI
- Market and promote solar power at WPI
- Create solar power oriented educational activities

These goals build on each other. The solar installation and accompanying Solar Learning Lab software is mainly intended as an education tool that will be integrated into some of the solar power education, such as WPI's on-campus outreach programs. Marketing the attractiveness of the installation to WPI will help to make it an integral part of the campus. In the sections below, we describe how we accomplished each goal by listing and discussing how we approached and completed each of their objectives.

3.1 Establishing the Solar Installation

A key goal to our project is to establish a 1-kilowatt solar installation on the WPI campus. This solar installation will include all necessary components for grid connected power generation and data logging of the power produced. This installation serves our purpose as an educational tool for promotion of solar power awareness and is a vital component of our IQP. However, it also benefits many of our stakeholders and serves their purposes as well. Heliotronics will benefit from this installation because it will promote their Solar Learning Lab software and data acquisition systems. WPI will have the benefits of the use of the solar installation as an educational tool for their engineering curriculums and outreach programs. More importantly, we believe the installation has the potential of improving WPI's image. WPI will have the marketing and publicity benefit of saying that they are generating clean, sustainable, solar power. Further, the solar installation will be a distinctive characteristic of this institute that will set it apart from other universities. It will also illustrate WPI's concern toward environmental issues and help support its slogan of "The University of Science and Technology. And Life."

3.1.1 Obtaining Additional Funding and Reducing Costs

Obtaining funding for the solar installation was originally a major obstacle of establishing the system. Our initial budget was $10,000, obtained through a donation from the class of 1975. The previous team examined Solar Works Inc as a supplier of the power generating components. The components were very expensive since they were dealing with a for-profit company. The quotes that the first project team received from Solar Works listed prices that exceeded our budget by approximately $6,800. Our plans to overcome this obstacle were to solicit funding from WPI student organizations and find a less expensive supplier of materials. We were planning to ask the Student Government Association (SGA), with the environmental club GAEA (Global Awareness of Environmental Activity) as our supporter, for any additional funding that we might need. However, since we were able to find a less expensive supplier, we reduced our costs enough that we did not need any additional funding to complete the installation.

The alternative supplier that we were introduced to was the Massachusetts Energy Consumers Alliance. Mass Energy is a non-profit company that has received a grant from the Massachusetts Technology Collaborative (MTC) for a project to install solar panels in the greater Boston area, which allows it to give similar MTC installation credits, paid when we install the system, and MTC production incentive credits, paid over the course of three years. Also, because

Mass Energy is a non-profit organization, it can supply the power generating components at the bulk price. Going with Mass Energy as a supplier instead of Solar Works will save us a significant amount of money, and allows us to feasibly install the system without going beyond our budget of $10,000. Also, as a contingency option, we still had the option to approach SGA, with GAEA as our supporter, for any additional funds. However, all the necessary funding is in place and we did not need any additional funds.

3.1.2 Resolving Administrative and Logistical Issues Involving the Installation

In order for the installation to move forward, there were numerous administrative and logistical issues that had to be addressed. These issues ranged from obtaining WPI approval and support for our project to deciding how and where the physical components of the installation would be placed.

Administrative Issues

The previous project team was able to get key WPI organizations, such as Plant Services and Network Operations, on board with this project. However, for the installation to occur, more than a just verbal approval exchanged in a meeting was required. We reestablished contact with Plant Services, through Chris Salter (Director of Technical Trades) and John Miller (VP of Plant Services), and with Network Operations through Sean O'Connor (Manager of Network Operations). In the meetings we had with them, we confirmed their support and cooperation for the project. We also discussed the possibility of permanent ownership and maintenance responsibilities of the system for these two organizations.

The MTC, since they are the source of funding for the installation credits, required a letter documenting liability issues, insurance coverage, and licensing for all work done. We had John Miller from Plant Services draft a letter to document these issues to be sent to the MTC. Mass Energy also required a contract to be signed by WPI in order for the project to move forward. This draft contract was approved and signed by the proper WPI administrative authority, Vice President Steven Hebert. The signed contract along with the attached site plan and system electrical diagram can be found in Appendix G.

The following is a list of the major terms and conditions of the Mass Energy contract:

- **Insurance and Liability:** The owner (WPI) must provide liability insurance for the project that names WPI, Mass Energy, and the MTC as insured. The owner must also confirm that all subcontracted parties have proper insurance.
- **Labor, Permits, and Licenses:** The owner must furnish and supervise all labor and electrical work. The owner must also assure that all professional labor is properly licensed and performed by certified technicians.
- **Materials and Warranties:** The owner must obtain and pay for the additional components not supplied by Mass Energy. These components must have 5-year warranties, that will replace or restore any degraded components
- **Project Planning and Design:** The owner must create a site plan and system electrical diagram, which will be attached to the contract.
- **Production Tracking and Incentive Funds:** The owner must agree to participate in the Production Tracking System in order to obtain MTC "Production Incentive"

funds. The owner must also allow the MTC to inspect the system throughout the period that WPI is receiving these funds.

Participation in the MTC Production Tracking System [PTS] requires a system representative to submit monthly production reports and allow MTC officials access to the system. On the registration form, we listed Chris Salter who has access to the equipment and is willing to undertake the responsibility for the next three years. The completed form can be found in Appendix I.

Establishing a grid-connected power generation facility requires approval by the power utility. We submitted a Notice of Intent to Interconnect form with Mass Electric Company, WPI's electricity provider. This form notifies the utility provider of the details our equipment and our installation. Once our equipment was approved we were allowed to proceed with the installation and wiring. However, we were not allowed to close the AC switch between the inverter and the electric panel, until it was properly inspected and verified. First, Worcester wire inspectors examined the system, which was documented in a second form. Then a Mass Electric inspector verified the system and gave the final approval for interconnection. The paperwork and forms associated with this process can be found in Appendix H.

Logistical Issues

The first IQP team was able to determine a favorable location for the solar panels on the roof of Morgan Residence Hall. Their criteria for locations for the installation were safety, space availability, accessibility, security, connectivity, and sunlight exposure. In their report they go over their process of using a value matrix to determine that the roof of Morgan Hall would best fit the criteria out of all the possible locations. A logistical issue addressed by our team was where specifically on the roof the panels would be placed. With advice from Chris Salter, we decided to place the panels on the north-most end of the roof, because it was one of the two places that had adequate space and it was much more accessible than the other option of the west-most end of the roof. Also, the location we chose is far away from any obstructions that could block sunlight from reaching the panels, allowing for maximum power generation.

We also addressed was the placement and interconnection of the other power generating components and the data acquisitions components. These components include the inverter, the transducers, the data logger, and the PC for the Sun Server software. Locating these components would be dictated by their own individual criteria for safety, space availability, accessibility, security, inter-connectivity, and exposure to the elements. To address this issue, we researched the technical details of the wiring needed between components, and we discussed it in a meeting with Sean O'Connor. We considered the above criteria for locating these components and we roughly determined where they would be located. The final decisions about where to place the components will likely be made jointly by our group and Chris Salter, since he has more expertise in this area than any of us.

Another logistical issue was acquiring the other miscellaneous components, such as wiring, conduits, and switchboxes, which are not provided by the solar installation package that we received from Mass Energy. We discussed this matter with Chris Salter from Plant Services and he purchased these additional components out of the Plant Services budget. Also, the Heliotronics data acquisition required us to supply our own computer to run the Sun Server software. We spoke to Sean O'Connor about this and he donated a suitable computer that was decommissioned by WPI.

As a part of the solar installation, we wanted some sort of display that will present real-time information from the Heliotronics data acquisition system, such as power output, efficiency, pollution prevented, and fossil fuels saved. The first IQP determined some possible options for such a display and possible locations through discussions with Sean O'Connor and Thomas Lynch (VP of Information Technology). We continued this discussion about possible real-time informational displays with Sean O'Connor. We secured the large plasma screen displays that Network Operations has in the "Wedge" (lounge area outside of Morgan Dining Hall) as location for exhibiting the information from the SunViewer software. Also, an interactive kiosk that will be placed in the campus center over the summer has been donated to WPI. Sean O'Connor has some influence as to what will be displayed on the kiosk.

3.1.3 Installing the System

The students of this project team will do the actual act of installing the system in order to cut labor costs. We will have the help of WPI Plant Services, who will oversee this process and provide a properly licensed roofer and electrician, and WPI Network Operations, who will help set up the PC that runs the Sun Server software and resolve any network issues that occur. Also, the students of the previous team have expressed an eager interest to participate in this step and would be very helpful in the installation process. By Plant Services' estimates, once the weather is suitable and all the components have arrived, it will take only a few days for the system to be set up.

3.1.4 Creating a Structure for Maintenance and Upkeep of the Installation

The purpose of establishing the solar installation is to not only to install it, but also to ensure that it will remain functional for its entire expected operating lifetime of about 20 years. Without a proper structure to maintain and upkeep the installation, it may fall into disrepair after a few years of negligence. The key foundation to such a structure would involve ownership of the system by a permanent organization on campus. Therefore, a very important objective for our group to complete is to establish the ownership of the system. We plan on creating motivation for ownership of the system by arguing the benefits of such an installation at WPI and possibly providing financial incentives for ownership. We have to market the installation to WPI, as described in Section 3.2.1. Ideally, we would like to have permanent organizations at WPI own the installation and feel responsible for its upkeep.

The organizations that will own the installation are Plant Services and Network Operations. Plant Services will maintain the physical components, generally the power generating aspect of the system, and Network Operations will maintain the networking and PC components of the system, generally the data acquisition aspect. When we approached these organizations for approval and help with our project, we discussed and confirmed their commitment to ownership. Further, we brought GAEA, a well-established student organization, on board as an organization that will have some ownership and simple maintenance responsibilities such as cleaning the panels and regular visual inspection of the system. GAEA will also contribute to our project financially by providing the $250 annual licensing fee for the Heliotronics software.

3.2 Marketing and Education of Solar Power

A major goal that we set out to accomplish in our project is to help create awareness of solar power and to promote it through various means. Establishing the installation and finding people who will maintain it is just the first step in this process. We also had to consider how we could ensure the long term viability of the installation and how we could use the installation to promote education and awareness. Our approach to long term viability and education was split into two major areas. First, to ensure that the installation and educational programs are maintained on a long term basis we undertook efforts to generate enthusiasm about the project in key members of the WPI community and administration. Further, we created a combination of activities for classroom use, for use in WPI outreach programs, and for professional development workshops to help teachers to spread awareness and knowledge of solar power systems.

3.2.1 Ensuring that the Installation Becomes an Integral Part of WPI

The overall goal of establishing this installation is not only to create a tool that can be used to promote solar awareness and education, but to also create a landmark that will benefit WPI long into the future. We want to see this solar installation live on, not as a leftover burden of a forgotten IQP, but rather as a vital part of the WPI community. To accomplish the task of ensuring the long term viability of the installation and our educational efforts we contacted and met with a variety of key individuals in the WPI community and administration. The team sought to generate enthusiasm with these individuals that would carry over into the rest of the community and maintain long term interest in the overall project. The key benefits and drawbacks of the project that the we felt were important in generating enthusiasm for the project are as follows:

Benefits:

- The physical installation is a new landmark on the WPI campus
- The installation is grid connected and will pay for itself over time
- The installation shows WPI as being committed to sustainable energy
- The educational outreach will promote positive awareness of WPI
- The educational outreach will draw students to WPI
- The project is a positive depiction of the WPI Plan
- The project is an ongoing, dynamic entity to serve WPI

Drawbacks:

- The physical installation requires an initial investment by WPI staff
- The installation will require periodic maintenance and upkeep
- The installation will eventually no longer produce electricity
- The installation requires a small annual software fee

The individuals the team decided to approach in the promotion of the project, and their importance, are as follows:

Michael Dorsey

Mr. Dorsey is the Director of Marketing and Communications at WPI and thus is involved in many of the key publications that are distributed to the WPI community including intra-campus; to faculty, staff, and students, and outside of campus; alumni and supporters of WPI. As such we felt that creating enthusiasm for the project with Mr. Dorsey would help to create positive publicity in the WPI community by way of the publications the community receives.

Kevin Wynn

Mr. Wynn is the Assistant Director of Media Relations at WPI and is responsible for promoting WPI through more general media outlets, as compared to the WPI specific outlets that Michael Dorsey is involved with. We felt Mr. Wynn would be critical in generating publicity for our project in general media outlets such as local and regional newspapers and possible television. Further, our hope was that this publicity would generate enthusiasm in the local area for solar energy education and would assist in the adoption of our educational material in local classrooms.

John Miller

Mr. Miller is the Director of Physical Plant at WPI. He is a key individual responsible for overseeing most of the staff operations at WPI, including overseeing Plant Services. We felt that creating enthusiasm with Mr. Miller would ensure that the installation would remain important to the staff at WPI on a long term basis. Further, as Mr. Miller was involved with the entire installation process he is a knowledgeable stakeholder and could be an enthusiastic resource for other interested persons or parties.

Martha Cyr

Mrs. Cyr is the Director of K-12 Outreach at WPI. She is involved with a great number of efforts on the part of WPI to assist students and educators in the K-12 system and to promote WPI as a higher learning institution with these same groups. We felt Mrs. Cyr would be able to promote our educational programs with local educators. Further, if she was enthusiastic about the installation it was our hope that she would be able to continue the use of the installation after this project was completed.

Throughout the duration of the project the team made efforts to contact and meet with these key individuals to discuss with them our project. The goal was to be able to sit down with each individual at least once and discuss the overall benefit of the project and its positive effects on WPI, as outlined above.

3.2.2 Developing Activities for Middle School and High School Classrooms

Our primary goal for this part of the project was to produce several teaching modules for classrooms that can be given to middle or high school teachers to be used to teach their students about sustainable and solar energy. In order to accomplish this, we first needed to research what guidelines are used to develop teaching modules and how these modules are generally constructed. This information was drawn from several sources, as described in Section 2.3.2. For instance, the Massachusetts Science and Technology/Engineering Curriculum Frameworks provided good guidelines on the material students at the 8th or 9th grade level can be expected to understand. Further, we drew upon several key websites that describe initiatives in the U.S. that are currently underway to teach secondary school students about solar energy. These websites are: www.schoolpowernaturally.org , www.wattsonschools.com , and www.nyserda.org . These three websites were used as examples of existing, successful educational programs that would allow us to draw information and activities, verbatim if necessary, for our own project.

Using this information we worked with closely with Martha Cyr, the Director of K-12 Outreach at WPI, to generate our educational material. Dr. Cyr's experience in secondary level education provided us with a valuable source of insight and feedback on the directions we were taking our educational material and how our modules might be accepted by educators. Further, Martha Cyr suggested that she would assist our project by disseminating our educational material throughout the network of educators she worked closely with, provided she felt the material was of high enough quality and presented an attractive package for teachers.

3.2.3 Developing a Professional Development Workshop for Teachers

The final aspect of education outreach that we pursued was creating a professional development point (PDP) workshop for teachers. These workshops are generally a combination of presentation, lecture, and hands-on learning that gives educators a thorough understanding of a new topic or educational technique that they could then bring back to their students. In our discussions with Martha Cyr she brought to our attention a PDP workshop, hosted by WPI, that she will be running in the summer of 2004. The title of this workshop is the Design Process with Solar Energy. The goal of the workshop is to integrate teaching educators about the engineering design process and solar energy. Further, Dr. Cyr offered to allow us to develop a well structured yet loosely focused section of this workshop to help promote solar energy. We worked closely with Martha Cyr to develop what we believe will be a valuable section of the workshop that will allow us to help teach about the engineering design process and broach key issues about solar energy.

4 Results and Analysis

This chapter presents the results of our methodology broken into down three major categories. First, we describe and analyze the outcome of our efforts to have a physical solar power installation on the WPI campus, including power generating hardware, data acquisition hardware, and data acquisition software. Second, we describe and analyze the outcome of our efforts to create an educational program to help teach middle and high school aged students about solar energy and promote overall awareness in the educational community. Finally, we describe and analyze our efforts to present this project to WPI as a valuable asset to both the university and the Worcester community.

4.1 Results and Analysis of the Physical Installation

The grid-connected solar installation that we are working to establish will reside on the roof of Morgan Residence Hall, providing roughly 1 kW of clean, renewable power. It is part of the Solar Learning Lab, an educational product of our sponsor Heliotronics, which includes a data acquisition system, the SunServer software, and the SunViewer educational client software. The key purpose of this physical installation is not only the "green" power that it generates, but also the "green" education that it has to potential to generate. The installation is not complete as of the end of the 2004 academic year. The team plans to continue to work on the installation process with a target completion date of May 15, 2004.

4.1.1 Recommendations of Team 1

The recommendations of the previous project team relating to the physical installation and how we addressed them are listed below. Our team's recommendations can be found in the Conclusions and Recommendations chapter. Where applicable, we will make reference to other sections that provide greater detail, for each of the topics below.

- **"We recommend that the Solar PV array be installed on the North Side of the Morgan Residence Hall roof at WPI."**
  The first solar project team decided on this location through a decision matrix (as described in Section 3.1.2). We met with Chris Salter, Manager of Technical Trades for Plant Services, and we agreed on keeping Morgan Hall as the roof that we will use. Once we found out more about the sizes and dimensions of the solar array, we visited the roof and confirmed that the north side of the roof was one of the only two options, regarding the issue of space, and much more easily accessible than the second option on the west end of the roof.

- **"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."**
  We will acknowledge our key sponsors around or on the main display screens. However, since we are no longer working with Solar Works Inc, this list will change to

Heliotronics, Mass Energy Consumers Alliance, Mass Technology Collaborative, WPI Class of 1975, WPI Plant Services, WPI Network Operations, and GAEA.

- **"We recommend that the next project group contact the Information Technology (IT) department about obtaining a PC to run the SunServer™ software."**
  Sean O'Connor has committed a PC from NetOps to running the SunServer™ software. The PC will serve as the primary data collection and display server.

- **"We recommend that the next project group continue pursuing funds with groups on campus that have not yet been contacted."**
  We contacted GAEA [Global Awareness of Environmental Activity], the student environmental organization, regarding funding for our project from their budget. They unanimously supported our project, and we planned to obtain funding from the Student Government Association [SGA] with GAEA as our supporter. Although, we do not need additional funding for the installation of the solar system, we needed continuous funding for the annual licensing fees for the Solar Learning Lab software. We have arranged for these funds to be provided by GAEA.

- **"We recommend that Heliotronics help research alternative ways in which to make the project more economically feasible."**
  Heliotronics brought us into contact with the Mass Energy Consumers Alliance. Mass Energy was able to provide us with power generating components at a bulk discount and provide us with installation and production credits from the MTC.

- **"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 are in the process planning a "ribbon cutting" ceremony for the Solar Learning Lab. We will invite everyone that we contacted regarding this project. Morgan Residence Hall has no safety railing in the area of the panels. Due to the safety issues that arise from this fact, we will probably host the event in the "Wedge", next to the display screens. The metaphorical "ribbon cutting" will be in reality the commissioning of the system and activating the AC connect switch.

- **"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."**
  In our meetings with Plant Services and Network Operations (a department of Information Technology), we discussed the issue of long-term ownership. Both organizations were willing to undertake the responsibility. Plant Services will maintain the power generation aspect of the system and Network Operations will maintain the data acquisition aspect of the system.

4.1.2 Analysis of the Hardware/Software/Vendor Choices

We have made several changes in the hardware, software, and vendors we used for our project. The previous project team suggested that we obtain the power generation components from Solar

Works Inc. We switched suppliers to Mass Energy (actual components from RWE Schott Solar), who was introduced to us by Matt Arner. Mass Energy is a non-profit organization, as opposed to Solar Works, which is a for-profit business, and was able to save us thousands of dollars on our power generating components. Mass Energy facilitated the purchase of the power generating components from RWE Schott Solar at bulk prices and was able to provide generous installation and production credits from the MTC. The table below represents what we paid for the entire system, using RWE Schott as our power generation system supplier.

Heliotronics	Data Acquisition System	$5,096
RWE Schott Solar	Power Generation System	$7,646.50
Combined Cost of System		$12,742.50
Class of 1975 Donation		–$10,000
Additional Funds Required at delivery (Plant Services provided this)		$2,742.50
MTC Installation Credits (30 days after installation)		–$3,780
Positive Balance (30 days after installation)		$1,037.50
Estimated MTC Production Credits (Paid over next 3 years)		–$1,620
Positive Balance (3 years from now)		$2,657.50

Table 4-1: Costs and Budget Balances as Time Progresses

In the above table, we list three items in bold. These items are how much money we have at specific dates throughout the purchasing, installation, and operation. Without the MTC credits, the combined cost of the system components that we purchased is still greater than the $10,000 we have budgeted for this project. John Miller, VP of Plant Services, has agreed to facilitate the purchase of the components and front the $2,700 out of Plant Services' operating budget. However, he will be reimbursed by the MTC installation credits, which arrive 30 days after the installation is completed. The installation credits, which total $3,780, bring our budget balance to approximately $1,000 in surplus. Over the next 3 years, the MTC production credits, which totals to approximately $1,620, will bring our budget balance to approximately $2,600 in surplus. This surplus will be received by Plant Services and will be used to pay for any incidental costs related to the long term upkeep of the installation including routine maintenance or replacement of failed components.

We were confident in choosing Mass Energy as a supplier, not only because they reduce the costs of our projects by thousands of dollars in comparison to Solar Works, but also because Heliotronics, who pursued competitive quotes from various suppliers, recommended Mass Energy. Mass Energy acted as an intermediary between RWE Schott and our team. Mass Energy were able to secure bulk pricing (due to the volume of business they provide) and additionally provide us with MTC solar incentive credits.

4.1.3 Description of Hardware and Software

This section is a detailed description of the solar installation. It includes a description of the components of the power generation and data acquisition sub-systems, details of the physical location of the components, and details of the electrical interconnection (power and data) between the components.

Description of Components

We purchased the power generation components for the installation from RWE Schott Solar and the data acquisition components from Heliotronics. The specific power generation components consisted of four RWE Schott AES-300-DGF/50 photovoltaic modules, an SMA Sunny Boy 1800U inverter, a mounting rack, and balance of system components. This power generating setup is a single-phase 120 volt system capable of 1.080 AC kW. More information about these specific products is provided in the appendices. Plant Services also donated several minor components, such as wiring, conduits, and switches, and their services, including supplying a professional electrician, a certified roofer, and Chris Salter as the project supervisor.

The complete package that we purchased from Heliotronics included the Feynman Data Acquisition System, their SunViewer/SunServer educational software, and their SunViewer.net internet portal software. The Feynman Data Acquisition System includes the following components and features:

- SunViewer/SunServer educational display software
- Data Logger with power supply and RS 422 adaptor
- DC current/voltage transducer
- AC current/voltage transducer
- Net energy meter with pulse output
- Pyranometer (solar irradiation measurement device) with plane of array alignment bracket
- Anemometer (wind force and velocity measurement device)
- Module temperature sensor
- Instrument cluster bracket

The SunServer software runs on a PC connected to the Data Logger through the RS 422 connection standard. SunServer software records the data onto the PC and also broadcasts the data to the WPI local area network. The SunViewer software can be run on any PC on the local area network to view the data about the installation's statistics (such as power production and inverter efficiency). The SunViewer software will be the software that will run on the display screen in the Wedge, a lounge like area outside of the Morgan Dining Hall on the ground floor of Morgan Residence Hall. The computer for the SunServer software to operate on was donated by WPI Network Operations. The specifications of the computer are unknown at this point due to the fact that the installation and setup has not yet happened. An additional feature that we purchased from Heliotronics is the SunViewer.net (not to be confused with SunViewer) web access portal. It provides a web-based access to the power production data that comes from the SunServer software.

Physical Location of Components

A logistical issue that was addressed by the first team was the placement of the solar panel array. The solar panel array is the largest and most cumbersome component of the system and had specific location requirements such as shading, safety, and accessibility. The final location that we decided upon was the north end of the Morgan roof as shown in the Figure 4.1.

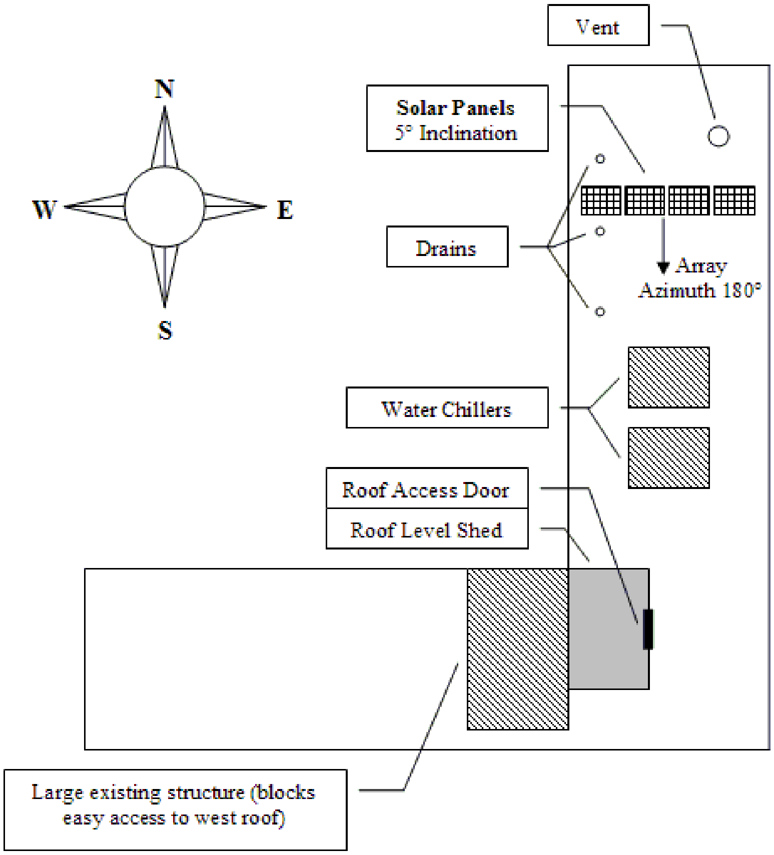


Figure 4.1: Site Diagram of Location of Solar Panel Array

As shown in the above diagram, the four solar panels are arranged length-wise in a single row. The dimensions of the panels are 6.21 ft (74.5 in) by 4.21 feet (50.5 in). Arranged lengthwise and accounting for gaps between panels, the overall length of the array is approximately 28 feet, which is much shorter than the roof dimension of approximately 40 feet.

As for the other components, the inverter will be housed inside of the roof level shed; the Heliotronics data logger will be placed close to the inverter; the meteorological instrument cluster will be placed near the solar panels. The exact location details will be worked out during installation process.

Electrical Diagram of System

Shown below, in Figure 4.2, is the electrical diagram of the system. This diagram illustrates how the components are conceptually interconnected and shows the flow of power and data through our system.

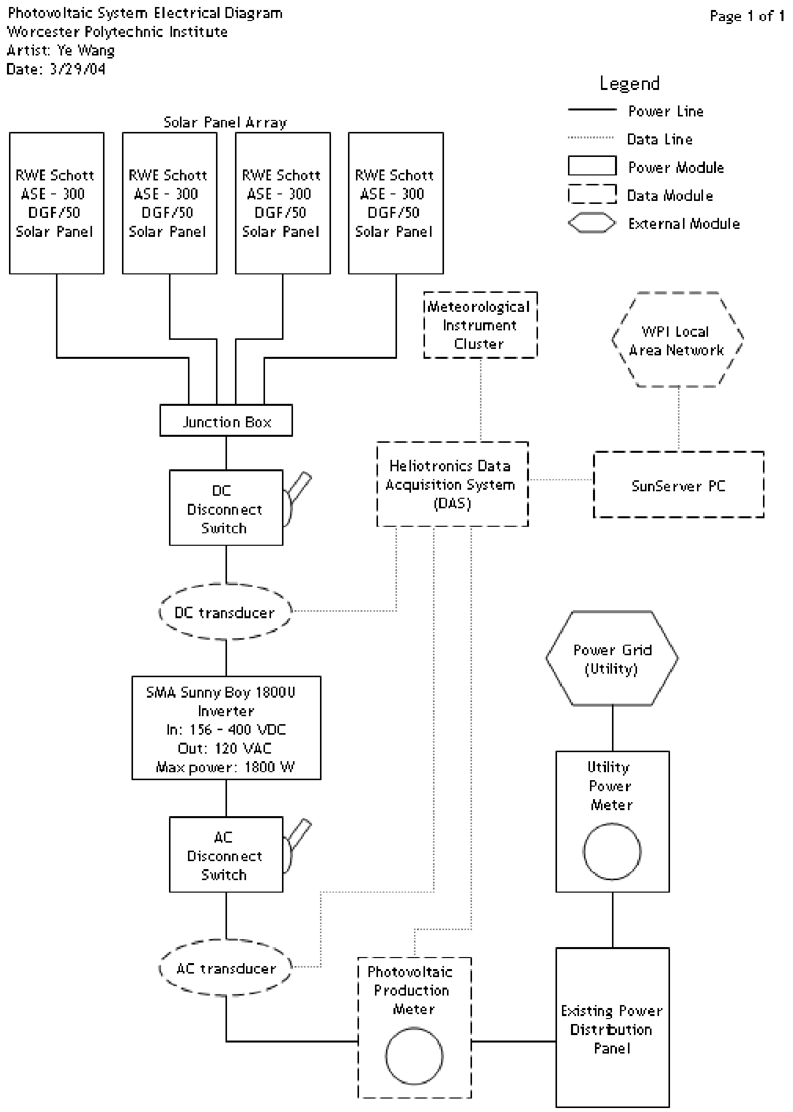


Figure 4.2: Electrical Diagram of the Overall System

4.1.4 Contributions of Stakeholders in the Physical Installation

The contributions of each installation stakeholder toward completing the solar installation are described below.

WPI Plant Services

We owe much of the success of accomplishing the physical installation to WPI Plant Services. They facilitated all of the purchases by absorbing the costs with their budget until they could be reimbursed by MTC funds. They were also essential in the approval process of modifying a WPI building. Chris Salter, manager of technical trades, and John Miller, VP of Plant Services, were both very enthusiastic about this project and provided us will all the support that we requested. Chris Salter will supervise the final installation and Plant Services employees will perform all of the professional work. In the long run, Plant Services has agreed to own and maintain the power generation aspect of the system.

Heliotronics

Heliotronics was the sponsor our project and their data acquisition system was the foundation of the educational and awareness aspects of our project. Their hardware and software was also the motivation for us to establish a solar installation for the purpose of hands-on solar education. They pursued more competitive suppliers of power generation components and introduced us to Mass Energy, which saved us a significant amount of money. Throughout the project, they were always there to answer our technical questions and advise us on our decisions.

Mass Energy Consumers Alliance and the Massachusetts Technology Collaborative

Mass Energy facilitated the purchase of components from RWE Schott by securing bulk prices for the components and they provided us credits from the Massachusetts Technology Collaborative [MTC]. We obtained these privileges in exchange for participating in their MTC funded program to create solar installations in the greater Boston area. Our 1-kW installation contributes to their goal of a combined 100 kW from all of their sponsored installations.

WPI Network Operations

Network Operations donated a PC to our project for the purpose of running the SunServer software. Also, they assisted us in various computer setup and networking issues, including the logistics of wiring the PC into the network from the roof of Morgan Hall. In the long run, Network Operations has agreed to own and maintain the data acquisition aspect of the system.

WPI Class of 1975

The Class of 1975's generous donation of $10,000 was essential to our project. Without it, we would have had the difficult task of soliciting for almost $10,000. Without their contribution to our budget, our project may not have been accomplished in a single academic year.

4.1.5 Analysis of Long Term Viability of the Installation

The long-term viability of the physical installation depends on continued maintenance and support throughout its expected lifetime of 20 years. In order to insure that the installation is properly maintained, we decided that we need permanent organizations at WPI to claim ownership and maintain it. This ownership will continue long after the members of this project team graduate and possibly even after the faculty involved retires or leaves WPI. We discussed this objective with WPI Plant Services and WPI Network Operations and established these organizations as the co-owners and those responsible for its maintenance. We also gave GAEA, the student environmental organization, with the responsibility of simple maintenance issues (such as cleaning the panels, occasional visual inspections) and a slight financial responsibility.

Plant Services will own and maintain the power generation aspect of our system. A solar installation is generally a low-maintenance system, but Plant Services will be there for upkeep in the rare occurrence that something malfunctions. All of the major power generation components have 5-year comprehensive warranties, so the installation is covered for that beginning portion of time. Solar panels typically will not abruptly fail; rather, they will only degrade in efficiency and operation slowly over their lifetime. The inverter is the most likely component to abruptly fail. In the worst case, where it completely fails after its warranty period has ended, the MTC production credits will have accumulated to an amount that can fund the cost of a new inverter.

Network Operations will own and maintain the data acquisition aspect of our system. Mainly this will be comprised of networking maintenance and upkeep of the PC running the SunServer software. They will also insure that the information from the SunViewer software is presented on their plasma display screens on the ground floor of Morgan Residence Hall.

The role of GAEA involves providing funding for the annual licensing fee for the Heliotronics software and simple maintenance responsibilities. To pay for this fee they will write the amount of $250 into their annual budget. By doing this they insure that the data acquisition and educational aspect of the software endures. Also, they will perform simple maintenance responsibilities such as cleaning the panels to maintain their optimal efficiency and occasional visual inspections of the system.

4.2 Educational Outreach

Another one of the major goals of the Solar Demonstration project was to promote education and awareness about solar energy through outreach to schools and other organizations. Working closely with Martha Cyr and using our background research as a guide the team developed educational material in two key areas. First, we developed a seven day educational program for implementation in 8th and 9th grade classrooms. Second, we developed a portion of a professional development point (PDP) workshop that will be run by Martha Cyr in the summer of 2004.

4.2.1 Description and Analysis of Classroom Outreach

In generating educational material for 8th and 9th grade students our team felt that the two major issues we needed to address were teaching students about solar energy and drawing attention to WPI as an educational resource, specifically drawing attention to the solar installation.

Therefore the team has developed a seven day, modular lesson plan package for 8th and 9th grade teachers. The goal of the package is to introduce students to energy as a whole, including sources of renewable and non-renewable energy, and then to introduce photovoltaics as a source of renewable energy. Activities within the seven day lesson period include activities designed to demonstrate, in a simple manner, how photovoltaics work and activities designed to allow students to interact with data from an actual installation. Ideally the students will gather data from the WPI solar installation through the SunViewer.net portal or even through a field trip to the campus.

Further, the educational package is designed to be modular to allow teachers to use their discretion to choose how much, or how little, of the package they will employ. Although designed as a complete unit that flows from one day to the next, the team believes that any individual day or group of days can be picked from the package and still present a useful and complete lesson tool for teachers. Martha Cyr has indicated that she will disseminate our educational package to the educators and administrators that she regularly works with in an effort to promote widespread adoption of solar energy education.

Please refer to Appendix O for the complete lesson plan package.

4.2.2 Description and Analysis of Professional Development Outreach

The other area of education outreach that the team addressed was developing a program for the Design Process with Solar Energy PDP workshop the Martha Cyr will be running in the summer of 2004. The goal of this workshop is to introduce participants to the engineering design process using solar energy to teach them about both design topics and solar energy topics. Workshop participants will be involved in a number of activities over a nine day period including rigidly structures design exercises, more loosely design and exploratory exercises, educational field trips, and lectures and discussions with a variety of speakers. Refer to Appendix P for the PDP schedule.

Our contribution to this workshop comes in the form of a guide for an eight day activity where participants will use the engineering design process to design a solution to an energy problem start to finish. The title for each day's activity is as follows:

Day 1: Identify Problems and Constraints
Day 2: Research the Problem
Day 3: Develop Solutions
Day 4: Select a Solution
Day 5: Construct a Model
Day 6: Test and Evaluate
Day 7: Share Your Solutions
Day 8: Redesign

Since the focus of the workshop is solar energy our guide is structured to encourage participants to investigate solar energy solutions.

One hour each day will be dedicated to our portion of the workshop. Participants will be initially divided into small groups of about three or four and at the beginning of each one hour session they will be given brief instructions or a brief background lecture and will then be asked to work together as a team to solve a given problem. At the end of the workshop participants will present their solutions to the problem and will then be given a packet of material which will contain our team's classroom lesson package. In this way participants will be able to learn about solar energy and then will have a complete lesson plan that they can bring back to their schools and easily implement in classrooms to teach students about solar energy.

Please refer to Appendix Q for the complete PDP workshop guide.

4.3 Marketing and Publicity for the Project

Beyond just installing a Solar Learning Lab^{TM} at WPI and developing educational material about sustainable energy to take advantage of the installation, both Solar project teams felt the third key component to the project would be marketing. We believe that this has been and will continue to be a dynamic project. The solar installation and educational material present long term resources to those who would be willing to use them and as such we felt that it was necessary to generate as much interest in and awareness of the project as possible while there was still a team actively working on the project. This section presents a description and analysis of our efforts to market the Solar Demonstration project to individuals at WPI and to WPI as a whole.

4.3.1 Benefits of the Project to WPI

One of the key things we had to consider in marketing this project was what the overall appeal to WPI would be. While individuals at the university might be enthusiastic about the project for a variety of reasons, to appeal to WPI as a single entity the project must present a marketable asset that will generate a positive image of WPI. The team believes that each of the two major aspects of the project, the physical installation and educational outreach, both provide marketable assets to WPI and create a positive image. Therefore we focused our marketing efforts at generating interest with key individuals within the WPI community and also on generating publicity for the project to broaden awareness of it to key sections of the WPI community. The team's methodology for approaching individuals and generating enthusiasm was to describe the goals of the project, describe the status of the project, and to then outline the benefits and drawbacks of the project, as listed in Section 3.2.1.

4.3.2 Description and Analysis of Marketing and Publicity

The results of our interaction presenting the above benefits and drawbacks to key individuals on the WPI campus are as follows:

Michael Dorsey

Mr. Dorsey is the Director of Marketing and Communications at WPI. We initially contacted Mr. Dorsey by email explaining in some detail the goals of our project and the tasks we set to accomplish these goals. In a meeting with Mr. Dorsey he expressed a great deal of enthusiasm about the project and indicated that once the physical installation is in place he will have a writer and a photographer generate a write-up about the project to appear in Transformations magazine. Transformations is a quarterly WPI publication with a distribution base of approximately 30,000 WPI alumni, supporters, and interested parties.

Kevin Wynn

Mr. Wynn is the Assistant Director of Media Relations at WPI. We initially contacted Mr. Wynn by email explaining in some detail the goals of our project and the tasks we set to accomplish these goals. In a meeting with Mr. Wynn he was very enthusiastic about the project and indicated that he will attempt to have a reporter document the installation process for the solar panels and interview both teams involved. Further, he indicated that during the summer of 2004, once the project has been in place for some time, he will draft a WPI press release regarding the physical installation and the goals of the project. Mr. Wynn also expressed interest in any further project work relating to the solar installation or education programs.

John Miller

Mr. Miller is the Director of Physical Plant at WPI. Each Solar Team was in regular contact throughout the duration of the project with Mr. Miller and each team met with him on several occasions. As Mr. Miller was involved with the purchase of the installation and will also be involved with the installing the solar array he is very knowledgeable about the project. Further Mr. Miller has demonstrated through both his communications and actions that he fully supports our project.

Martha Cyr

Mrs. Cyr is the Director of K-12 Outreach at WPI. The team met regularly with Mrs. Cyr throughout the term to work with her in developing our educational material. At the same time we discussed how to promote our material with educators. Mrs. Cyr indicated that she will distribute our classroom package to the educators she regularly works closely with. Further, she indicated that she will distribute our classroom package to participants in the Design Process with Solar Energy PDP workshop during the summer of 2004. Mrs. Cyr also indicated that she will consider distributing our classroom package at future PDP workshops and through the educational websites she is involved with.

The team believes the publicity and marketing resulting from the support and enthusiasm of this small group of individuals will help to ensure the acceptance and long term viability of the project in the WPI community and in the Worcester community. We believe that Mr. Miller will be an enthusiastic source of information about the project for any interested WPI faculty or staff. Given the level of enthusiasm displayed by the individuals we met with the team believes that there will be widespread enthusiasm for the project once there is widespread awareness. Finally, we believe the project write-up in Transformations will be instrumental in making the physical installation a new campus landmark and in promoting the project with WPI alumni and supporters.

5 Conclusions and Recommendations

This chapter presents our team's recommendations for the future of the Solar Demonstration project and Solar Learning Lab^{TM} installation, along with the conclusions we have drawn regarding these recommendations. Our recommendations are broken down according to recommendations relating to the installation, to education, and to marketing.

Recommendations Regarding the Physical Installation

We recommend that WPI's Manager of Network Operations pursue an interactive terminal for the SunViewer^{TM} software, possibly using the touch screen plasma display to be installed in the Campus Center

While a static or even dynamic display of the software data is a valuable tool for bringing the installation from the roof to students and other people interested in the installation, it does not draw the user to the software and allow an in depth exploration of all its features. An interactive data terminal in the Campus center where a user could control the software would be helpful in allowing individual users to display what they are interested in. Further, having an interactive software presence in the Campus Center will promote awareness of the installation and will serve to get students and visitors interested in the installation and project. This idea has already been discussed with Sean O'Connor, WPI's Manager of Network Operations, and he has agreed to work towards this end.

We recommend that Network Operations maintain the SunServer^{TM} PC terminal and strive to achieve maximum uptime for the server.

The PC terminal running the SunServer^{TM} software is one of the key elements of this project. The terminal provides a link between the rooftop installation and people who are interested in the installation. Therefore we believe it is important that the terminal be running and displaying data as much as possible. We suggest that Network Operations implement a mechanism to be notified when the server is not responding. If this is not a feasible option, a default approach could be to occasionally check the server and web site and ensure its availability.

We recommend that Plant Services and Network Operations collaborate to install a visual display feed from the rooftop installation.

In addition to users being able to see the data that the SunViewer^{TM} software displays, a visual feed of the installation itself with the surrounding environment to indicate weather conditions would provide an additional facet that would attract users to the installation. This feed would ideally be a "web cam" type feed with periodically updated static pictures of the installation displayed alongside the current data from the software.

We recommend that Plant Services provide upkeep and maintenance for the installation.

Since the surplus funds resulting from MTC and production credits will go directly to Plant Services they have agreed to ensure that the installation runs smoothly and continuously and repair any major or minor damage to the hardware.

We recommend that GAEA and Plant Services collaborate to arrange periodic minor maintenance of the installation.
We believe that since GAEA has an important financial and promotional stake in the installation and that they may be interested in undertaking periodic maintenance of the installation. This could include such activities as washing the PV panels to ensure maximum efficiency and tracking the software data to ensure the installation is functioning normally.

We recommend that Plant Services investigate the feasibility of allowing interested parties to view the rooftop installation in person.
In addition to a visual feed from the roof installation we believe that having recourse available for interested parties to go to the roof to see the installation in person and in more detail would positively promote the installation as a valuable WPI landmark. We believe that roof access would be a difficult and complex issue and therefore would be suitable as a task for a future project team.

We recommend that the Web Development Office create a website for the installation on official WPI web space.
Having a website accessible from the main WPI web page would be a valuable resource for those interested in the project and the installation, and also a powerful statement for WPI in terms of embracing green energy. The website could contain the visual feed from the roof, a link to the SunViewer.net portal for the WPI installation, a description of the installation, and instructions for visiting the installation in person as indicated in the previous recommendation. This website could also contain our educational material and links to other similar projects as well as external sources of information. This recommendation is an important one and will play an integral role not just in enhancing the physical installation, but also in promoting our project and facilitating access to our educational material. We believe that the Web Development Office would be receptive to the idea for such a website if this was presented by a faculty member or by a student organization (GAEA).

We recommend that WPI's Manager of Technical Trades submit the monthly PTS data figure online.
The major responsibility for being registered with the Production Tracking System is that a monthly data figure of how much power we are generating must be submitted. This is done online and requires very little time and effort. We believe since Mr. Salter, the current WPI Manager of Technical Trades, will likely have the most frequent interaction and ease of access to the installation that he would be the appropriate person to submit this data. We have discussed this with him and he has agreed to submit this figure in the simple online format.

Recommendations Regarding Educational Material

We recommend that the Science Curriculum Liaison for Worcester Public Schools work actively to implement our educational programs in Worcester area school classrooms.
The educational programs we designed are an integral part of our project and it is our sincere hope and belief that they will find their way into school classrooms and serve to promote interest in renewable energy amongst the current generation of middle and high school students. Joseph Buckley, as Science liaison for Worcester public schools is the person in position to bring our intentions to reality. We trust that he will find these programs interesting and stimulating and will work in collaboration with Martha Cyr, WPI's Director of K-12 Outreach, to implement them in Worcester public school classrooms.

We recommend that WPI's Director of K-12 Outreach pursue developing educational modules for grades beyond the ones targeted by our educational program (8th and 9th).
Developing educational material for additional grade levels will promote sustainable energy education and WPI to a wider range of students. Eventually having a complete K-12 sustainable and solar energy educational program would be an incredibly valuable educational tool and would be appealing to schools and educators. Given Martha Cyr's experience and network of contacts we believe she may be able to enlist the help of enthusiastic educators and administrators. Based on our experience developing educational material for this project we also believe that the time and difficulty involved will require the attention of a project team.

We recommend that WPI's Director of K-12 Outreach and the director of WPI's summer programs pursue integrating our classroom education modules into summer educational programs hosted by WPI.
The summer programs for pre-college students that WPI hosts present an appealing market for our educational program. As the summer programs are held on campus it would be a simple matter to have the students work closely with the installation. If there is a positive reaction to our classroom modules we believe Martha Cyr and Susan Sontgerath (Director of summer programs) will have much success if they choose to integrate our educational material into WPI hosted summer programs.

We recommend that WPI's faculty investigate the possibility of integrating the installation into WPI curriculum, possibly by considering a major or minor in Renewable Energy engineering.
Although much of the team's work has been centered on educating pre-college students, the team feels that there is a place for sustainable and solar energy education at the college level. Given that the installation is already in place, we feel it is important to investigate if it is feasible to integrate sustainable energy education and the solar installation into the WPI curriculum. We understand that the creation of a new academic program will require a significant amount of effort, but we feel it is a worthwhile exercise and should certainly be looked at by the WPI faculty. This could probably be best

facilitated through another project team that would bring this proposal to the appropriate members of the WPI faculty who would in turn bring it to the attention of the WPI Committee on Academic Policy.

Recommendations Regarding Marketing

We recommend that WPI's Director of Marketing & Communications and Assistant Director of Media Relations undertake a long term effort to market and publicize the project in addition to their current roles.
Presently, Michael Dorsey (Director of Marketing & Communications) is working to get an article about our project in the next issue of Transformations, and Kevin Wynn (Assistant Director of Media Relations) is working to get articles about our project published in local newspapers. Although publicity for the installation and our educational program is valuable during the time this project is active, the ongoing, dynamic nature of the project presents a valuable opportunity for additional marketing and publicity. Future articles regarding the operation and changes to the installation along with any adoption and successes of the educational program should be pursued. Further, it is important that this information be disseminated to both the WPI community and the local or regional community.

We recommend that GAEA consider sponsoring events on the topics of sustainable and solar energy.
Given that there will be a PV installation at WPI we believe there is an opportunity for GAEA to sponsor events promoting sustainable and solar energy that would incorporate information about the installation. These events would be discussing a vitally important current topic, and would provide an excellent forum for the promotion and advancement of the project. GAEA could also easily organize table sittings to disseminate information about our project and renewable energy in general.

We recommend that Tech News publicize the project.
Tech News is an important media outlet that reaches a variety of students, faculty, and staff and as a newspaper they are often looking for worthwhile WPI related articles to publish. Therefore we believe that a Tech News feature publicizing the project, including the installation and the educational material, will help to increase awareness and interest in the project on campus.

We recommend that the Committee on Student Life Issues of the Student Government Association design a question about solar and renewable energy, specifically containing references to the installation, to be put on myWPI as a survey question early in the next academic year.
myWPI is a widely used learning and information portal for members of the WPI community. Posting a survey question on myWPI would help to gather information about how the student body feels about the issues of renewable energy while promoting our project and raising campus awareness of the installation.

We recommend that the WPI Admissions Office take an active interest in our project by including a mention of the installation on campus tours and featuring the installation in admissions literature.
The solar installation is a powerful tool that could be used to convey the message of social responsibility that WPI's tries to emphasize in its projects program. The installation would also serve as an excellent example of tangible real world results that students create through their work in the WPI projects program. As such it provides excellent material for inclusion in all forms of admissions publicity--literature, campus tours, open houses and many others.

Recommendations to the Advisors

We recommend that the current Solar Demonstration project advisors establish future, related projects.
While Teams 1 and 2 have worked to establish the installation at WPI, we believe that there is still a great deal of work available to be done to promote sustainable energy awareness and in other areas related to the WPI solar installation. Ensuring at least one future project team to work during the peak period of enthusiasm for these issues would facilitate greater advancement of awareness and the installation. Another project team would also be useful to oversee and guide the implementation of many of our other recommendations; as such a team would have an agenda focused entirely on installation issues. They could thus be the driving force working to ensure that our other recommendations are implemented by reminding and persuading the concerned parties.

We recommend that the project continue to be promoted to the WPI vice presidents and to the incoming WPI president by the project advisors.
The team believes that enthusiasm for the project at the highest levels of administration is important in ensuring the long term acceptance and viability of the project. Furthermore, a unique opportunity is presented by being able to present the project to the incoming WPI president as one of his first glimpses of the results of the WPI project system. Although some contact was made with WPI VP's by Team 1, we feel the greatest impact would be had if the project advisors presented the benefits of the project to the VP's and to the incoming president. The project could also be presented in the broader context of WPI's "green" policies as a whole.

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Appendix A: Stakeholder Contact Information

Administrative, Approval, and Installation
John E. Miller Directory of Physical Plant Email: jemiller@wpi.edu Office: 27 Hackfeld Road Telephone: 1-508-831-5500
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Suppliers, Sponsors, and Supporters

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Relations and Marketing
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Michael W. Dorsey Director of Communications Email: mwdorsey@wpi.edu Department and University Relations Telephone: 1-508-831-5609
Kevin J. Wynn Assistant Director of Media Relations Email: kwynn@wpi.edu University Marketing Telephone: 1-508-831-5706
Denise Rowe Rodino Executive Director of Corporate and Foundation Relations Email: drrodino@wpi.edu University Relations

Appendix B: Heliotronics Purchase Order and Quote

COMPLETE FORM - RETAIN PINK COPY AND SEND BALANCE OF SET TO PLANT SERVICES

TO: WPI Plant Services

REQUEST FOR (CHECK ONE)
☐ INVENTORY WITHDRAWAL
☐ PURCHASE ORDER

P.O.# K 7528

DATE 4/2/04

APPLICABLE PROJECT NO.

APPLICABLE WORK ORDER NO.

REQUESTED BY: John Miller

DEPARTMENT: PLANT SERVICES

CHARGE ACC'T. NO.: 11001-4640-7183

DEP'T. HEAD APPROVAL: John E Miller

VENDOR NAME: HELIOTRONICS

ADDRESS: 1083 MAIN STREET

CITY: HINGHAM, MA 02043

STATE, ZIP CODE

VENDOR CODE

DATE

A/C NO.

$

QTY.	UNIT	DESCRIPTION	UNIT PRICE	COST
		PER YOUR QUOTATION OF 29 MAR04 (ATTACHED) FURNISH DATA ACQUISITION SYSTEM AND ALL COMPONENTS AS LISTED	—	$ 5096
		☎ 617-730-5567		

MASSACHUSETTS SALES TAX EXEMPT
REGISTRATION NO. 042 121 659

CHARGE ACC'T. NO. ______ CREDIT ACC'T. NO. ______ TOTAL AMOUNT $ ______

APPROVAL ______ APPROVAL ______

HELIOTRONICS
products as reliable as sunrise

Email marner@Heliotronics.com
http://www.heliotronics.com
Tel: (617) 730-5436
Fax: (617) 730-5567

QUOTE #WPI01c

March 29, 2004

Dear Solar Team,

We are pleased to offer the following data acquisition system quote for the 1 kW photovoltaic (PV) array at WPI. The system quoted below will provide an educational Solar Learning Lab™ for WPI to raise awareness of energy issues at WPI and in the greater Worcester community.

This quote does not include installation costs. WPI will provide electricians to install the monitoring system and they will be responsible for installing all hardware, conduit, and appropriate wiring. Heliotronics will provide installation manuals and wiring schematics for the monitoring system. A representative of Heliotronics will also be on-site to assist with installation and start-up of the system.

We have provided two options for the data acquisition system; a touch screen kiosk and full weather instrumentation to be considered for installation at a later date when the project is able to raise more money.

The school must provide a personal computer to act as the data server. To ensure best results, it is highly recommended that the computer be dedicated to monitoring the PV system and not run any other applications. The requirements for this computer are:

-at least 3 gigabytes of unused hard drive space
-Pentium 3, Pentium 4, Celeron or Athlon processor
-Windows 2000 or later operating system
-LAN connection
-One available DB9 communications port

Please reference the Heliotronics' quote **#WPI01c** in your purchase order. We look forward to working with you on this project.

Sincerely,

Matthew Arner

HELIOTRONICS
products as reliable as sunrise

Email marner@Heliotronics.com
http://www.heliotronics.com
Tel: (617) 730-5436
Fax: (617) 730-5567

QUOTE #WPI01c

Manager of Business Development

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http://www.heliotronics.com
Tel: (617) 730-5436
Fax: (617) 730-5567

HELIOTRONICS
products as reliable as sunrise

QUOTE #WPI01c

Feynman Data Acquisition System
3749

- ✓ SunViewer™/SunServer™ educational display software
- ✓ Data Logger w/Power supply and RS 422 adaptor
- ✓ DC current/voltage transducer
- ✓ AC current/voltage transducer
- ✓ Energy meter with pulse output
- ✓ Pyranometer with plane of array alignment bracket
- ✓ Ambient temperature sensor with radiation gill shield
- ✓ Anemometer
- ✓ Module Temperature Sensor
- ✓ Cluster Bracket

SunViewer™ Software Site License	499
One day (8 hrs) of on-site installation support	600
Branded internet portal (SunViewer.net™)	
349 -Site setup	50
One-year of SunViewer.net web access (Annual Fee)	249
Discount for marketing value of future student projects (outreach to City of Worcester, schools, nature centers)	-400

TOTAL = $5096

Option 1
Touch Screen kiosk with computer (requires prepayment)
$4749
Option 2
Full weather instrumentation: added hardware includes wind vane,
rain ga$2970arometer, relative humidity sensor.

HELIOTRONICS
products as reliable as sunrise

Email marner@Heliotronics.com
http://www.heliotronics.com
Tel: (617) 730-5436
Fax: (617) 730-5567

QUOTE #WPI01c

Terms and Conditions

Prices quoted are for U.S. customers, and are subject to Heliotronics' terms and conditions. We will be pleased to honor this quotation for 30 days, after which time we reserve the right to modify its terms or withdraw it completely.

1. **Payment terms:** Net 30 except for touch screen kiosk. Please inquire at the time of order regarding prepayment terms for touch screen kiosk. Late payments will be subject to an additional fee of 1.5% per month or the maximum rate permitted by law, whichever is less. Customer agrees to pay all reasonable costs and expenses associated with collection, including, but not limited to, attorneys' fees, court costs and any other costs incurred by Heliotronics, Inc.

2. **Shipping**: FOB Heliotronics, Inc.

3. **Lead time:** Variable, inquire at the time of order.

4. **Warrantee:** The data acquisition system carries a 1 year warrantee. Any components found defective should be shipped back to Heliotronics, shipping prepaid, and we will at our option, repair or replace them. Heliotronics is not responsible for any damages resulting from vandalism.

5. **Technical Support:** Heliotronics will provide up to 3 hours of phone support or 7 phone calls, whichever comes first. Beyond 3 hours or 7 calls, Heliotronics will charge an hourly fee of $75 per hour for technical support with a minimum charge per call of $37.50.

Appendix C: Heliotronics Feynman Installation Guide

Installation Guide for the *Feynman* Package:

An *Epiphany*™ Series
Data Acquisition System

Heliotronics, Inc.
1083 Main Street
Hingham, MA 02043
(781) 749-9593

Rev 1.4: September 19, 2003

SYSTEM COMPONENT DESCRIPTION

The *Feynman* Data Acquisition System consists of the following items:

1. *Data monitor* with separate UL listed *+15 Volt wall transformer*,
2. *RS-422 to RS-232C converter* with *+9 Volt wall transformer*,
3. Revenue grade pulse *kilowatt-hour meter*,
4. 450 Volt AC *Current/Voltage transducer*,
5. 600 Volt DC *Current/Voltage transducer,*
6. *Cluster bracket* assembly including factory-wired sensors:
   a. Ambient temperature sensor,
   b. Module temperature sensor,
   c. Anemometer (wind speed sensor),
   d. Pyranometer (solar intensity sensor) with plane-of-array bracket.
7. *Epoxy* for mounting the module temperature sensor to the back of the module, and
8. *Screwdriver* for operating the terminals on the data monitor.

See Figure 1 for a picture of components.

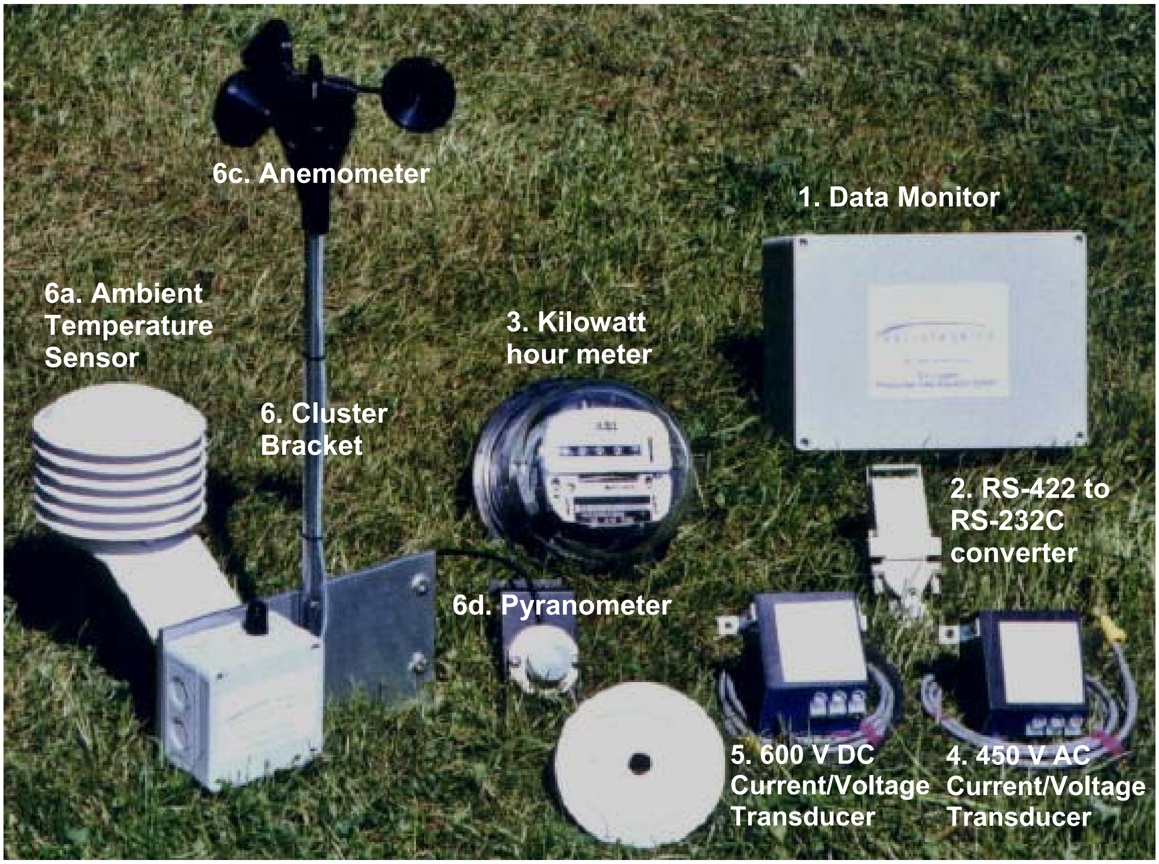


Figure 1. *Feynman* data acquisition system components. The module temperature sensor, wall transformers, screwdriver, and epoxy are not shown.

SYSTEM INSTALLATION

Typically the *data monitor*, *current/voltage transducers*, and *kilowatt-hour meter* are mounted near the inverter. See Figure 2 for the layout of a typical installation. It is recommended that the *data monitor* be mounted indoors. If it is desirable to mount it outdoors, contact Heliotronics Technical Support at 781-646-8622.

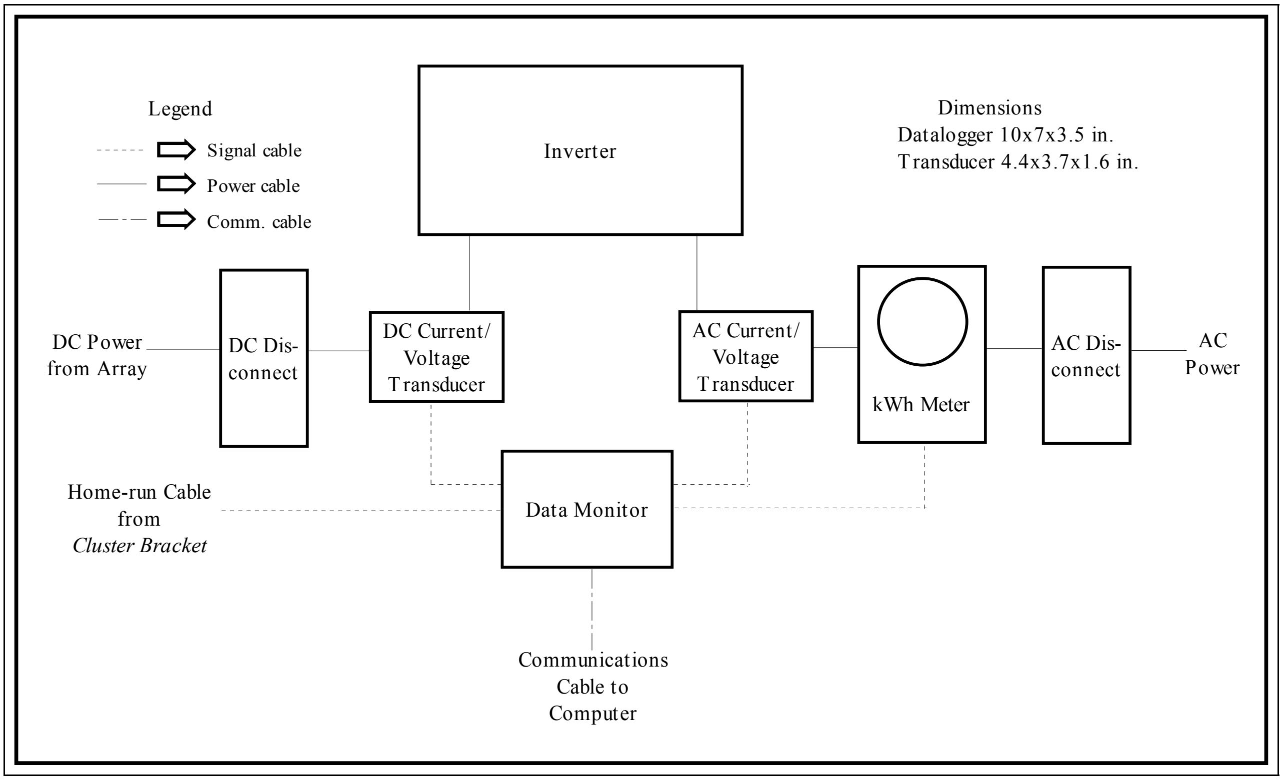


Figure 2. Example of hardware layout.

Throughout this guide you may want to refer to the detailed system wiring schematic provided in Appendix A and the Data Monitor Terminal Map provided in Appendix B.

WARNING: The *Current/Voltage Transducers* are sensitive to static electricity. To prevent damage due to static discharge during shipping, the *Current/Voltage Transducers* are shipped with a wire nut shorting the wires at the end of its cable. Once this wire nut is removed, a static wrist strap should be used until the unit is wired into the data monitor and the data monitor is grounded. Otherwise the transducer may be damaged. **DAMAGE FROM STATIC DISCHARGE IS NOT COVERED BY THE WARRANTEE.** Installers unfamiliar with the handling of static sensitive components should contact Heliotronics, Inc. technical support at (781) 646-8622.

CLUSTER BRACKET INSTALLATION

The *Cluster Bracket* should be mounted level and near the solar array. For accurate wind speed readings, the anemometer should be above any obstructions. Figure 3 shows a typical *cluster bracket* installation.

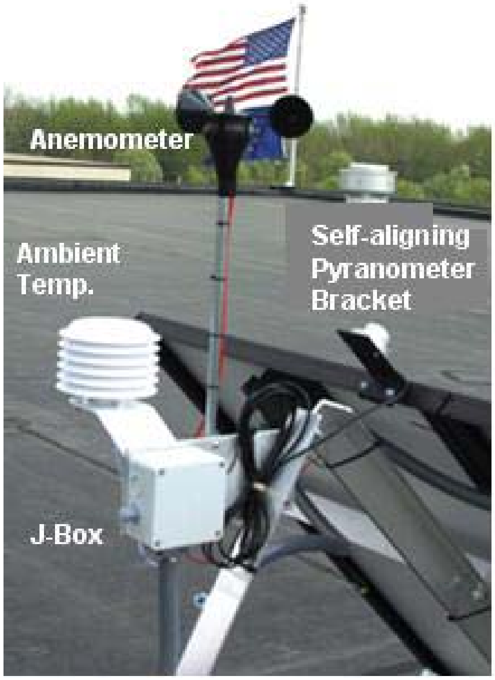


Figure 3. *Cluster Bracket* and plane-of-array pyranometer installed on a PV module.

All the meteorological sensor wires are connected to a terminal block residing in the small junction box on the cluster bracket. The installer needs to install a single "home run" cable from the *Cluster Bracket* junction box to the location of the data monitor. The "home run" cable should be eight-conductor AWG 22-24 shielded, twisted pair. Note: the cable should be shielded, though the individual pairs need not be. The cable should be fed through the bottom of the junction box and connected to the terminal block. Refer to the wiring schematic in Appendix A. Note that the pyranometer's bare copper conductor must be cut and disconnected from the terminal block.

Table 1. *Cluster* Bracket junction box wiring map. Terminal block position 1 is in the upper left corner and position 12 is in the lower right corner.

	SENSOR	SENSOR WIRE COLOR	HOMERUN WIRE COLOR (FILL IN)	DATA MONITOR TERMINAL
1	Anemometer	Black		Wind Speed0-
2	Anemometer	Red		Wind Speed0+
3	Pyranometer	Copper(cut and disconnect)		GND
4	Pyranometer	Green		Insol-
5	Pyranometer	White		Insol+
6	Ambient	Black		Temp0-

	Temperature			
7	Ambient Temperature	Red		Temp0+
8	Module Temperature	Black		Temp1-
9	Module Temperature	Red		Temp1+
10	Wind Vane	Not used		Not connected
11	Wind Vane	Not used		Not connected
12	Wind Vane	Not used		Not connected

Pyranometer Installation

The pyranometer should be mounted parallel to the plane of array in an un-shaded location. The recommended mounting location is on the module rail. Two self-tapping screws are included. If the pyranometer must be mounted to the frame of the solar module, it is recommended that the installer check with the module manufacture to confirm that this will not void the module warranty.

Module Temperature Sensor Installation

The module temperature sensor should be mounted to the bottom of the solar module with thermally conductive epoxy (included with the *Feynman* Data Acquisition System). Refer to Figure 4 for a picture of the installed module temperature sensor.

Figure 4. Photograph showing attachment of the module temperature sensor to the back of the photovoltaic module.

The sensor should be mounted in the center of the module. To install the module temperature sensor, use the following procedure:

1. Clean and dry the location on the module where the sensor will be installed.

2. Using strips of electrical tape, secure the temperature sensor wire to the back of the module. Make sure that the sensor itself is touching the back of the module.
3. DO NOT OPEN EPOXY! Remove the green clip from the epoxy packet.
4. Place the packet on a smooth flat surface and use the white rod like a squeegee to mix the epoxy in the unopened packet. Push one component of the epoxy toward the other in the envelope. Then repeat back in the other direction until the epoxy is completely mixed.
5. Open the envelope and apply a glob of epoxy over the temperature sensor. The white rod works well for this. Verify that there are no air bubbles in the glob of epoxy.
6. Apply small globs of the epoxy to the wire in four to six spots about 6 inches apart to secure the wire to the module.

KILOWATT-HOUR METER INSTALLATION

The *Feynman* Data Acquisition System and the included kilowatt-hour meter are compatible with 240, 208, and 120 Volt systems. The meter socket should be wired so that the "load" side is connected to the utility and the "line" side is connected to the inverter. It is best to install the kilowatt-hour meter close to the data monitor to avoid splicing additional signal wire. Route the signal wire to the data monitor and connect as indicated in Table 2.

Table 2. Kilowatt-hour meter wiring map.

WIRE COLOR	DATA MONITOR CONNECTION POINT
Yellow	Dig Aux 0
Red	GND

CURRENT/VOLTAGE TRANSDUCER INSTALLATION

Two *Current/Voltage Transducers* are supplied with the *Feynman* Data Acquisition System. The **600 Volt transducer is installed on the DC side of the inverter** and the **450 Volt transducer is installed on the AC side of the inverter**. Check the transducer label to ensure that the transducer is installed in the proper location.

Typically each transducer is installed in a dedicated eight by eight inch steel electrical box that can be obtained at the electrical supply store.

WARNING: Remember that the *Current/Voltage Transducers* are sensitive to static electricity. To prevent damage due to static discharge during shipping, the *Current/Voltage Transducers* are shipped with a wire nut shorting the wires at the end of its cable. Once this wire nut is removed, a static wrist strap must be used until the unit is wired into the data monitor and the data monitor is grounded. Otherwise the transducer could be damaged. **DAMAGE FROM STATIC DISCHARGE IS NOT COVERED**

BY THE WARRANTEE. Installers unfamiliar with the handling of static sensitive components should contact Heliotronics, Inc. technical support at (781) 646-8622.

For a schematic of the *Current/Voltage Transducer* connections, see the *Feynman* Installation Schematic at the end of this guide (Appendix A). Also see Table 3 for a list of the *Current/Voltage Transducer* connections on the AC side and Table 4 for connections on the DC side of the inverter.

Table 3. *Current/Voltage Transducer* connections on the AC side of the inverter.

CURRENT/VOLTAGE TRANSDUCER CONNECTIONS OR WIRE COLOR	**CONNECTIONS FOR 120 VOLT SYSTEM**	**CONNECTIONS FOR 208/240 VOLT SYSTEM**
Red	+12V on data monitor	Same as 120V
White	AC V on data monitor	"
Blue	-12V on data monitor	"
Green	Vcc on data monitor	"
Orange	Analog Aux 0- on data monitor	"
Black	GND on data monitor	"
Line AC/DC	Line	Line 1
Neutral In	Neutral from utility	Line 2 from utility
Neutral Out	Neutral from inverter	Line 2 from inverter

Table 4. *Current/Voltage Transducer* connections on the DC side of the inverter.

CURRENT/VOLTAGE TRANSDUCER CONNECTIONS OR WIRE COLOR	**CONNECTIONS FOR THE DC SIDE**
Red	+12V on data monitor
White	Pos DC V on data monitor
Blue	-12V on data monitor
Green	Vcc on data monitor
Orange	Analog Aux 1- on data monitor
Black	GND on data monitor
Line AC/DC	+DC
Neutral In	-DC from inverter
Neutral Out	-DC from array

SERIAL COMMUNICATIONS INSTALLATION

Epiphany™ series data acquisition systems are equipped with an RS-422 serial communications interface to allow long cable runs (up to 4000 feet) between the data monitor and the computer. We recommend using four conductor shielded CAT 5 cable.

Connect one pair from the communications cable to the "+R" and "-R" terminals on the data monitor, and connect the other pair to the "+T" and "-T" terminals on the data monitor. These terminals are located on the small daughter board in the data monitor. Route the cable to the appropriate computer (where the software will be installed). At the computer, connect the communications cable to the RS-422 to RS-232C converter as indicated in Table 5. The RS-422 to RS-232C converter should then be connected to the computer's COM1 serial port. **NOTE:** Review table 5 carefully. T stands for transmit and R stands for receive. The transmit connections at the monitor connect to the receive connections at the RS 422 – RS 232 converter. So +R at the monitor goes to T+ at the RS 422 – RS 232 converter. Similarly with the other three connections.

Table 5. RS-422 to RS-232C converter connections.

DATA MONITOR CONNECTION POINT	**COMMUNICATION LINE WIRE COLOR** (FILL IN)	**RS-422 TO RS-232C CONVERTER CONNECTION POINT**
+R		T+
-R		T-
+T		R+
-T		R-

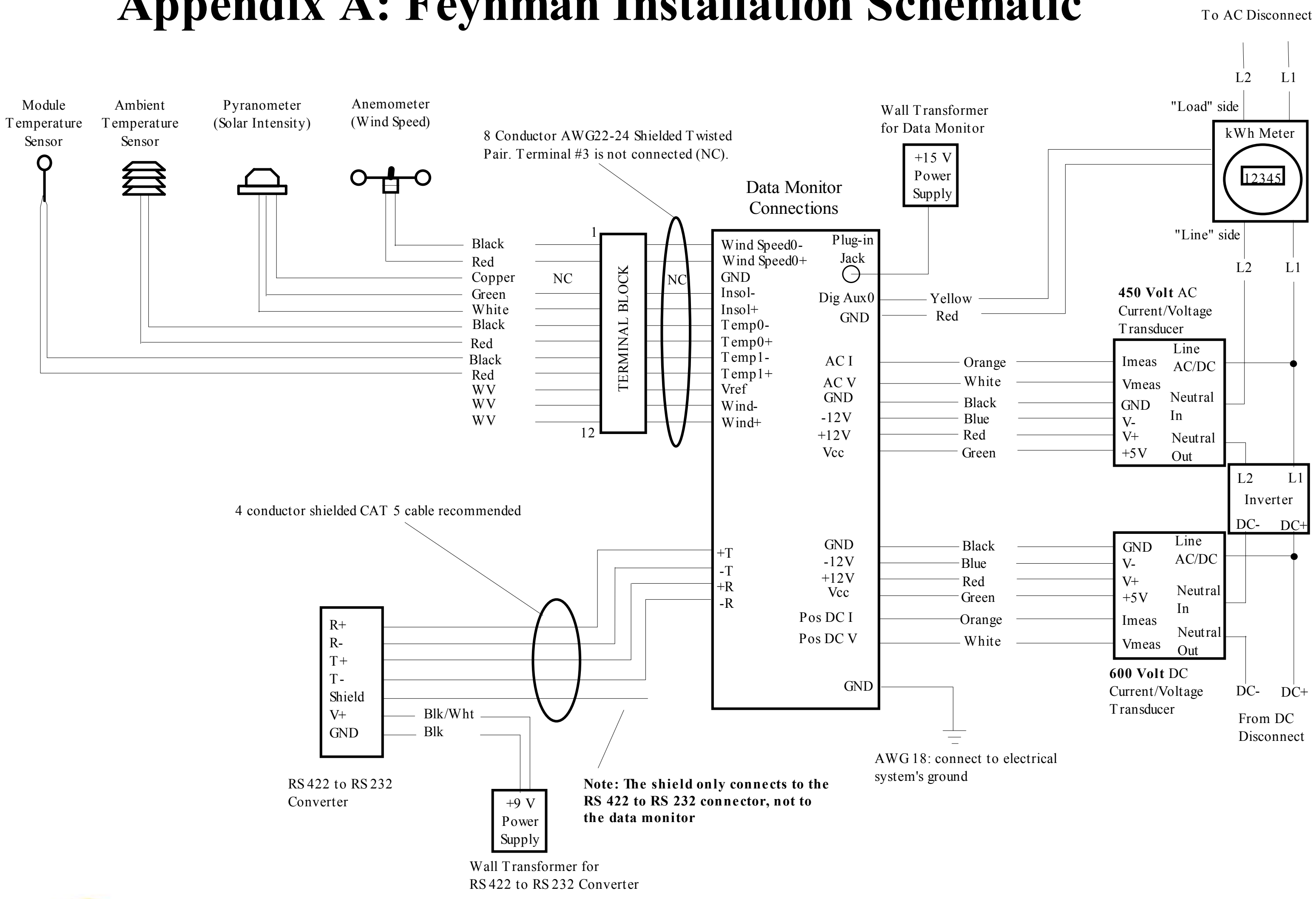
The RS-422 to RS-232C converter requires power from the supplied +9 Volt wall transformer. The transformer is often pre-wired at the factory, however if it is not, then refer to the system wiring schematic in Appendix A. Connect the striped (black and white) wire from the +9 Volt wall transformer to the *+V* terminal on the converter, and connect the solid black wire from the +9 Volt wall transformer to the *GND* terminal on the converter.

DATA MONITOR POWER INSTALLATION

A +15 Volt wall transformer is provided with the *Feynman* Data Acquisition System to power the data monitor. The transformer plugs into the jack on the upper right corner of the data monitor motherboard. Note that the wall transformer is **RATED FOR INDOOR USE ONLY**.

One of the terminals marked "GND" (see Appendix B) on the data monitor should be connected to the electrical system's ground. Use a wire size of AWG 18 for the ground connection.

Appendix A: Feynman Installation Schematic



8 Conductor AWG22-24 Shielded Twisted Pair. Terminal #3 is not connected (NC).

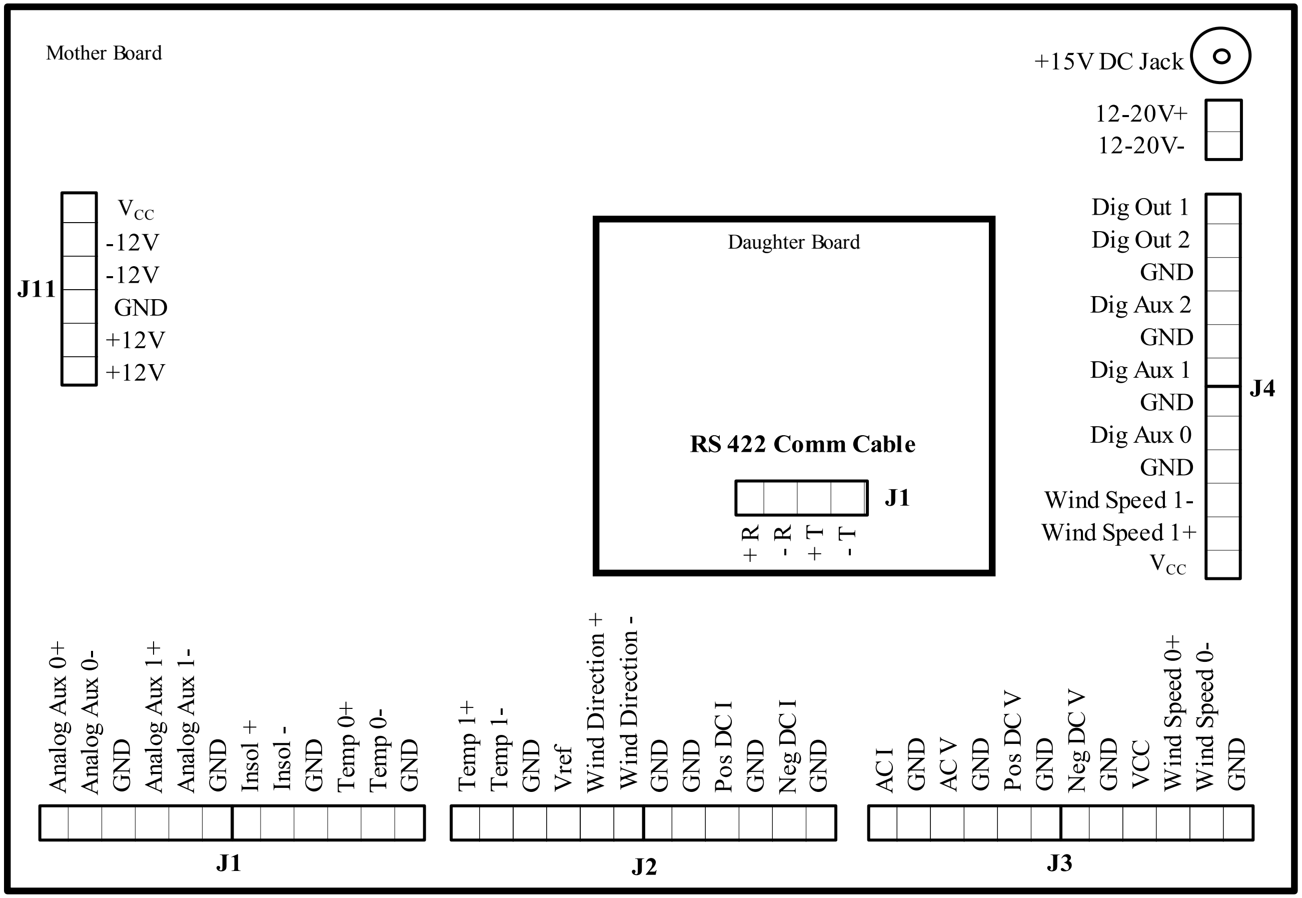
4 conductor shielded CAT 5 cable recommended

Note: The shield only connects to the RS 422 to RS 232 connector, not to the data monitor

AWG 18: connect to electrical system's ground

Heliotronics, Inc.

Appendix B: Data Monitor Terminal Map - RS 422



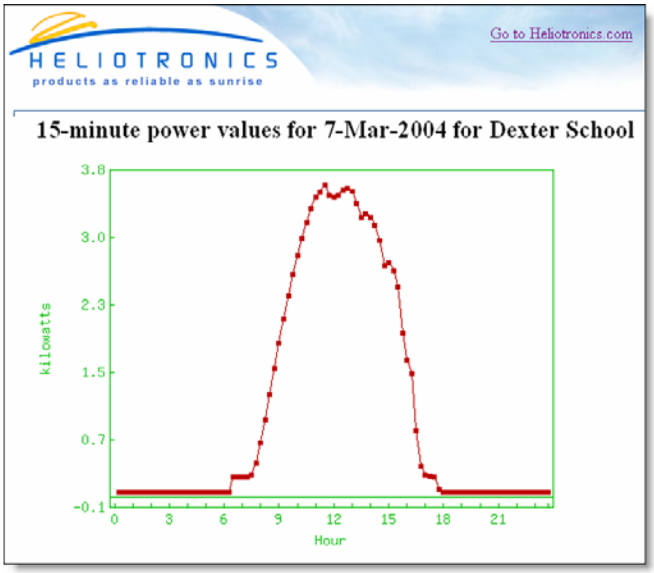
Heliotronics, Inc.

Appendix D: Heliotronics SunView.net Infosheet

Email: marner@heliotronics.com
www.heliotronics.com
Heliotronics, Inc.
Tel: 617-730-5436
Fax: 617-730-5567

SunViewer.net ™
Web Enabled Data Monitoring

SunViewer.net™ is a powerful, interactive tool that enables you to view the performance of your distributed generation systems over the Internet. In addition to graphing a variety of quantities of interest, SunViewer.net™ allows users to download data in a spreadsheet compatible format for further analysis.



Along with *Epiphany*™ series data monitoring systems, Heliotronics can provide a branded web portal for your solar project. This portal allows you to seamlessly integrate a solar data display into your existing website. We've addressed all of the details so you don't have to.

Go to:
www.sunviewer.net/portals/Dexter/index.html
for an example of our project portals.

For larger programs with multiple installations, we also offer an aggregated data viewing capability. In addition to viewing data from individual sites, the database is able to aggregate multiple systems into one output. For example, if your state had 50 schools, *SunViewer.net* would allow users to answer questions such as, how much pollution was avoided due to the renewable energy production of all 50 schools in one particular day.

The system can store power and energy data as well as meteorological data from any site that has an Internet connection and a compatible data acquisition system. Heliotronics offers their *Epiphany*™ series data acquisition systems for this purpose. The screenshot on the back of this page illustrates what data is available and the simplicity of making powerful queries to the database.

SunViewer.net™ enables schools and other institutions to provide national access to data from their renewable energy system. *SunViewer.net*™ is a powerful education and research tool that provides data, processed in fun and informative ways.

For more information, visit **www.Heliotronics.com** or contact Matt Arner by email at marner@heliotronics.com.

Dexter School Solar Power

Date: Jan 1 2004

Daily data	● Power ○ Module Temperature ○ Ambient Temperature ○ Irradiance
Monthly data	○ Energy by day ○ Peak power by day ○ Peak Module Temperature by day ○ Peak irradiance by day
Annual data	○ Energy by month ○ Incident energy by month ○ Avoided CO2 ○ Avoided SOX ○ Avoided NOX
Current data	○ Current data updated every 15 minutes
Output format	● Graph ○ Table ○ CSV
Powered By: HELIOTRONICS	Get Data

Screenshot of a SunViewer.net™ data selection page. Aggregated data for multiple installations is also available.

Appendix E: Responsibilities of Materials (from Mass Energy)

Responsibilities for Materials

1. Solar PV system design.
2. Electrical one-line diagram.
3. Solar PV modules
4. Electrical inverter, with installation instructions.
5. UniRac mounting rails, hardware and accessories.
6. DC disconnect switch.
7. AC disconnect switch.
8. Module termination box (for transition to standard wiring).
9. String interconnection wires (quick-connect, module to module).
10. PV module ground lugs, I per module.
11. AC meter and enclosure (to measure production of inverter).
12. Electrical permit from local municipal agency.
13. Lag bolts or screws to attach UniRac to house or building.
14. Standard DC wiring and conduit from module termination box to DC disconnect switch, then from switch to the inverter.
15. Standard AC wiring and conduit from inverter to AC disconnect switch, then from switch to the production meter and on to the customer's electrical distribution panel.
16. New 15- to 30-amp breaker in the customer's electrical distribution panel, to be backfed from inverter.
17. Labor to install all of the above (PV modules, inverter, meter and wiring)
18. Removal of any construction debris.
19. Cutting, patching, coring, painting and flashing required to restore any parts of the house or building altered by the installation of the solar PV system.

Appendix F: Letter from John Miller to Mass Energy

WPI

100 Institute Road
Worcester, MA 01609-2280, USA
508-831-5500, Fax 508-831-5855
www.wpi.edu

Plant Services

18 February 2004

To Whom It May Concern:

On behalf of Worcester Polytechnic Institute this letter is verify that the liability insurance currently maintained by this University will meet or exceed all the insurance requirements as outlined in Article 6 of the Agreement proposed by the Project Sponsor, Massachusetts Energy Consumers Alliance.

Furthermore, the work that will be undertaken to install the system at WPI will be overseen by administrators of Worcester Polytechnic Institute, and all work will be covered by current WPI insurance. The work will be directly supervised, and done under the license of Mr. Christopher Salter, Manager of Technical Trades – Mass. Electrical license No. 11605A,
Mass. Construction Supervisor license No. 80640

Any questions or concerns should be directed to Mr. John E. Miller, Director of Physical Plant at 508-831-5130, or JEMiller@WPI.edu.

Sincerely yours,

John E. Miller
Director of Physical Plant

CC: D. Cove
C. Salter

Appendix G: Contract with Mass Energy (includes Site Plan, Electrical Diagram, and Green Power Attributes Disclosure)

Solar to Market Initiative (SMI) PARTICIPANTS AGREEMENT

This **AGREEMENT** is made and entered into as of this 30T day of MARCH 2004 **Among** the Owner & Installer ("Owner"), Worcester Polytechnic Institute; and the Project Sponsor, Massachusetts Energy Consumers Alliance, 670 Centre Street, Boston, MA 02130 for the following Project:

Installation of a 1080 kW (AC) photovoltaic (PV) system on the Owner's property at Worcester Polytechnic Institute, 100 Institute Road, Worcester, MA, per the Plans as described in article 1 below. The Project is eligible for incentives from the Project Sponsor as set forth in Article 4.

The Owner will be utilizing its own employees, including licensed electricians, to perform the installation at Owner's expense.

This SMI Participant's Agreement is in conformity with the requirements of the Project Sponsor's Grant Agreement with the Massachusetts Technology Collaborative (MTC) for the Clustered PV Installations Solicitation (SMI-03-05).

The Owner and Project Sponsor agree as follows:

ARTICLE 1
CONTRACT DOCUMENTS

The Owner shall complete the Work on the Project pursuant to the following Contract Documents:

The Project Plans as prepared by the Owner with consultation services from outside vendors as necessary. A copy of the Project Plans are attached to this Agreement. Project Plans are to include site analysis and electrical production estimates.

ARTICLE 2

DATE OF COMMENCEMENT AND SUBSTANTIAL COMPLETION DATE

The date of commencement shall be no later than May 4th, 2004. The installation shall be complete within thirty days of this date, subject to the availability of installation labor supplied by the Owner and any adjustment by written Change Order.

ARTICLE 3
PAYMENT

3.1 The Project Sponsor shall apply its payment to the Owner as follows:

$3780 at the completion of the work, as certified by the Owner and Sponsor after thirty days of the PV system's operation (based on $3.50 per AC Watt installed as defined by MTC).

3.2 The Owner shall be eligible for Energy Production Incentive payments from the Massachusetts Technology Collaborative Grant administered by the Project Sponsor of up to $1620($1.50 per AC Watt installed) at a rate of $0.38/kilowatt hour produced. This is contingent upon participation in the Production Tracking System as described in Article 4.

It is expressly understood that the Project Sponsor's responsibility for the above incentives is dependent upon funding from the Massachusetts Technology Collaborative Grant for Clustered PV Installations Solicitation (SMI-03-05). If that MTC Grant is no longer available in the future for any reason the above incentives will not be available. Neither Project Sponsor nor MTC shall have any liability to Owner or any other party in the case of the elimination of the incentives due to unavailability of such funding.

ARTICLE 4
OWNER RESPONSIBILITIES

4.1 The Owner shall be responsible for all material necessary for the installation, including the Solar PV system design, PV modules, inverter, mounting equipment, disconnects and production meter, conduit, wire, and electrical breakers, as well as for applying for interconnection with the utility.

4.2 The Owner shall supervise and direct the work on the Project, using the best skill and attention. The

Owner shall be solely responsible for and have control over the construction means, method, techniques, sequences and procedures.

4.3 The Owner hereby certifies that it has all valid licenses required by the Commonwealth to perform its work on the Project and that none of its licenses have been suspended or revoked within the last five (5) years.

4.4 The Owner agrees to furnish all labor and materials required for the installation of equipment and completion of all electrical work specified per the Plans as described in Article 1.

4.5 During the term of this Agreement and during any period that the Owner may apply for energy Production Incentives, the Owner agrees as follows:

As a condition of the receipt of Production Incentive funds supplied by the Project Sponsor, the Owner agrees to participate in a Production Tracking System (PTS) which will require the Owner to:
-Assist MTC and participate in its Production Tracking System by collecting and reporting monthly production data from the installed system for a period of three (3) years, beginning thirty (30) days after the system begins operation.

4.6 If the Owner selects to purchase an educational Data Acquisition System a supplemental agreement regarding that equipment with its supplier will be executed.

4.7 Inspections: "The Owner agrees to allow the Project Sponsor, Massachusetts Technology Collaborative or its agents to inspect the installed system as necessary throughout the term of this Agreement and during any period that the Owner would be eligible to receive energy Production Incentive payments.

ARTICLE 5
WARRANTIES

5.1 Owner shall purchase and install only equipment that is warranted by the manufacturer/supplier to be free of defects causing a breakdown or degradation of electrical output of more than ten percent from the originally-rated electrical output for five (5) years from the date of completion. This warranty shall cover the cost of any required replacement components and systems required to restore the system to the warranted level of operation during the warranty period.

5.2 Owner shall purchase and install only PV modules that are warranted by the manufacturer/supplier to be free of defects causing a breakdown or degradation of electrical output of more than twenty percent from the originally-rated electrical output for twenty-five (25) years from the date of completion. This warranty covers the cost of any required replacement modules required to restore the system to the warranted level of operation during the warranty period.

5.3 Installation labor and services over the lifetime of said warranties shall remain the responsibility of the Owner.

5.4 These warranties shall be the Owners' exclusive remedy and are in lieu of any other warranties, express or implied and is in addition to and not in limitation of any other or remedy required by law.

5.5 Limitation on Project Sponsor: It is expressly understood that neither the Project Sponsor Massachusetts Energy Consumer Alliance nor the MTC have any design, construction or supervision responsibilities for the Project and that all warranties hereunder are provided by the Owner and, if applicable, by equipment manufacturers, suppliers, and Owner's consultants.

ARTICLE 6
INSURANCE

6.1 The Owner shall provide Contractor's Liability and other insurance as follows: Commercial General Liability insurance of $2,000,000 per occurrence for bodily injury and property damage; $2,000,000 per occurrence for personal and advertising injury; $4,000,000 general aggregate (applied per job); and $4,000,000 products and completed operations aggregate written on an occurrence basis.

6.2 Said insurance shall name the Project Sponsor Massachusetts Energy Consumer Alliance and the Massachusetts Technology Collaborative as additional named insureds.

6.3 The Owner shall confirm that any subcontractor employed to perform work on the Project carries all legally mandated insurance coverage and general liability coverage of $1,000,000 with a $1,000,000 umbrella.

6.4 The Owner hereby certifies that the Owner has and shall maintain a commercial insurance policy covering damage to the property, including the PV system.

6.5 The Owner shall obtain an endorsement to its general liability insurance policy to cover the Contractor's obligations hereunder.

6.6 Certificates of Insurance shall be provided by the Owner showing their respective coverages prior to commencement of the Work.

ARTICLE 7
CONSUMER DISCLOSURES

The Owner shall have title to the PV System's non-energy attributes. Attached hereto is a consumer disclosure statement explaining the concept and potential value of the non-energy attributes.

ARTICLE 8
OTHER TERMS AND CONDITIONS

8.1 Indemnification: To the fullest extent permitted by law, the Owner shall indemnify and hold harmless the MTC, and the Massachusetts Energy Consumer Alliance, their agents, officers and employees, against any and all liability, loss, damages, penalties, costs or expenses for personal injury or damage to real or tangible personal property which the MTC or the Massachusetts Energy Consumer Alliance may sustain, incur or be required to pay, resulting from, arising out of, or in any connection with the services performed by or delivered under this Agreement by reason of acts, inactions, omissions, negligence, recklessness or intentional misconduct of the Owner as to its installation duties and services on this Project.

8.2 Mediation/Arbitration: In the event of any disputes under this Agreement, the parties hereby agree to submit such dispute to binding arbitration in accordance with the Construction Industry Arbitration Rules. If any party request Mediation prior to Arbitration, the parties will mediate their dispute in accordance with the Construction Industry Mediation Rules. The parties to any such dispute shall share the mediator/arbitrator fees equally.

This Agreement entered into as of the day and year first written above.

OWNER
Worcester Polytechnic Institute
Stephen J. Hebert
(signature)
Steve Hebert
Vice President
Worcester Polytechnic Institute
100 Institute Rd.
Worcester, MA 01609
(printed name, title and address)

PROJECT SPONSOR
Massachusetts Energy
Consumers Alliance
(signature)
Larry Chretien
Executive Director
Mass Energy
670 Centre St.
Jamaica Plain, MA 02130
(printed name, title and address)

Site Plan, Energy Calculation, and Shading Coefficient

Job Number:

Worcester Polytechnic Institute
Department of Plant Services
100 Institute Road
Worcester, MA 01609

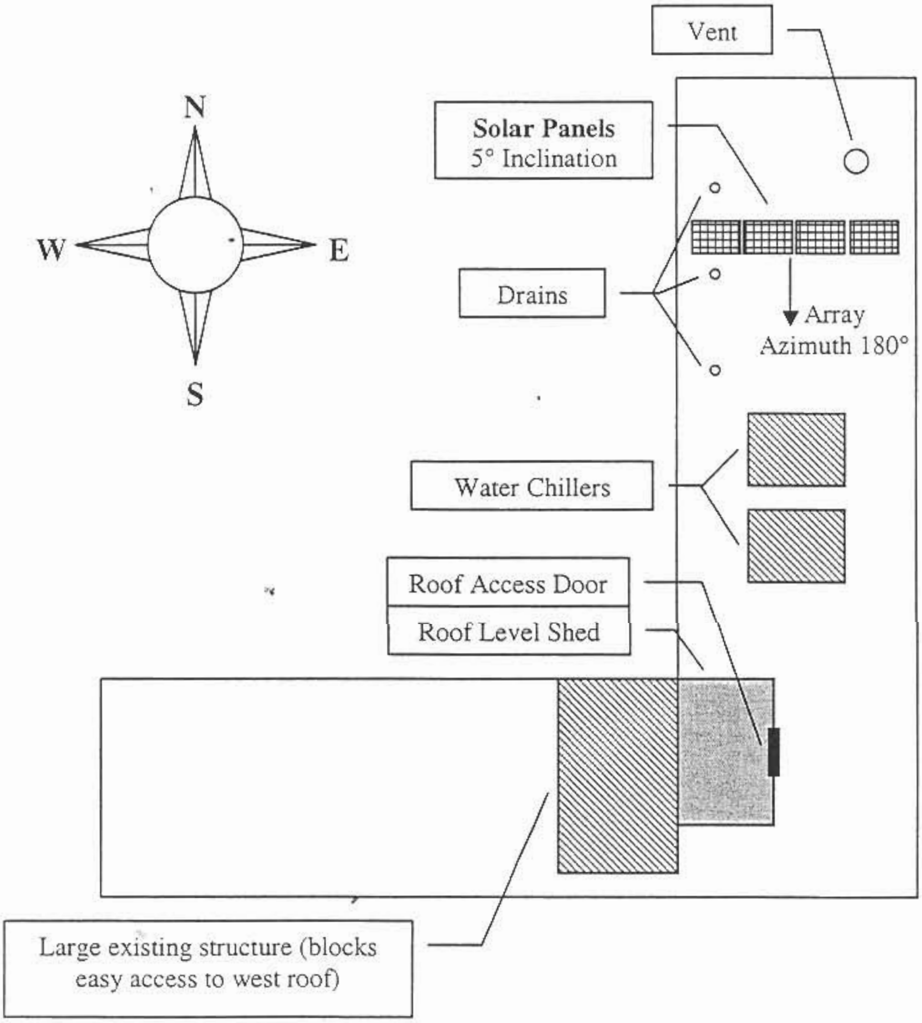
Energy Calculation:

System AC Power Rating:	1.080 kW
(kWh/yr)/kW AC	1200
Energy Output	**1296 kWh**

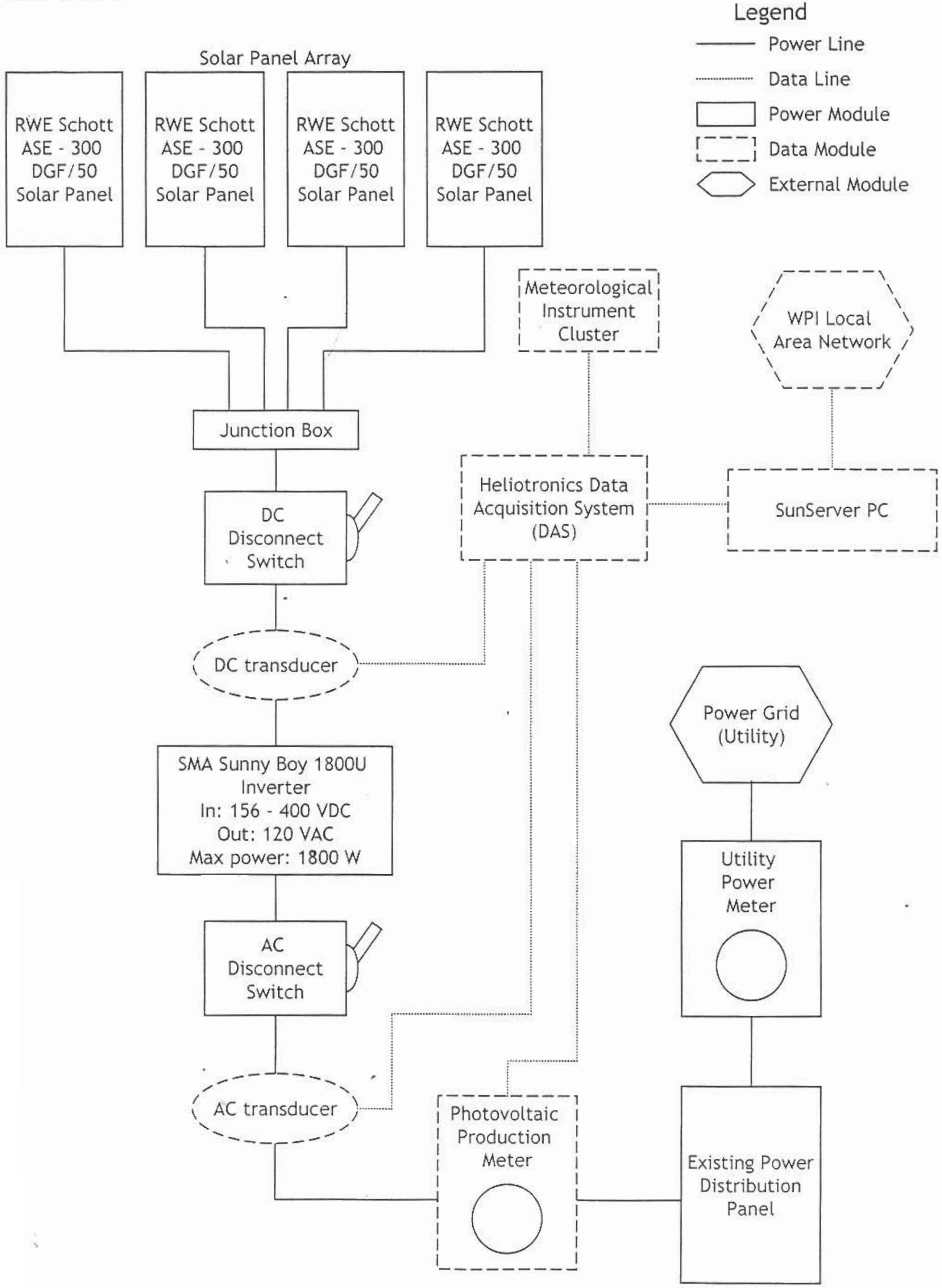
Shading Coefficient:

less than 1% from antenna

Site Plan:



Photovoltaic System Electrical Diagram
Worcester Polytechnic Institute
Artist: Ye Wang
Date: 3/29/04



Green Power Attribute Disclosure Statement

Defining Energy and Attribute Components of Electricity Production

Participants in Mass Energy's solar grant program should be aware that there is value associated with both the "energy" and "attribute" components of the electricity generated by their solar equipment.

When electricity is generated, two separate "products" are created: 1) the electrons (energy) which flow over transmission and distribution wires and into the homes and businesses of electricity customers; and 2) the attributes, or characteristics, (environmental, labor, or otherwise) associated with those electrons. Due to the physics of electricity flow, there is no way to control the destination of the electrons from a particular plant. Therefore, accounting for electricity attributes is critical to the process of determining the characteristics and impacts of electricity usage.

In New England, there is a region-wide accounting system that tracks the flow of electricity attributes. This accounting system, called the Generation Information System (GIS), tracks electricity attributes in one megawatthour (1 MWh) increments, called "certificates." Each certificate describes a range of characteristics associated with its generation source, such as the type of generator, the emissions rates for various pollutants, the date the generator went into operation, etc. Electricity suppliers will report their certificate holdings each quarter as part of a mandatory disclosure to their customers.[1]

A market for certificates from renewable energy sources has developed in Massachusetts and across New England. This market is driven by two key factors. First, starting in 2003, state law requires electricity suppliers to comply with a Renewable Portfolio Standard (RPS) which mandates that a minimum percentage of their electricity sales come from new renewable energy sources. Compliance with this mandate is tracked in the form of renewable energy certificates. If suppliers are unable or unwilling to purchase renewable energy certificates directly, they will have the option to comply by making an "Alternative Compliance Payment" of 5 cents per kilowatt hour for the required quantity of kilowatt hours. In addition, some electricity suppliers are offering consumers the opportunity to voluntarily support renewable energy. These sources could include solar energy, such as that which could be generated from your rooftop.

Title to Energy and Attributes

A typical system installed through this program should produce approximately 3,000 kilowatthours (kWh), or three MWhs, of energy and attributes per year. Participants in

---

[1] Currently, disclosure labels are based on purchase power agreements and not on certificate holdings due to the fact that the GIS was only introduced in mid-2002. The Massachusetts Department of Telecommunications and Energy will require suppliers to use GIS certificate holdings as the basis for disclosure labels starting in XX.

Mass Energy's solar grant program will automatically gain title to the energy and attributes associated with the electricity generated by their solar equipment.

Opportunities for Sale of Energy through Net Metering

According to Massachusetts regulations (220 CMR 11.04) "a customer of a Distribution Company with an on-site Generation Facility of 60 kilowatts or less in size has the option to run the meter backward and may choose to receive a credit from the Distribution Company equal to the average monthly market price of generation per kilowatt-hour, as determined by the Department [of Telecommunications and Energy], in any month during which there was a positive net difference between kilowatt-hours generated and consumed."

Due to the size of solar equipment installed through this program, the majority of the solar energy produced will be consumed by the participant. However, since the amount electricity customers pay per kWh on their electricity bill is greater than the amount that the Distribution Company would credit a customer for net energy production (since the electricity bill includes per-kWh charges for services other than electricity generation), the most valuable energy produced by solar equipment is the portion which is consumed on-site.

Opportunities for Sale of Attributes

In addition to saving money on electricity bills, and possibly receiving credit for net energy production, program participants can receive a revenue stream from the attributes produced by their solar equipment. In order to be traded in the GIS system, attributes must add up to one MWh increments, and they must be registered in the GIS as "certificates." A participant could either allow their attributes to be aggregated with those from other solar projects and then registered in the GIS by a third-party, or they could wait until the output from their own equipment exceeds one MWh and register their own certificate with the GIS.

✸ Mass Energy is now extending offers to program participants to purchase attributes for an initial period of three years. We are offering to compensate program participants at a rate of $0.06 per kilowatt hour of attributes produced. We will issue checks quarterly for these attributes. Purchases will be based on output that is recorded in the MTC Production Tracking System (PTS). Mass Energy will combine solar attributes from a variety of solar projects into GIS certificates that we will incorporate into our green electricity product, *New England GreenStart*^{SM}.

Other entities may approach program participants to purchase attributes, and participants are free to sell their attributes to an entity other than Mass Energy. However, Mass Energy would greatly appreciate the opportunity to purchase attributes from the projects that we have helped facilitate, as those attributes could play an important role in making

Mass Energy's *New England GreenStart*^{SM} product more compelling to potential customers. We believe that the price we are willing to pay is quite competitive. By selling attributes to Mass Energy for inclusion in our *New England GreenStart*^{SM} product, participants would essentially spread the cost of their solar equipment more broadly, allowing Mass Energy's green electricity customers to share in the solar investment.

In order to avoid double counting of attributes, it is important for program participants to recognize that they cannot sell the same attributes to more than one party. Furthermore, any claims made regarding the environmental characteristics and benefits of the PV system must be accompanied by disclosure about the sale of GIS certificates to Mass Energy. Furthermore, attributes associated with a given unit of output must remain "bundled." Therefore, one could not sell the greenhouse gas offset benefits of their energy output to one entity while selling the acid rain benefits of that same output to another entity.

If you have any questions about this disclosure statement, please call Mass Energy at 617-524-3950 and ask to speak with Leslie Grossman or Debra Perry.

Appendix H: Mass Electric Notice of Intent to Interconnect Form

Exhibit C: Simplified Process Interconnection Application

Instructions

General Information

If you wish to submit an application to interconnect your generating Facility using the Simplified Process (10KW or less, inverter-based, UL1741-listed) please fill out the attached application form down to the space for your signature. Once complete, please sign and attach any documentation provided by the generator manufacturer describing the UL1741 listing for the generator. The process is as follows:

1. Application process:
    a. Interconnecting Customer submits a Simplified Application filled out properly and completely.
    b. The electric utility Company acknowledges to the Interconnecting Customer receipt of the application within three business days of receipt.
    c. Company evaluates the application for completeness and notifies the Interconnecting Customer within 10 days of receipt that the application is or is not complete and, if not, advises what is missing.
2. Company verifies Facility equipment can be interconnected safely and reliably. Company signs application approval line and sends to Customer. In certain rare circumstances, the Company may require the Interconnecting Customer to pay for minor System Modifications, if so, an estimate will be sent back with the approved application requiring the Interconnecting Customer's consent to pay for the modifications.
3. After installation, customer returns Certificate of Completion. Prior to parallel operation Company may inspect Facility for compliance with standards which may include a witness test, and schedules appropriate metering replacement, if necessary.

Company notifies Interconnecting Customer in writing that interconnection of the Facility is authorized. If the witness test is not satisfactory, the Company has the right to disconnect the Facility. The Interconnecting Customer has no right to operate in parallel until a witness test has been performed or previously waived on the Application Form. The Company is obligated to complete this witness test within 10 days of the receipt of the Certificate of Completion. If the Company does not inspect in 10 days or by mutual agreement of the Parties, the Witness Test is deemed waived.

Contact Information: You must provide the contact information for the legal applicant (i.e. the Interconnecting Customer). If another party is responsible for interfacing with the Company (utility), you should provide his/her/its contact information as well.

Ownership Information: Please enter the legal names of the owner or owners of the Facility. Include the percentage ownership (if any) by any Company or public utility holding company, or by any entity owned by either.

Confidentiality Statement: In an ongoing effort to improve the interconnection process for Interconnecting Customers, the information you provide and the results of the application process will be aggregated with the information of other applicants and periodically reviewed by a DG Collaborative of industry participants that has been organized by the Massachusetts Department of Telecommunications and Energy (DTE). The aggregation process mixes the data together so that specific details for one Interconnecting Customer are not revealed. In addition to this process, you may choose to allow the information specific to your application to be shared with the Collaborative by answering "Yes" to the Confidentiality Statement question on the first page. Please note that even in this case your identification information (contact data) and specific Facility location will not be shared.

Facility Information

UL1741 Listed? This standard ("Inverters, Converters, and Controllers for Use in Independent Power Systems") addresses the electrical interconnection design of various forms of generating equipment. Many manufacturers choose to submit their equipment to a Nationally Recognized Testing Laboratory (NRTL) that verifies compliance with UL1741. This "listing" is then marked on the equipment and supporting documentation.

DEP Air Quality Permit Needed? A Facility may be considered a point source of emissions of concern by the Massachusetts Department of Environmental Protection (DEP). Therefore, when submitting this application, please indicate whether the proposed Facility will require an Air Quality Permit. You must answer these questions, however, your specific answers will not affect whether your application is deemed complete. Please contact the DEP to determine whether the generating technology planned for your Facility qualifies for a DEP waiver or requires a permit.

Simplified Interconnection Application and Service Agreement for Facilities with Inverter Capacity of 10KW and under

Contact Information

Legal Name and address of Interconnecting Customer applicant (or, if an Individual, Individual's Name)

Company Name: WPI Plant Services Contact Person: Chris Salter
Mailing Address: WPI Plant Services 100 Institute Road
City: Worcester State: MA Zip Code: 01609
Telephone (Daytime): 508-831-6060 (Evening): ____
Facsimile Number: 508-831-5551 E-Mail Address: csalter@wpi.edu

Alternative Contact Information (if different from Applicant)
Name: John Miller
Mailing Address: WPI Plant Services 100 Institute Road
City: Worcester State: MA Zip Code: 01609
Telephone (Daytime): 508-831-5500 (Evening): ____
Facsimile Number: 508-831-5855 E-Mail Address: jemiller@wpi.edu
Ownership (include % ownership by any electric utility): WPI Plant Services

Confidentiality Statement: "I agree to allow information regarding the processing of my application (without my name and address) to be reviewed by the Massachusetts DG Collaborative that is exploring ways to further expedite future interconnections." Yes X No____

Facility Information

Location (if different from above): WPI Morgan Residence Hall (at same Address)
Electric Service Company: Massachusetts Electric
Account Number (if available): 19111 15250 03
Inverter Manufacturer: SMA Model Sunny Boy 1800U
Nameplate Rating: 0.96 (KW) 0.96 (kVA) 120 (AC Volts) Single X or Three____ Phase
System Design Capacity: 0.96 (KW) 0.96 (kVA)
Prime Mover: Photovoltaic ☒ Reciprocating Engine ☐ Fuel Cell ☐ Turbine ☐ Other ____
Energy Source: Solar ☒ Wind ☐ Hydro ☐ Diesel ☐ Natural Gas ☐ Fuel Oil ☐ Other____
UL1741 Listed? Yes X No ____ Need an air quality permit from DEP? Yes____ No X Not Sure ____
If "yes", have you applied for it? Yes___No ___
Estimated Install Date: 4/18/04 Est. In-Service Date: 5/4/2004

Customer Signature (attach manufacturer's cutsheet showing UL1741 listing & sign here)

I hereby certify that, to the best of my knowledge, all of the information provided in this application is true and I agree to the Terms and Conditions on the following page:
Interconnecting Customer Signature: ____ Title: DIRECTOR OF PHYSICAL PLANT Date: 4/8/04

Approval to Install Facility (For Company use only)

Installation of the Facility is approved contingent upon the terms and conditions of this Agreement, and agreement to any system modifications, if required (Are system modifications required? Yes___ No___):

Company Signature: ____ Title: ____ Date: ____
Application ID number: ____ Company waives inspection/witness test? Yes___No___

Terms and Conditions for Simplified Interconnections

1. **Construction of the Facility**. The Interconnecting Customer may proceed to construct the Facility once the Approval to Install the Facility has been signed by the Company.

2. **Interconnection and operation. The Interconnecting Customer may operate Facility and interconnect with the Company's system once the following has occurred:**
   - 2.1. **Municipal Inspection:** Upon completing construction, the Interconnecting Customer will cause the Facility to be inspected or otherwise certified by the local electrical wiring inspector with jurisdiction.
   - 2.2. **Certificate of Completion:** The Interconnecting Customer returns the Certificate of Completion appearing as Attachment 2 to the Agreement to the Company at address noted.
   - 2.3. **Company has completed or waived the right to inspection.**

3. **Company Right of Inspection.** Within ten (10) business days after receipt of the Certificate of Completion, the Company may, upon reasonable notice and at a mutually convenient time, conduct an inspection of the Facility to ensure that all equipment has been appropriately installed and that all electrical connections have been made in accordance with the Tariff. The Company has the right to disconnect the Facility in the event of improper installation or failure to return Certificate of Completion. If the Company does not inspect in 10 days or by mutual agreement of the Parties, the Witness Test is deemed waived.

4. **Safe Operations and Maintenance.** The Interconnecting Customer shall be fully responsible to operate, maintain, and repair the Facility.

5. **Access.** The Company shall have access to the disconnect switch (if required) of the Facility at all times.

6. **Disconnection.** The Company may temporarily disconnect the Facility to facilitate planned or emergency Company work.

7. **Metering and Billing**. All Facilities approved under this Agreement qualify for net metering, as approved by the Department from time to time, and the following is necessary to implement the net metering provisions:
   - 7.1. **Interconnecting Customer Provides Meter Socket**. The Interconnecting Customer shall furnish and install, if not already in place, the necessary meter socket and wiring in accordance with accepted electrical standards.
   - 7.2. **Company Installs Meter**. The Company shall furnish and install a meter capable of net metering within ten (10) business days after receipt of the Certificate of Completion if inspection is waived, or within 10 business days after the inspection is completed, if such meter is not already in place.

8. **Indemnification**. Interconnecting Customer and Company shall each indemnify, defend and hold the other, its directors, officers, employees and agents (including, but not limited to, Affiliates and contractors and their employees), harmless from and against all liabilities, damages, losses, penalties, claims, demands, suits and proceedings of any nature whatsoever for personal injury (including death) or property damages to unaffiliated third parties that arise out of, or are in any manner connected with, the performance of this Agreement by that party, except to the extent that such injury or damages to unaffiliated third parties may be attributable to the negligence or willful misconduct of the party seeking indemnification.

9. **Limitation of Liability**. Each party's liability to the other party for any loss, cost, claim, injury, liability, or expense, including reasonable attorney's fees, relating to or arising from any act or omission in its performance of this Agreement, shall be limited to the amount of direct damage actually incurred. In no event shall either party be liable to the other party for any indirect, incidental, special, consequential, or punitive damages of any kind whatsoever.

10. **Termination**. This Agreement may be terminated under the following conditions:

    - 10.1. **By Mutual Agreement**. The Parties agree in writing to terminate the Agreement.
    - 10.2. **By Interconnecting Customer**. The Interconnecting Customer may terminate this Agreement by providing written notice to Company.
    - 10.3. **By the Company**. The Company may terminate this Agreement (1) if the Facility fails to operate for any consecutive 12 month period, or (2) in the event that the Facility impairs the operation of the electric distribution system or service to other customers or materially impairs the local circuit and the Interconnecting Customer does not cure the impairment.
11. **Assignment/Transfer of Ownership of the Facility**: This Agreement shall survive the transfer of ownership of the Facility to a new owner when the new owner agrees in writing to comply with the terms of this Agreement and so notifies the Company.
12. **Interconnection Tariff:** These Terms and Conditions are pursuant to the Company's Tariff for the Interconnection of Interconnecting Customer-Owned Generating Facilities, as approved by the Department of Telecommunications and Energy and as the same may be amended from time to time ("Interconnection Tariff"). All defined terms set forth in these Terms and Conditions are as defined in the Interconnection Tariff (see Company's website for complete tariff).

ATTACHMENT 2

SIMPLIFIED PROCESS INTERCONNECTION

Certificate of Completion

Installation Information ☐ Check if owner-installed

Interconnecting Customer: ________________________ Contact Person: ________________________

Mailing Address: ____

Location of Facility (if different from above): ________________________________

City: ______________________ State: ________________ Zip Code: ________

Telephone (Daytime): ________________ (Evening): ________________________

Facsimile Number: ________________ E-Mail Address: ________________________

Electrician:

Name: ____

Mailing Address: ____

City: ______________________ State: ________________ Zip Code: ________

Telephone (Daytime): ________________ (Evening): ________________________

Facsimile Number: ________________ E-Mail Address: ________________________

License number: ________________________

Date Approval of Install Facility granted by the Company: ________________

Application ID number: ______________________

Inspection:

The system has been installed and inspected in compliance with the local Building/Electrical Code of

____
(City/County)

Signed (Local Electrical Wiring Inspector, or attach signed electrical inspection): ____________________

Name (printed): ____

Date: ________

As a condition of interconnection you are required to send/fax a copy of this form along with a copy of the signed electrical permit to (insert Company's name below):

Name: ________________
Company: ______________
Mail 1: ________________
Mail 2: ________________
City, State ZIP: __________
Fax No.: ______________

Appendix I: Mass Technology Collaborative Production Tracking System Form

System name:
System ID: (PTS will automatically generate)

System Owner Information:		
	First Name	Chris
	Last Name	Salter
	Company/Organization	WPI Plant Services
	Address	100 Institute Road
	City	Worcester
	State	MA
	Zip Code	01609
	Phone	1 508-831-6060
	Email	csalter@wpi.edu
	PTS user name:	
	PTS password:	

System Representative Information:		
	First Name	Chris
	Last Name	Salter
	Company/Organization	WPI Plant Services
	Address	100 Institute Road
	City	Worcester
	State	MA
	Zip Code	01609
	Phone	1 508-831-6060
	Email	csalter@wpi.edu
	PTS user name:	
	PTS password:	

Site Name:		WPI Morgan Hall
	Address	100 Institute Road
	City	Worcester
	State	MA
	Zip	01609

PV Panel

Model	**Manufacturer**	**Quantity**
ASE-300-DGF/50	RWE Schott Solar	4

Inverter

Model	**Manufacturer**	**Quantity**
SunnyBoy2500U	SMA	1

System Meter

Model
Manufacturer

Storage System

None

Maximum Rated Output	1.080 kW
Estimated Annual Production	1296 kWh

PV Panel Details

Orientation	Fixed
Azimuth	180
Inclination	5

PV Surface Area 4*6.208 feet*4.208 =	104.5 square feet
Rated Efficiency	%
Number of daylight hours that panel is shaded by nearby objects:	0

System Installation

Costs

Main Equipment Cost	$12,374
Peripheral Equipment Cost	
Installation Cost	$0
Utility Interconnection Fees	
Total Cost:	$

Details

Date Contract Signed	3/30/04
System Installer	WPI Plant Services
Electric Utility	Mass Electric Company

Appendix J: RWE Schott Quote

RWE
SCHOTT Solar

RWE SCHOTT Solar, Inc.
4 Suburban Park Drive, Billerica, MA 01821-2868
Phone 800.977.0777
Fax 978.663.2868

To:
Debra Perry
Program Coordinator, Mass. Energy
670 Centre Street
Boston, MA 02130
Phone 617.524.3950
Fax
Email debra@massenergy.com

Originator Jamie Braman
Phone 978.947.5505
Email jamie.braman@rweschottsolar.us

Ref: Solar Boston Equipment Supply
MTC Clusters - 70 kW hardware purchase

9-Apr-04

QUOTATION

100633

Confidential

Item	Description	Qty	Price/unit	Price ext.	Per watt
1	**PV Modules**				
1 kW System	ASE 300w./50v. PVModules	4	$ 1,044.00	$ 4,176.00	$ 3.48
2 kW System	ASE 300w./50v. PVModules	8	$ 1,044.00	$ 8,352.00	$ 3.48
2	**Inverters**				
1 kW System	SMA Sunny Boy 1800U (120v.) w/o display	1	$ 1,676.00	$ 1,676.00	$ 1.40
2 kW System	SMA Sunny Boy 2500U (240v.) w/o display	1	$ 2,050.00	$ 2,050.00	$ 0.85
	...inverters above with display option	*1*	*$ 99.00*		
	...inverters above with Sunny Breeze Fan Kit	*1*	*$ 99.00*		
3	**Mounting Hardware**				
	Flat Roofs				
1 kW System	FS Mounting System	1	$ 1,029.00	$ 1,029.00	$ 0.86
2 kW System	FS Mounting System	1	$ 1,530.00	$ 1,530.00	$ 0.64
Layout:	1 row/4 modules: 2 rows/8 modules				
	Pitched Roofs				
1 kW System	RSS RoofJack Residential Mounting System	1	$ 151.00	$ 151.00	$ 0.06
2 kW System	RSS RoofJack Residential Mounting System	1	$ 286.00	$ 286.00	$ 0.12
Layout:	1 row - 4/8 modules				
Note:	These hardware packages consist of the necessary equipment for the specific layouts above. Any changes to the system design and layout may incur additional hardware fees.				
4	**Balance of System**				
1 kW System	AC Switch, DC Switch, DC Combiner Box, Revenue grade kWh Meter with base, MC return cable, ground wiring	1	$ 493.00	$ 493.00	$ 0.41
2 kW System	AC Switch, DC Switch, DC Combiner Box, Revenue grade kWh Meter with base, MC return cable, ground wiring	1	$ 538.00	$ 538.00	$ 0.45
5	**Design Consultation - Drawings**				
	Drawings: Mechanical, Electrical for 1 and 2 kW systems above		$ 580.00	$ 580.00	
Note:	This design package of drawings many be used for all of the systems above, and is a one time fee. Any changes to the system design may incur additional fees.				
6	**Other Consultation**				
	Hourly engineering and consultation including: phone support, additional mechanical/electrical drawings, custom system design…Does not include any site visits, implementation of action items, or on-site work.		$ 140.00	$ 140.00	
Note:	Engineering Services must be scheduled a minimum of 30 days in advance.				

This quote is valid for 160 days

Signed: ____________________

Subtotal	
Shipping	
Sales Tax	n/a
TOTAL	$ -

Appendix K: RWE Schott Purchase Order

WORCESTER
POLYTECHNIC
INSTITUTE

Department of Plant Services
100 Institute Road
Worcester, MA 01609-2280
(508) 831-5500
FAX: (508)831-5855

FAX COVER SHEET

TO: RWE SCHOTT SOLAR DATE:

ATTENTION: JAMES BRAMAN PAGES TO FOLLOW:

FAX NUMBER:( ) 978-663-2868

FROM: JMiller

WPI DEPT OF PLANT SERVICES PHONE NUMBER:( )

REMARKS: PLEASE FURNISH AS PER ATTACHED PURCHASE REQUISITION.

SHIPPER SHOULD CALL AHEAD
BEFORE DELIVERY FOR DIRECTIONS
CALL: JOHN Miller 508-831-5130
OR CHRIS SALTER 508-831-6060

PLEASE NOTIFY IMMEDIATELY IF FAX INCOMPLETE

RWE
SCHOTT Solar

RWE SCHOTT Solar, Inc.
4 Suburban Park Drive, Billerica, MA 01821-2868
Phone 800.977.0777
Fax 978.663.2868

To:	Debra Perry Program Coordinator, Mass. Energy 670 Centre Street Boston, MA 02130 Phone 617.524.3950 Fax Email debra@massenergy.com	Originator Phone Email	Jamie Braman 978.947.5505 jamie.braman@rweschottsolar.us
		Ref:	Solar Boston Equipment Supply MTC Clusters - 70 kW hardware purchase

9-Apr-04 **QUOTATION** 100633 *Confidential*

Item	Description	Qty	Price/unit	Price ext.	Per watt
1	**PV Modules**				
1 kW System	ASE 300w./50v. PVModules	4	$ 1,044.00	$ 4,176.00	$ 3.48
2 kW System	ASE 300w./50v. PVModules	8	$ 1,044.00	$ 8,352.00	$ 3.48
2	**Inverters**				
1 kW System	SMA Sunny Boy 1800U (120v.) w/o display	1	$ 1,676.00	$ 1,676.00	$ 1.40
2 kW System	SMA Sunny Boy 2500U (240v.) w/o display	1	$ 2,050.00	$ 2,050.00	$ 0.85
	...inverters above with display option	*1*	*$ 99.00*		
	...inverters above with Sunny Breeze Fan Kit	*1*	*$ 99.00*		
3	**Mounting Hardware**				
	Flat Roofs				
1 kW System	FS Mounting System	1	$ 1,029.00	$ 1,029.00	$ 0.86
2 kW System	FS Mounting System	1	$ 1,530.00	$ 1,530.00	$ 0.64
Layout:	1 row/4 modules: 2 rows/8 modules				
	Pitched Roofs				
1 kW System	RSS RoofJack Residential Mounting System	1	$ 151.00	$ 151.00	$ 0.06
2 kW System	RSS RoofJack Residential Mounting System	1	$ 286.00	$ 286.00	$ 0.12
Layout:	1 row - 4/8 modules				
Note:	These hardware packages consist of the necessary equipment for the specific layouts above. Any changes to the system design and layout may incur additional hardware fees.				
4	**Balance of System**				
1 kW System	AC Switch, DC Switch, DC Combiner Box, Revenue grade kWh Meter with base, MC return cable, ground wiring	1	$ 493.00	$ 493.00	$ 0.41
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5	**Design Consultation - Drawings**				
	Drawings: Mechanical, Electrical for 1 and 2 kW systems above		$ 580.00	$ 580.00	
Note:	This design package of drawings many be used for all of the systems above. and is a one time fee. Any changes to the system design may incur additional fees.				
6	**Other Consultation**				
	Hourly engineering and consultation including: phone support, additional mechanical/electrical drawings, custom system design...Does not include any site visits, implementation of action items, or on-site work.		$ 140.00	$ 140.00	
Note:	Engineering Services must be scheduled a minimum of 30 days in advance.				

This quote is valid for 160 days

Signed: ______________________

Subtotal	
Shipping	
Sales Tax	n/a
TOTAL	$ -

COMPLETE FORM - RETAIN PINK COPY AND SEND BALANCE OF SET TO PLANT SERVICES

TO: WPI Plant Services

REQUEST FOR (CHECK ONE)
☐ INVENTORY WITHDRAWAL
☐ PURCHASE ORDER

P.O.# K 7529

DATE

APPLICABLE PROJECT NO.

APPLICABLE WORK ORDER NO.

REQUESTED BY: JOHN MILLER

DEPARTMENT: PLANT SERVICES

CHARGE ACC'T. NO.: 11001-4640-7183

DEP'T. HEAD APPROVAL: 4/15/04

VENDOR NAME: RWE SCHOTT SOLAR, INC

ADDRESS: 4 SUBURBAN PARK DRIVE

CITY: BILLERICA, MA 01821-2868

STATE, ZIP CODE: ATTN: (F) 978-663-2868 JAMES BRAMAN

VENDOR CODE

DATE

A/C NO.

$

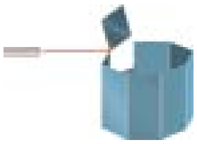
QTY.	UNIT	DESCRIPTION	UNIT PRICE	COST
		FURNISH PV COMPONENTS AS PER ATTACHED QUOTATION 100633 DTD 9 APRIL 04-		
		TOTAL COST		$7146
		ESTIMATED SHIPPING		500
		TOTAL		$7646

MASSACHUSETTS SALES TAX EXEMPT
REGISTRATION NO. 042 121 659

CHARGE ACC'T. NO. ____ CREDIT ACC'T. NO. ____ TOTAL AMOUNT $____

APPROVAL ____ APPROVAL ____

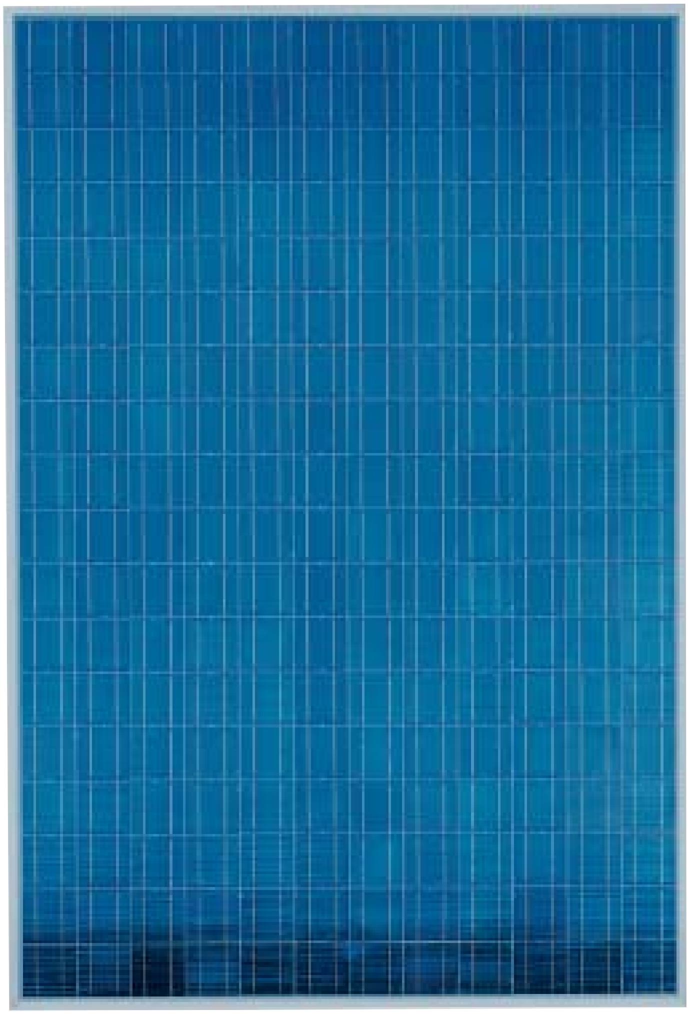
Appendix L: RWE Schott AES Photovoltaic Panel Infosheet



RWE
SCHOTT Solar

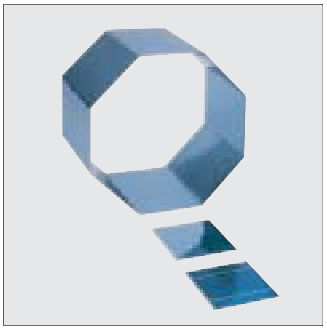
ASE-300-DGF/50

World's Most Powerful Photovoltaic Module with Crystal Clean™ EFG Cell Technology



ASE-300-DGF/50

ASE-300-DGF/50 connection box with bypass diodes, U-V resistant cables with MC®-plug.



Crystalline octagonal Si tubes are drawn from the melt. There are no losses due to sawing.

Designation:

DG = Double Glass
F = Frame
/50 = Nominal Voltage at STC

The ASE-300-DGF/50 is RWE SCHOTT Solar's Flagship Module used in a wide range of applications, including the toughest military, utility and commercial settings. It is also becoming extremely popular in large pumping systems that require higher voltages. As the world's largest and most powerful PV module, installers, architects and owners credit the ASE-300 with significant cost savings and peace of mind. Give your PV system the ASE 300 advantage.

Design and Installation Advantage

We designed the ASE-300-DGF/50 to save time and cost.

- The uniquely high module voltage (Vp 50.5 volts) allows system integrators to "fine tune" a system by providing just the right number of modules to meet the specified power.
- Large area requires fewer interconnects and structural members.
- Module-module and source circuit wiring can be incorporated in the module.
- Unique ASE quick-connects reduce source circuit wiring time to minutes. We offer connector options to suit your needs.

Reliability Advantage

- Advanced proprietary encapsulation system overcomes the decline in module performance associated with degradation of traditional EVA encapsulant.
- Weather barrier system on both the front and back of the module protects against tear, penetration, fire, electrical conductance, delamination, and moisture.
- Our patented no-lead high reliability soldering system ensures long life, while making the module environmentally benign for disposal or recycling.

Quality Advantage

RWE SCHOTT Solar's quality program is focused on meeting or exceeding expected perfomance and reducing system losses:

- Each module is individually tested under RWE SCHOTT Solar's calibrated solar simulator.
- Module-module wiring losses are included in rating.
- Each of the 216 crystalline silicon cells is inspected and power matched.

Certification Advantage

- To provide our customers with the highest level of confidence, the ASE-300-DG/50 is independently IEEE 1262 and IEC 1215 certified. It is UL (Underwriters Laboratories) listed with the only Class A fire rating in the industry.

Available Versions

The standard power rating is 285 watts at STC with versions at 300 watt and 265 watt also available. We offer a variety of wiring/connector options. Modules without frames are also available.

RWE SCHOTT Solar Core Advantage

RWE SCHOTT Solar's patented EFG process (Edge-defined Film-fed Growth) produces silicon octagons of correct thickness and width. Energy, hazardous waste and material intensive wafer sawing is replaced by highly efficient advanced laser cutting.

ASE-300-DGF/50

Electrical data

The electrical data applies to standard test conditions (STC):
Irradiance at the module level of 1,000 W/m^2 with spectrum AM 1.5 and a cell temperature of 25° C.

Power (max.)	P_p (watts)	285 W	300 W	265 W
Voltage at maximum-power point	V_p (volts)	50.5 V	51.0 V	50.0 V
Current at maximum-power point	I_p (amps)	5.6 A	5.9 A	5.3 A
Open-circuit voltage	V_{oc} (volts)	60.0 V	60.0 V	60.0 V
Short-circuit current	I_{sc} (amps)	6.2 A	6.5 A	5.8 A

The quoted technical data refer to the usual series cell configuration.
The rated power may only vary by ± 4% and all other electrical parameters by ±10%.
NOCT-value (800 W/m^2, 20° C, 1m/sec.): 45° C.

Dimensions and weights

Length mm (in)	1,892.3 (74.5")
Width mm (in)	1,282.7 (50.5")
Weight kg (lbs)	46.6 ± 2 kg (107 ± 5lbs
Area	2.43 sq meters (26.13 ft sq)

Characteristic data

Solar cells per module	216
Type of solar cell	Multi-crystalline solar cells (EFG process), 10x10 cm^2
Connections	14 AWG w/Single Pole Quick Connectors Optional Connections – 16AWG w/Double Pole Quick Connectors. Conventional Junction Box module comes with 6 built in bypass diodes

Cell temperature coefficients

Power	$T_K (P_p)$	- 0.47 % / °C
Open-circuit voltage	$T_K (V_{oc})$	- 0.38 % / °C
Short-circuit current	$T_K (I_{sc})$	+ 0.10 % / °C

Limits

Max. system voltage	600 V_{DC} U.S. 700 V_{DC} Europe
Operating module temperature	-40... +90° C
Test wind conditions	Wind speed of 130 km/h (120 mph)

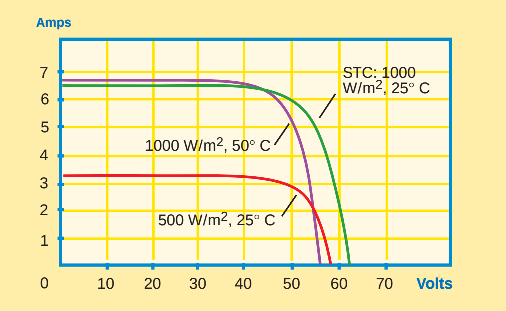
The right is reserved to make technical modifications.

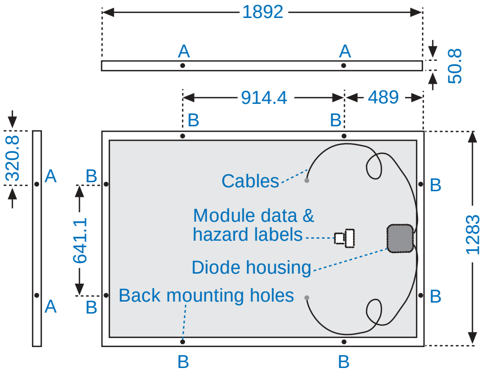
For detailed product drawings and specifications please contact your distributor or our office.

Certifications and Warranty

The ASE-300-DGF/50 has been independently certified to IEC 1215 and IEEE 1262, UL 1703 (Class A Fire rating). It meets Electrical Protection Class II and EU guidelines, e.g. EMC according to DIN EN. The ASE-300-DGF/50 comes with a 20 year power warranty (see terms and conditions for details)

Current/voltage characteristics with dependence on irradiance and module-temperature.





A = Side mounting holes ø = 10.5
B = Back mounting holes ø = 10.5
(all dimensions in mm)

RWE SCHOTT Solar
RWE SCHOTT Solar, Inc.
4 Suburban Park Drive
Billerica, MA 01821-3980 USA
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Appendix M: Sunny Boy 1800 U Inverter Infosheet

Sunny Boy 1800U

The leading grid-tied photovoltaic inverters in Europe and America

UL 1741 Listed for grid interactive inverters

5-year comprehensive warranty

Rugged NEMA 4X stainless steel outdoor enclosure standard

Exceptional reliability and energy capture ratio

Easy to install three-point mounting system

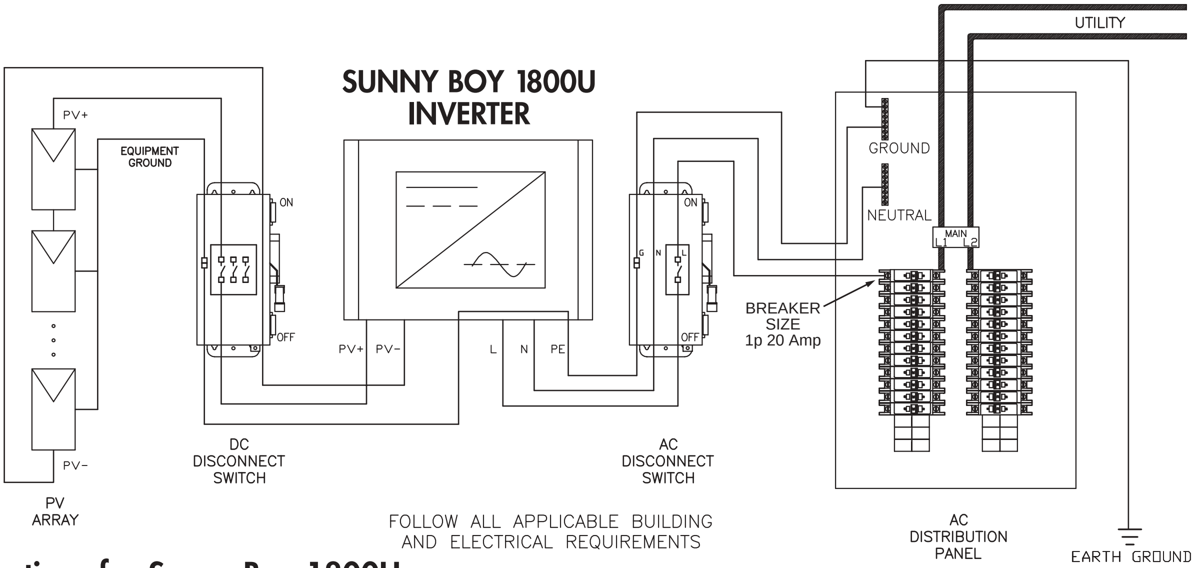
Comprehensive communications and data collection options

SMA's Modular String inverter design is expandable to virtually any system size

LISTED
1741,1998

Shown with optional display

The SMA Sunny Boy inverter, the most popular grid-tied photovoltaic inverter in Europe, is now UL 1741 Listed and available in North America. Sunny Boy's extensive track record in some of the world's most demanding markets has made it the favorite among PV professionals everywhere. Over 200,000 Sunny Boy inverters have been installed worldwide. Having achieved the highest reliability of any PV inverter, Sunny Boy gained immediate acceptance in the US and Canadian markets. Superior design, rock-solid German engineering, and exceptional real-world efficiency have made Sunny Boy the top choice for American solar designers. These professionals know that Sunny Boy is a grid-tied inverter that they can recommend without reservation and install with confidence.



FOLLOW ALL APPLICABLE BUILDING
AND ELECTRICAL REQUIREMENTS

Specifications for Sunny Boy 1800U

Inverter Technology	Real sine-wave, current source, high frequency PWM
AC Input Voltage	106 – 132 (120 V AC nominal)
AC Input Frequency	59.3–60.5 (60 Hz), 50 Hz also available
DC Input Voltage	156 – 400 V DC
Peak Power Tracking Voltage	156 – 350 V DC
Minimum DC Input Voltage	139–170 V DC dependent on available line voltage
Maximum Array Input Power (DC @ STC)	2200 W
Maximum AC Power Output	1800 W
Current THD	Less than 4%
Power Factor	Unity
Peak Inverter Efficiency	93.6%
Cooling	Convection cooling (no fan)*
PV Start Voltage	190 V DC
Maximum AC Output Current	15A
Maximum DC Input Current	12A
DC Voltage Ripple	Less than 5%
Power Consumption	0 W nighttime, < 0.1 W standby
Ambient Temperature Rating	45 °C
Enclosure	NEMA 4X stainless steel
Size	17.1 W x 11.6 H x 8.4 D inches (434 W x 295 H x 214 D mm)
Weight	59.4 lbs (27 kg)
Compliance	United States: UL 1741, E210376, UL 1998, IEEE 519, IEEE 929 ANSI C62.41 C1 & C3, FCC part 15 A&B International: DIN EN50082 Part 1, 61000-32, 50081, 50014, 600055 Part 2, 55011 Group 1 Class B, 50178, 60146 Part 1-1

ALL SPECS MAY CHANGE WITHOUT NOTICE

Sunny Boy's unsurpassed reliability and efficiency is the result of SMA's manufacturing philosophy that combines simple design with robust execution. SMA's state-of-the-art maximum power point tracking performance results in greater real-world energy capture than any other grid-tied PV inverter. Sunny Boy's safety and reliability record is also exceptional due, in part, to the inverter's redundant grid monitoring and built-in ground fault detection and interruption protection. The inverter's IGBT power stage generates a nearly perfect sine wave with the lowest harmonic distortion in the industry and meets ultra-strict FCC EMC standards. SMA's unique String Inverter technology makes future system expansion simple. SMA advanced communication options are available to satisfy almost any application.

DISTRIBUTED BY

**Optional external fan (Sunny Breeze) available*

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Phone 530-273-4895 • Fax 530-274-7271
www.SMA-AMERICA.com • email: info@SMA-AMERICA.com

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Energy Tomorrow

Sunnyboy
Solar powered systems.

Rev. 9/25/03

Appendix N: RWE Schott FS System Installation Guide

SunRoof FS Mounting System – ASE 300 Modules Installation Guide

1. Preparation

We recommend that you read the instructions completely before starting to install this system. These instructions assume that the installation team is familiar with common construction techniques and typical practices. If you have questions, please contact RWE Schott Solar prior to starting work.

1.1. Parts

The FS mounting system consists of 4 main mounting components, plus hardware and other items. The quantity of each item will depend on the specific installation.

- Tall Support Bracket (10.3” H x 4.25” W x 3” D)
- Short Support Bracket (6.2” H x 4.25” W x 3.3” D)
- Base Plate (28” L x 11.5” W)
- Locking Plate (33” L x 3.5” W)
- 5/16” Stainless Steel nuts and washers
- Output Cables, #10 AWG with quick connectors
- Module Grounding Kits
- Ground Lugs

In addition to these items, you will need to supply various materials to complete the installation. These include, but are not limited to, the following:

- 1.25” PVC Conduit
- Single Hole Heavy Wall Conduit Clamps for 1.25” PVC
- Additional wire and conduit from each combiner box to point of interconnection
- Conduit supports (Pipe Pier®, Trex blocks or equivalent)

1.2. Recommended Tools

The following tools are recommended. This list is only a starting point, you may find other tools helpful or required, depending on your particular installation.

- Socket set
- Screwdrivers (straight blade and Phillips)
- Wire cutters
- Pry bar
- Band cutters
- 100 ft. measuring tape
- Compass
- Chalk lines or layout string
- Cordless impact hammer
- Lifting equipment (as required for the site)
- Wire strippers
- Digital multimeter

- 25’ measuring tape
- Channel lock pliers
- Utility knife
- Diagonal cutters
- Electrical tape (black and red)
- File or conduit deburring tool

1.3. Planning

Before starting work, go over the entire project. In particular, review the following items.

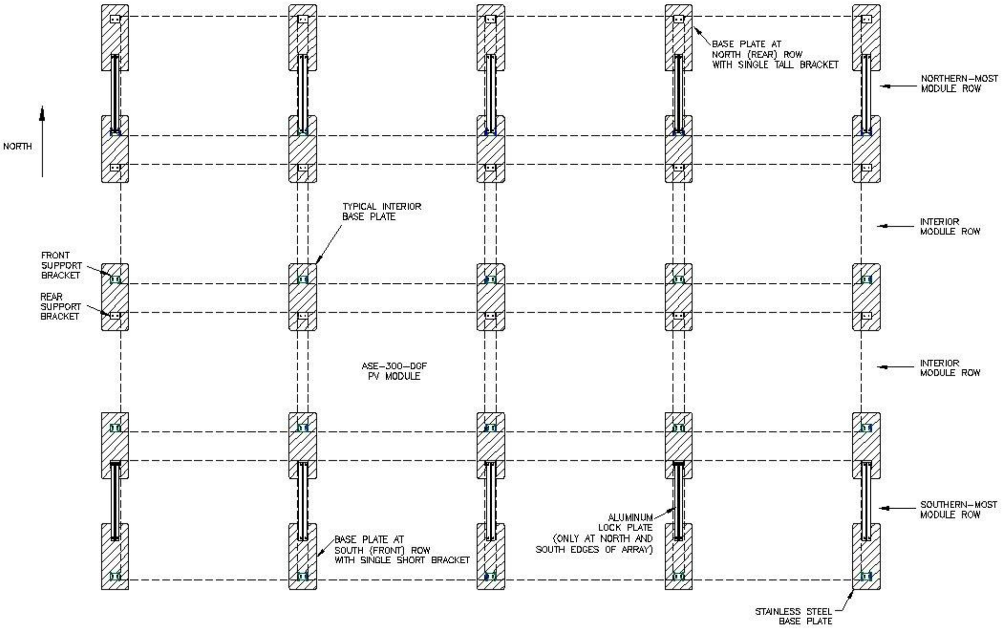
A. Shading – The selected array location should be free from shading from 9 AM to 3 PM throughout the year. If you are unsure about the potential for shading, perform a shading analysis with a Solar Pathfinder or similar tool.
B. Orientation – As much as possible, the array should face due south. Due south varies slightly from magnetic South according to local declination.
C. Module crate placement – A loaded module crate weighs approximately 2,400 lbs. Make sure that the roof surface is capable of supporting this weight.
D. Conduit placement – The working space between the finished array rows is very narrow, approximately 12”. If you plan to run conduits below the array rows, you may wish to install the conduits before placing the modules.
E. Electrical Equipment – The placement of conduit routes and position of junction boxes should be considered before assembling the array.
F. Roof Obstructions – Roof obstructions such as drains, vents, skylights, HVAC equipment are very common. The position of these items needs to be accounted for in the layout.
G. Safety – Have a safety plan and observe all safety practices required for performing construction work of this type.

1.4. Roof Layout

1.4.1. Mounting Plate Configurations

Review the array layout drawing to determine the placement of the base plates relative to the modules. The FS mounting system supports each module at the four corners. In the middle of the array field, the base plates are between the rows (not underneath). Each base plate normally has two support brackets (one tall and one short), and each stand supports two modules.

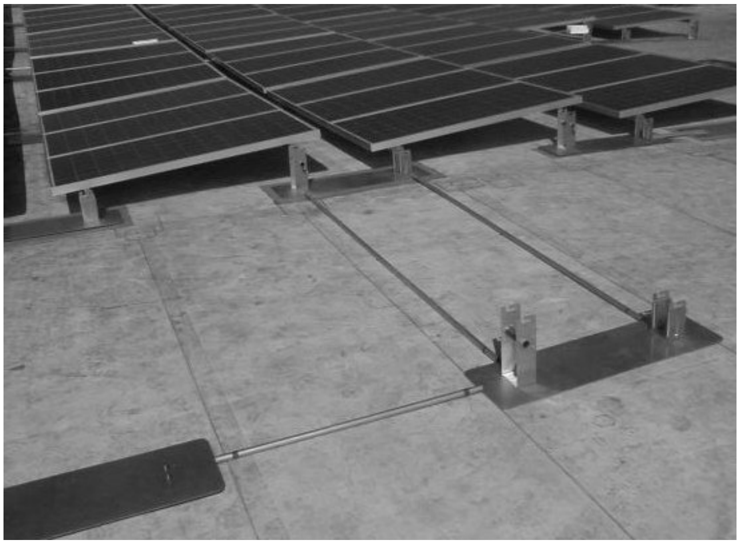
At the south edge (front) of the array, the base plate has a single short support bracket. The plate is moved so that the unused set of threaded studs is beneath the array. A locking plate then connects these studs to the base plate in the next row behind it. At the north edge, the situation is similar: the base plate has a single tall support bracket. The base plate and locking plate are moved to connect to base plate in the row in front of it.

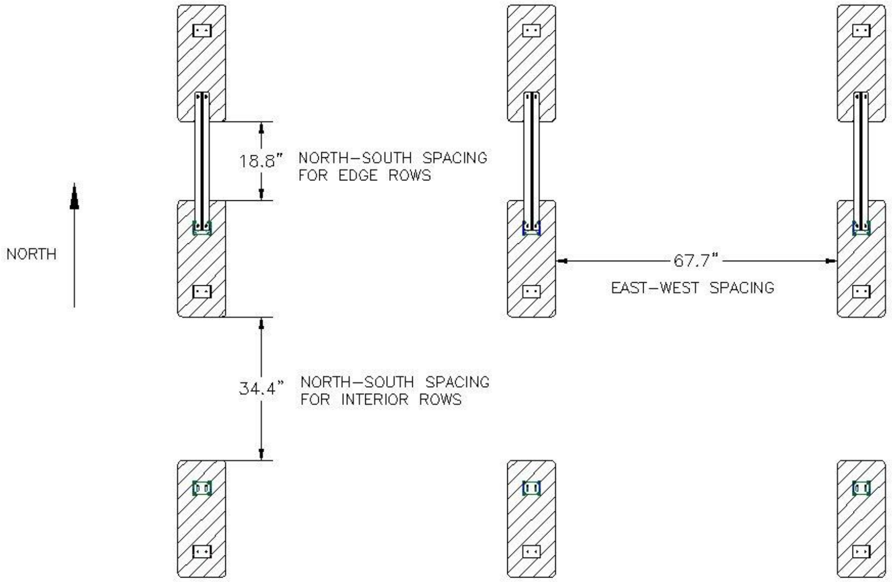


1.4.2. Establishing the Array Layout

An accurate array layout is important for a good installation. Errors in the initial layout can cause problems placing the modules and may result in the need to remove and re-install base plates. While each layout may be unique, the following recommendations may help.

A. Establish two reference lines along the sides of the array. Generally it is most helpful to use the longest pair of sides of the array. Also establish a perpendicular line through the center of the array.
B. On membrane roofs, a pair of assembled base plates can be used to support a string line without penetrating the roof.
C. Check the diagonals of the array layout to ensure that the layout is square.
D. Cut a couple of pieces of excess conduit to serve as placement jigs. Note that the N-S separation between interior base plates is not the same as the N-S distance at the edge of the array.





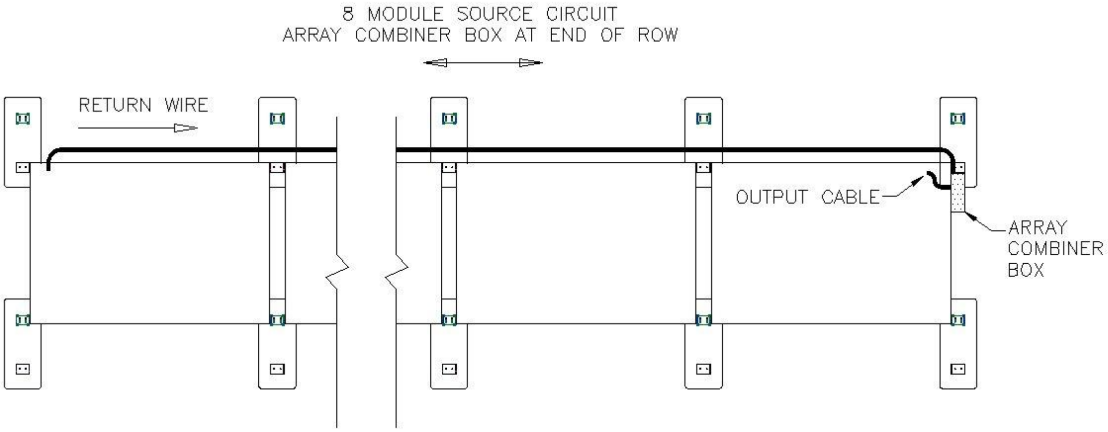
Refer also to Section 2.2.

1.5. Electrical Configuration

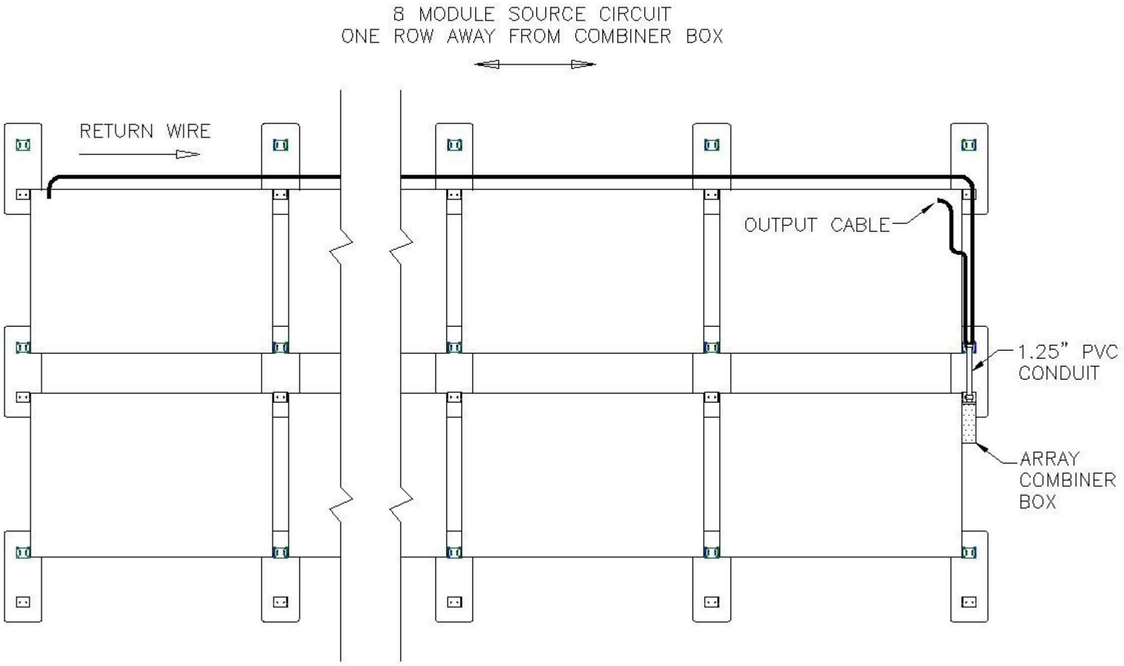
Planning for the appropriate electrical configuration is a key part of the installation. For a system with ASE 300/50 modules, eight modules are connected in series to form one source circuit. The most straightforward layout occurs when each group of eight modules are located in a single row. A source circuit can also be formed from eight modules in different rows, but this requires more care.

1.5.1. Single Row Circuits

Eight modules together in the same row constitute a single row source circuit. Each module is connected in series to the module(s) adjacent to it. If an array combiner box can be placed at one end of the row, then it is very simple to wire the source circuit to the combiner box. One connector from the adjacent module runs to the combiner box. The other polarity runs via a return wire along the length of the row and then to the combiner box. Note that the combiner box can be located at either end of the row.

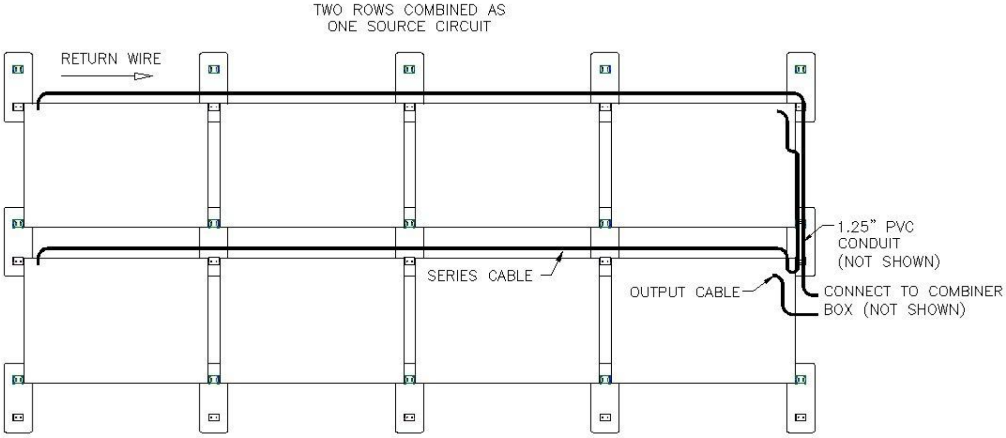


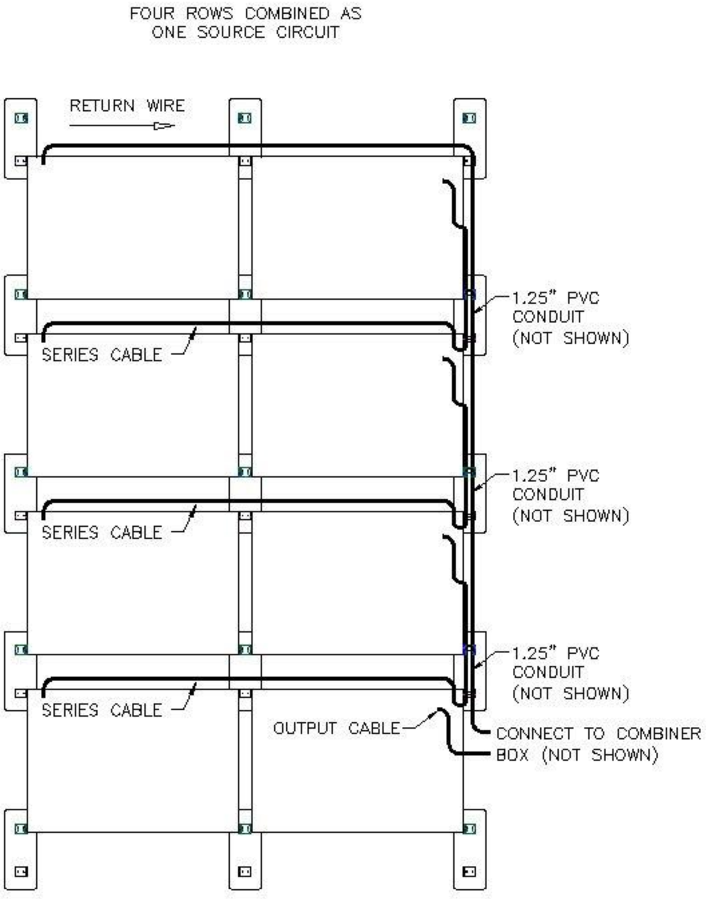
If the single row source circuit is one row ahead or behind the combiner box, then longer output cables are used to connect the source circuit to the combiner box. The cables are run through a piece of 1.25" PVC run between the base plates for protection.



1.5.2. Multi - Row Circuits

When the eight modules in a source circuit do not lie in the same row, then jumpers are used to join the each segment of the electrical string. Refer to the following examples. If you still have questions, please contact RWE Schott Solar.





2. Array Assembly

2.1. Base Plate Pre-Assembly

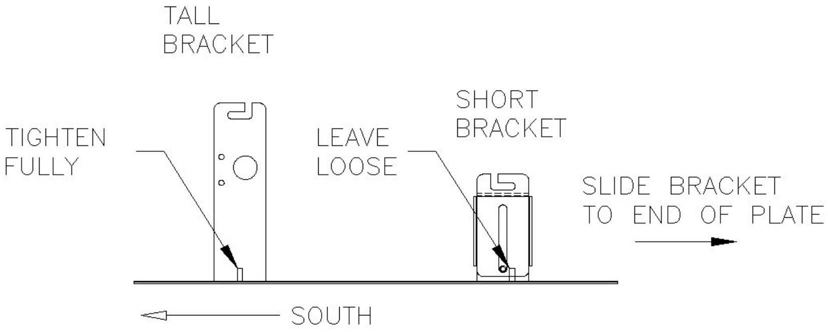
Before placing the base plates on the roof, the plates and brackets must first be assembled. There are two types of assemblies:

- Interior base plates, with both a tall bracket and a short bracket.
- "Edge-of-array" base plates, with **either** one tall bracket **or** one short bracket.

2.1.1. Interior Base Plates

To assemble an interior base plate, perform the following steps:

A. There are 2 pairs of threaded studs near each end of the base plate. Place a tall bracket over the studs at one end of the plate and a short bracket at the other.
B. Note that there is a correct orientation for the brackets on the base plate. The "L" slots will face in different directions. Place the brackets as shown below –



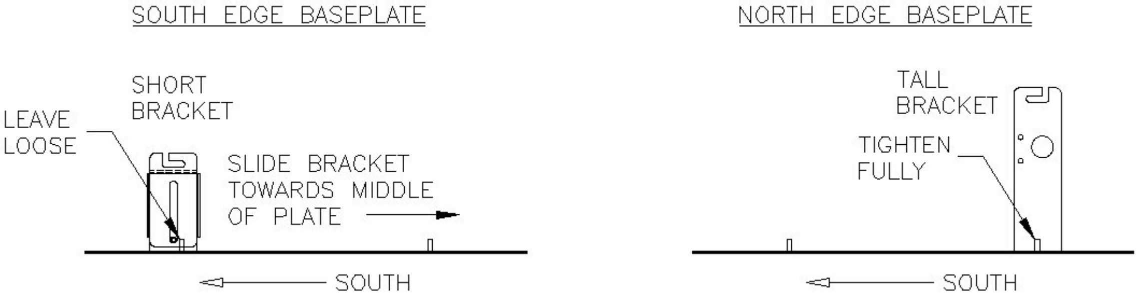
C. Attach the brackets using two of the 5/16" kep-nuts provided. The tall brackets are fixed, and the nuts may be fully tightened. The short brackets have slotted holes in the base, and the nuts should be left loose to allow the bracket to slide over plate. Slide the short bracket towards the end of the base plate for now. During the module installation step, the brackets will be slid towards the middle of the plate to lock the module in place.

2.1.2. Edge-of-Array Base Plates

The edge-of-array base plates are similar to the interior plates.

A. Each edge-of-array base plate has a single bracket (either tall or short). During the installation phase, a lock plate will be placed over the unused studs to connect the plate to another base plate.

B. The placement of the bracket is reversed as compared to the interior base plates:



C. Attach the bracket as noted for the interior base plate. The short jack should still be left loose so that it can slide.

2.2. FS Support Installation

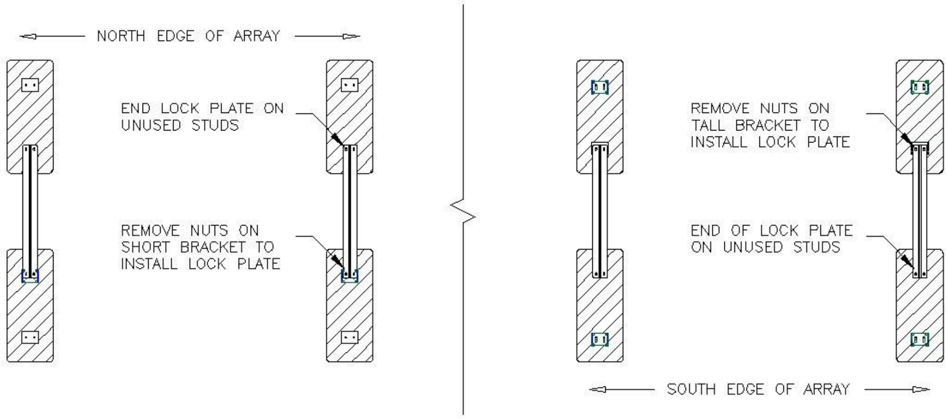
Once the basic array boundaries have been laid out and the base plates have been assembled, you can install the FS Supports on the roof.

A. Begin laying out the assembled base plates on the roof. It is recommended to begin near the center line of the array, placing a complete row and then moving on to the next one.

B. If there is an obstruction on the roof that absolutely must be avoided, then start placing base plates in the appropriate locations around this obstruction.

C. If you are using jigs to place the base plates, be aware that it is easy to create a cumulative error that will grow progressively worse during assembly as the array grows in size. Establish some intermediate check points to confirm that the rows are being placed correctly and that errors have not crept in. A string line along a long row or column is also recommended to keep the plates in a straight line.

D. Once all the base plates have been placed accurately on the roof, install the lock plates at the north and south rows. One end of the lock plate fits over the two threaded studs on the edge of array base plate. The other end of the lock plate goes on the studs of the next plate. You will need to remove the nuts holding down the bracket on this plate in order to get the lock plate installed.



E. Reminder: do not yet tighten the nuts on the short brackets.

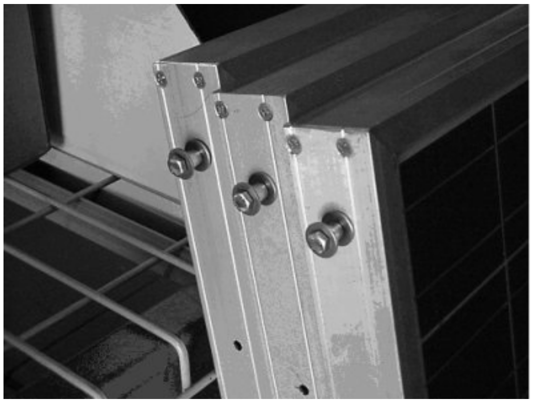
2.3. Module Installation

ASE-300-DGF modules have been designed to be easily interconnected. Each ASE-300-DGF/50 module has two wires, one positive (+) and the other negative (-), that are connected inside of the diode housing. No pre-assembly of the module is required. Each module is supplied complete with cable clips, support pins and a small bag containing a ground lug kit.

2.3.1. Module Handling Precautions

Observe the following precautions when handling the modules.

A. Modules are normally drop shipped to site in wooden crates and should be handled with a fork lift. A fully loaded crate holds 20 modules and weighs approximately 2,400 lbs.
B. Do not place crate on a roof or other surface that is not structural capable of supporting the load. Place the crate on a level surface
C. Open the crate from the side marked ‘Open This Side’. Remove the fixing screws on the timber retaining the modules. A power driver is useful for this process.
D. The modules are wrapped in plastic film progressively from the back of the crate. This is to help prevent the modules falling forward. Take care not to let modules fall from the crate. Make sure that as modules are removed from the crate, the center of gravity does not shift or cause the crate to tip.
E. The mounting support pins are pre-assembled onto the modules. Do not damage these pins during handling.



F. Each module weighs 107 lbs and should be handled by two people.

CAUTION

Never leave a module unsupported or unsecured. If a module should fall, the glass may break. A module with broken glass cannot be repaired and must not be used.

2.3.2. Module Installation

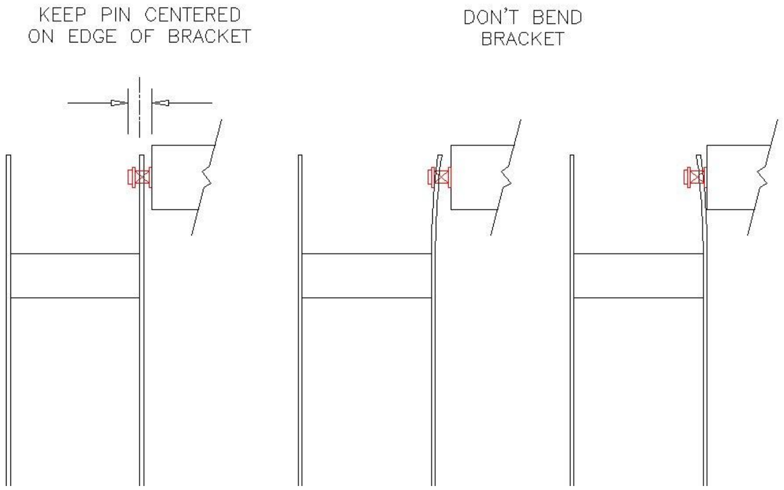
Each module has four mounting pins which are designed to fit into the slots at the top of the support brackets.

A. Orient the modules in landscape position (long edges running East-West) with the black diode housing on the west side.

B. Place the module so that the pins fit into the slots on mounting brackets, then slide the module to the south, so the pin is fully engaged in the “L” slot.

C. Be careful not to bump the base plates out of position when installing the modules.

D. If the base plates have been accurately positioned, the edge of the bracket will be centered on the pin. Some small variation is acceptable, but the pins should not be so far off center that they are pushing or pulling the brackets from vertical.



E. It is recommended to install modules one row at time. Interconnect the modules into series strings of eight (8) modules as they are placed. See Section 3.1 for more information about wiring the array.

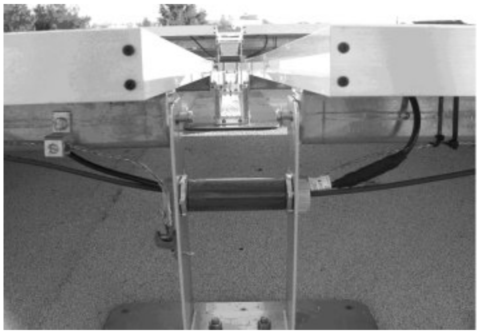
F. Take the quick connector at the edge of the module and route it through the short PVC conduit on the tall bracket. At the other side, take the connector and mate it with the appropriate connector on the other module. Push each plug firmly into the corresponding receptacle. Make sure the MC connectors are fully pushed together leaving no gap between the rubber boots.

G. Use the cable clips on the edge of the module frame to hold the connector inside the edge of the frame. This keeps the connections out of the sun and rain.

H. Caution: Never attempt to make or break the module output cables when the system is generating power. The cables are not rated to interrupt a working circuit.

I. When all the modules are in place, tighten the nuts holding the short brackets to the base plate. A cordless impact driver can be very useful for this.

J. After all modules are placed and the brackets are tightened, lift the front edge (south edge) of each module. The short jack should slide freely, without resistance.



WARNING
Modules generate electricity and pose an electric shock risk whenever exposed to sunlight. Serious injury or death can result. Make sure that all personnel working with the modules are aware of these risks and take appropriate precautions to prevent electric shocks.

2.4. Combiner Box Installation

The array combiner boxes for the FS System are specially designed to fit between the uprights of the tall support bracket. Each combiner box can accommodate up to two (2) source circuits, each with 8 modules.

A. Consider the overall electrical plan before installing any combiner boxes. Refer to Section 1.5 for additional information about planning the electrical configuration of the array.
B. Remove the short piece of PVC conduit from between the sides of the tall support bracket. This piece may be discarded.
C. Slide the two tabs on the combiner box over the sets of holes on the sides of the tall bracket. Attach the combiner box using the hardware provided.
D. The combiner boxes are designed to be mounted horizontally, with the lid on top. Correctly installed, the inside of combiner box is easily accessible after the array has been completed.

2.5. Conduit Installation

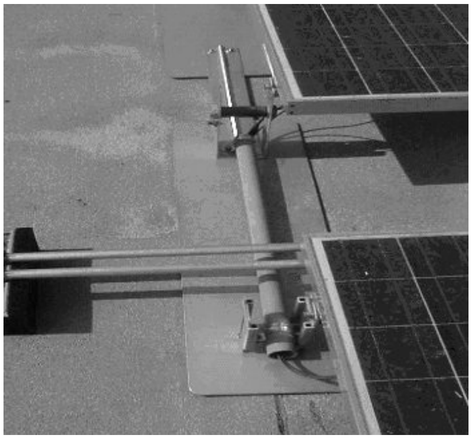
2.5.1. Source Circuit Conduits (Modules to Array Combiner Box)

A piece of 1.25 inch UV rated PVC conduit is used to protect source-circuit wires that are run from one row to another. This situation can occur when

- Output wires from the source circuit must cross between rows to reach the array combiner box
- Wires from one part of the electrical string must be connected to another part of the same string.

This conduit can be installed as follows

A. Cut a piece of 1.25” conduit to the appropriate length, approximately 38”. This may vary depending on the type of clamps used.
B. Deburr the inside edge of the conduit.
C. Using a single hole conduit clamp, attach the clamp to one of the studs that secure the bracket to the base plate. You will need to remove the nuts that hold the bracket to the plate to get the clamp on.
D. In some cases, the clamp must be bent slightly to accommodate the installation.



2.5.2. Combiner Output Conduits (Array Combiner Box to Inverter)

Conduit from the array combiner boxes to the inverter can be run along side the FS mounting components. The correct size and type of conduit should be confirmed from the electrical plans.

It is beyond the scope of these instructions to detail how to run and attach this conduit. However, it is recommended that conduit should not be laid directly on the roof surface. Use a conduit support instead.

For membrane roofs (or just a clean installation), ready made conduit supports can be purchased that have a soft foam or plastic base.

3. Electrical Connection

3.1. Connecting Strings

Once the modules have been installed and the series connection made, there will be a loose output cable at each end of the row. Additional output cables are included to complete the wiring and bring the circuit back to the array combiner box. These cables have a male quick connector at one end and a female connector at the other.

In some cases, the cable will need to be cut in the middle to provide two cables. It is recommended to lay out the longer run first and only cut what is needed. You may need the full length of the remaining piece to make a connection elsewhere.

3.1.1. Connecting the Ends of String to Combiner Box

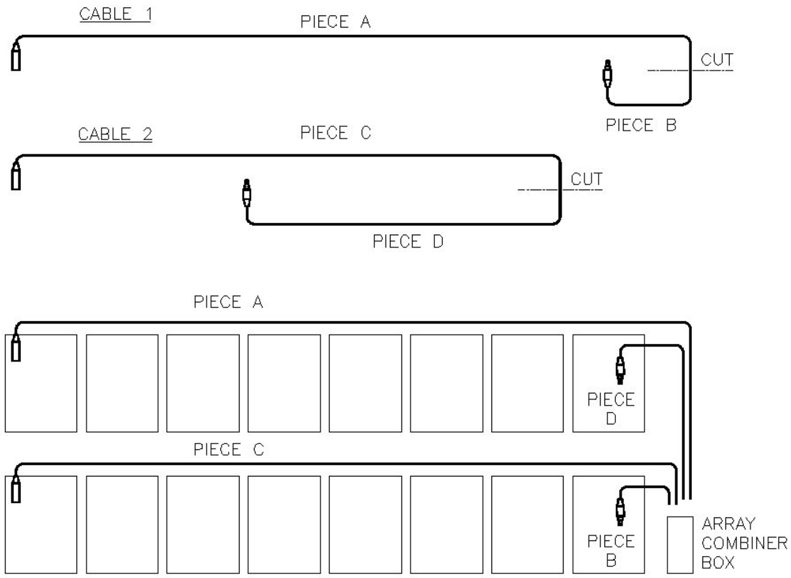
To connect the ends of a string of 8 modules to the array combiner box, perform the following steps –

A. Attach one of the output cables to the quick connector on the module furthest from the combiner box. Route the conductor under the modules and through the PVC conduits on the tall support brackets. Run the wire back to the array combiner box. Determine the necessary amount of wire required and cut the output cable to the correct length. Save the unused output cable.
B. Terminate the conductor at the proper terminal within the combiner box, marking the polarity with colored electrical tape.
C. Take the remainder of the output cable and attach it to the quick connector on the module closest to the array combiner box. Route this wire to the array combiner box. Cut the wire to the correct length. (You may have a short piece of cable with no connectors on either end. This cable can be discarded).
D. Terminate the conductor at the proper terminal within the combiner box, marking the polarity with colored electrical tape.
E. Do not cut wires or remove connectors on the modules themselves. This will void the warranty of the module.
F. Check the voltage and polarity of the output circuit. Use appropriate safety precautions for working with high DC voltage.
G. Support the wiring with the cable clips on the module frame. If additional support is needed, use cable ties to support the wires from the existing wires that are already secured to the module frame.
H. If the additional wiring still needs to be completed and you are not ready for voltage on the source circuits, you can open one of the quick connector junctions to open-circuit the string. Warning – do NOT attempt this if the system is operating or under load!

Refer to the diagrams in Section 1.5.

Note: When two rows of modules use the same combiner box, but one row is farther from the combiner box than the other, you can get the best length by cutting two cables as follows. Cut two output cables unequally and use the longest piece of each cable for the row of modules that is farthest from the combiner box.

For example, cut one output cable so that Piece A serves as the longest return wire needed. Cut the second cable so that Piece C is the second return wire. Now Piece D is longer than B, so use Piece D for the row of modules that is farther from the combiner box:



3.1.2. Connecting Parts of a Series String Together

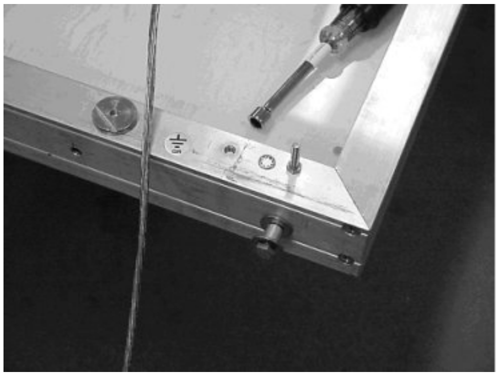
When the 8 modules used to comprise a series string a split among multiple rows, you will need to connect each group of modules together. This is similar to wiring the ends of the strings to the combiner box –

A. Attach one of the output cables to the quick connector on the module. Route the conductor under the modules and through the PVC conduits on the tall support brackets. Run the wire through the 1.25" PVC conduit between rows and plug the quick connector into the appropriate connector on the other group of modules. Do not cut the output cable.
B. Support the wiring with the cable clips on the module frame. If additional support is needed, use cable ties to support the wires from the existing wires that are already secured to the module frame.
C. Consistency is important when dealing with multiple groups of modules. If you have a consistent pattern to making the series connections, it will make your job easier and allow for easier maintenance and troubleshooting in the finished array.

Refer to the diagrams in Section 1.5.

3.2. Grounding

Grounding the system is required for a safe installation and to meet the National Electrical Code. Copper ground wire is run to each array support and module and is terminated at the combiner boxes.



Each module is supplied with one grounding lug kit. In each kit there are 3 components, the brass washer, the stainless steel fixing screw and lock washer. On assembly, the groove in the brass washer should be aligned with the copper ground wire and the wire is pinched against the module frame.

A. Attach the module grounding kit after the modules have been installed. The ground lug should be installed from the bottom side of the frame using the provided lock washer and bolt. The bolt should be torqued to **50-70 in-lbs.**
B. Attach the ground wire to the tall support bracket farthest from the array combiner box. There is a

ground lug on the side of the support bracket for this purpose.

C. Route the wire to the module and attach it to the ground washer on the module. Continue to run the ground wire, alternating between the modules and through the conduit on the tall brackets.
D. Run the ground wire to the array combiner box. If necessary, run the ground wire through a piece of 1.25” PVC conduit between rows.
E. Attach the ground wire to the lug on the outside of the combiner box.

3.3. System Wiring

Complete the remainder of the system wiring in accordance with Article 690 of the National Electrical Code (NEC). All conductors used should have an insulation rating of 90 ºC. System wiring is the responsibility of the installer and must be performed by a qualified person.

WARNING

Do not disconnect the Multi-Contact quick connectors under load. A large arc may result. Only disconnect the connectors when there is no array current.

For additional information:

contact our Rocklin CA facility at:

RWE SCHOTT Solar, Inc.
Phone: (916) -625-9033
Fax: (916) - 625-9032

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Appendix O: Educational Program

SOLAR ENERGY AND PHOTOVOLTAICS EDUCATIONAL PROGRAM

Created in partial fulfillment of an Interactive Qualifying Project
By students of
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Introduction

The use of many conventional energy sources, such as fossil fuels, rapidly depletes natural resources, damages the environment, and threatens public health. These energy sources are not sustainable. A common definition of sustainability is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainable energy sources, such as wind and solar energy, do not pollute and will not become depleted. Therefore they can meet the needs of the present without compromising the future.

However, as it stands, sustainable energy accounts for less than one percent of global power production for a variety of reasons. Some reasons for not adopting sustainable energy include implementation cost and installation space (finding a large enough area for a high output wind or solar farm). At the same time there is a lack of fundamental education regarding sustainable energy at the K-12 and post secondary levels in this country and elsewhere. Therefore, while many people may be familiar with the idea of sustainable energy, young people are not necessarily fully educated about the issue. Furthermore, there is a general lack of awareness of sustainable energy in society.

Project

Two student projects were set up at Worcester Polytechnic Institute in the academic year 2003-2004 to promote awareness of sustainable energy in the Worcester area. Worcester Polytechnic Institute's approach to technical education is based on a 'learn by doing' philosophy which translates into a project based approach to learning. WPI's projects program requires students to complete three significant projects as part of their undergraduate education, the Sufficiency, the Interactive Qualifying Project (IQP) and the Major Qualifying Project (MQP).

The IQP challenges students to identify, investigate, and report on a topic examining how science or technology interacts with societal structures and values. The objective of the IQP is to enable WPI graduates to understand, as citizens and as professionals, how their careers will affect the larger society of which they are a part.

We are a group of four students that chose to work towards creating a program tentatively called WPI Community Solar Initiative for our IQPs. The overall vision of our project is to positively change attitudes toward solar energy at WPI, Worcester public schools, and the general Worcester area. The main goals that we established in order to work toward our vision are:

- Establish a photovoltaic installation and Solar Learning Lab™ at WPI
- Market and promote solar power at WPI
- Create solar power oriented educational activities

Establishing the Solar Learning Lab™ is an essential goal to our project because it serves as a tool for promoting awareness and education of solar power. Marketing the attractiveness of solar power at WPI supports the survival of the installation and works toward our vision of promoting solar power awareness. The solar power oriented educational activities supports our efforts of educating K-12 students about renewable energy.

The Solar Learning Lab™ is a product of our sponsor Heliotronics Inc. It consists of a data acquisition system, which is coupled a power generating photovoltaic array. The photovoltaic array was purchased separately from RWE Schott Solar Inc. The educational value of the Solar Learning Lab™ comes from its interactive software. The SunServer™ software runs a PC that communicates with the data acquisition module and broadcasts information over the local area network. This information can be accessed from the local area network with the SunViewer™ software. Also, the SunViewer.net™ software provides a web-portal for the Heliotronics software

Educational Program

One of the primary goals of our project was to develop educational programs about renewable energy in general and solar electricity (photovoltaics) in particular. We have developed a week long educational program for 8th/9th grade students under the guidance of Martha Cyr, a qualified educational expert and the director of K-12 outreach at WPI. These educational activities are intended to be ready-to-use, complete units for implementation in Worcester Public school classrooms. We also designed this educational program to be easily adapted to fit into WPI summer outreach programs and other forums. Detailed notes about the educational program are presented in the section below.

Notes about the Educational Program

- The program is aimed at students in grades 8-9.
- It is designed to be taught over a period of about one week with 7 provided activities and lectures that are designed to take between 45 minutes and an hour and a half each (also contains an optional extra day with a field trip to WPI to interact with the installation first hand.)
- The program is intended to be highly modular, to enable teachers to choose to do how much they want, and still move relatively seamlessly between activities.
- The program is designed to incorporate our project and promote it and WPI with it. We tried consciously to avoid making it merely a general introduction to renewable energy. Instead we worked to make it relate specifically to our project and WPI. In this effort we have used the Heliotronics Inc. software package wherever we had the opportunity.
- The program provides additional action projects/items at the end for those who are truly excited about solar energy and want to do more. It was our goal to spark interest in these topics and point students in the right direction.
- Throughout the educational program we strive to provide a context for the material being taught. There is a constant attempt to link the information to broader social issues, as we were informed that this would lead to a situation where students were most engaged and learned best.

- The curriculum included is multidisciplinary, not just science and technology based.
- Providing detailed standards correlations for every activity we created was an incredibly time intensive task and would require much painstaking research. As such it was well beyond the scope of the time we had for our IQP. Instead we elected to point to our primary sources in all our activities. These resources are the ones we have sourced all our material and activities from, and they include detailed standards correlations. Each day has a 'sourced from' section for teachers to refer to for standards correlations.

Outline of Educational Program

Presented below are the key points we wished to convey in our educational program and the order in which they are presented. This was arrived at bearing in mind all the above points and to convey the information we felt was important.

Background/ Lead up

- Energy as a whole – What is it? Where does it come from?
- Renewable/Non Renewable energy and the difference, why renewable is smarter
- Pollution, Renewable Energy Benefits, social implications of energy choices
- Sources of Energy – diff types of renewable energy
- Generation of electricity from these sources
- Focus on generation of electricity from Solar Energy - Photovoltaics

Photovoltaics

- How Photovoltaics work – Science and technology activity
- Use of software (SunViewer.net) to see how much pollution is saved, how much power is generated, other stuff
- Mathematical exercises – Data manipulation, plotting, averages etc.
- Action Projects/ point towards other resources

Day by day plan of activities and lessons

DAYS 1 and 2

LEARNING OUTCOME: As the result of participating in this activity that combines various teaching methods – lecture, discussion, simulation and a worksheet - students gain a broad introduction to renewable energy and its context.

LESSON OVERVIEW: Students first treat the broad topic of energy as a whole, defining what it is and where it comes from. They then learn the difference between renewable and non-renewable energy and participate in a simulation that is intended to demonstrate that conventional (non-renewable) fuel resources are finite and will eventually run out. They are led to deduce that conserving energy and moving to renewable energy are solutions to the problem of the energy supply of the world running out. In addition to merely the fact that conventional fuel resources are finite, students are also introduced to the harmful effects of fossil fuels on the atmosphere, thus setting a strong context for renewable energy.

DAY 3

LEARNING OUTCOME: Through this lecture based session students learn about the different sources of renewable energy and how electricity is generated from these resources (specifically solar.) They learn that the method of generating electricity from solar energy is photovoltaics, and also understand the benefits and drawbacks of photovoltaic systems.

LESSON OVERVIEW: Students are first taught about the different sources of renewable energy and are told that the focus will be on solar energy. They learn about generation of electricity from these resources since electricity is the most common form of energy consumption in our society. They are then led to examine the generation of electricity from solar energy (photovoltaics) in particular. They are led in a discussion of the benefits and limitations of photovoltaic systems and are presented some examples of their application.

DAY 4

LEARNING OUTCOME: Students are introduced to how photovoltaic cells work, and understand how varying conditions impact their performance.

LESSON OVERVIEW:
Students are introduced to photovoltaic cells and how they work through an initial brief lecture and discussion based session. They then conduct several experiments to familiarize them with photovoltaics, how they generate electricity, and their performance under varying conditions.

Background: Photovoltaics is a technology for converting light directly into electricity. Most photovoltaic cells have two layers of “semiconductor” material—the same material used in computer chips. When light hits the photovoltaic cell, electrons travel from one layer to the other, creating a voltage (or charge) that can power an electrical device. Photovoltaic cells (also called PV or solar cells) were first developed to power space satellites. Technical advances have steadily increased PV cell efficiencies, and their cost has dropped significantly. Solar cells are widely used in calculators and for remote power applications not connected to an electricity grid (such as rural villages, communications relays, and emergency lights, signs, and telephones). They are not yet economically competitive for large-scale electricity generation.

OPTIONAL DAY AFTER 4

This activity is to be used if you elect to include a field trip to WPI as one of your activities, or simply if you want to introduce them to elements of an educational PV system. This could be completed either on the WPI campus or at your school. Being at

WPI would probably enhance the experience as the students could possibly have the opportunity to interact with Photovoltaic systems first hand through interactive data terminals, and a possible tour of the installation.

LEARNING OUTCOME: Students will learn the basic components of their solar electric system, how it generates electricity, and what information is provided to them (data) to understand how it works.

LESSON OVERVIEW: Students will be led through a step by step lecture to learn how WPI's solar electric system works (typical of educational solar systems), and answer questions in a worksheet to test their understanding.

DAY 5

LEARNING OUTCOME: Students will learn about various topics related to Photovoltaic systems. Using software they will learn how much pollution is prevented by PV installations and how much energy is being generated by the panels. They will learn how to read a line graph and will understand that solar energy production is dependent upon the weather. Thus they will learn the key skills of observation, inference and validation that are an essential component of the scientific method and are needed to interpret data that constitutes most scientific results.

LESSON OVERVIEW:
Students will be led through SunViewer software, with particular emphasis being paid to sections that highlight the power generated and avoided emissions. Students will look at graphs of the power output (generated by the SunViewer software from Heliotronics) of a solar energy system and will make inferences about the weather. They will then compare the inferences they made about the weather with actual data of weather at that time and explain possible discrepancies.

DAY 6

LEARNING OUTCOME: Students will learn how to calculate the instantaneous energy conversion efficiency of a solar electric system and compare the energy conversion efficiency to that of other energy conversions.

LESSON OVERVIEW: Students will use data from the WPI solar electric system to learn how to calculate system efficiency. They will then verify their calculations against the efficiency data from the SunViewer software.

DAY 7 - OPTIONAL

This is a section with information that can be used to inform students about various existing solar projects and resources, so that they can continue to pursue their interest in solar energy and phototvoltaics if they choose to do so.

In a lecture and discussion based format students are pointed towards various existing solar programs and resources. At the end students are asked which programs seem most appealing to them and if they would like to attempt to participate in any.

Conclusion

Presented above are a background, overview, and outline for the educational programs attached to this packet. We hope you will find them interesting and stimulating and will work towards implementing them in Worcester public school classrooms. They form an integral part of our project, and it is our sincere hope that they will find their way into school classrooms and serve to promote interest in renewable energy amongst the current generation of middle and high school students.

DAYS 1 and 2

LEARNING OUTCOME: As the result of participating in this activity that combines various teaching methods – lecture, discussion, simulation and a worksheet - students gain a broad introduction to renewable energy and its context.

LESSON OVERVIEW: Students first treat the broad topic of energy as a whole, defining what it is and where it comes from. They then learn the difference between renewable and non-renewable energy and participate in a simulation that is intended to demonstrate that conventional (non-renewable) fuel resources are finite and will eventually run out. They are led to deduce that conserving energy and moving to renewable energy are solutions to the problem of the energy supply of the world running out. In addition to merely the fact that conventional fuel resources are finite, students are also introduced to the harmful effects of fossil fuels on the atmosphere, thus setting a strong context for renewable energy.

GRADES: 6–9; can be the basis for a shorter discussion for older students

SUBJECTS: science, social studies, mathematics

MATERIALS:

Overhead projector and transparency made from chart of U.S. Energy Consumption 2001 (included in this activity) alternatively, you can draw the chart on the blackboard or give a copy of it to each student.

For Renew-a-bean

Students will work in groups of five. Each group will need:

- a paper bag containing 100 beans (or poker chips, or different colored pieces of paper): 94 of one color, six of another color
- extra beans of both colors: 10 of first color, 40 of second color
- five copies of the student handout
- extra graph paper

PREPARATION: You may want to announce the topic of energy in advance and encourage students to look for newspaper or magazine pictures related to energy use or energy sources to post in the classroom.

TIME: 90 minutes (without pollution section). 120 minutes with the pollution section.

TEACHING THE LESSON:

1. Start off by asking students what they think of when they hear the word “energy.” Write down their answers. (Many students will likely think first about their own personal energy; e.g., “I don’t have much energy today.”)

2. As a class, come up with a definition for the word “energy” and the term “energy source.” Standard definitions are:

- energy—the ability to do work, or the cause of all activity
- energy source—something that can be tapped to provide heat, chemical, mechanical, nuclear, or radiant energy

3. Have the students list as many energy sources as they can. Write this list on the blackboard. Among scientists and energy professionals, a standard list of current energy sources would include:

biomass (plant matter)
nuclear
coal
oil
geothermal
solar
hydro (rivers) wave or tidal
natural gas
wind

Your students may come up with some variations on this list or additions to it that are also acceptable:

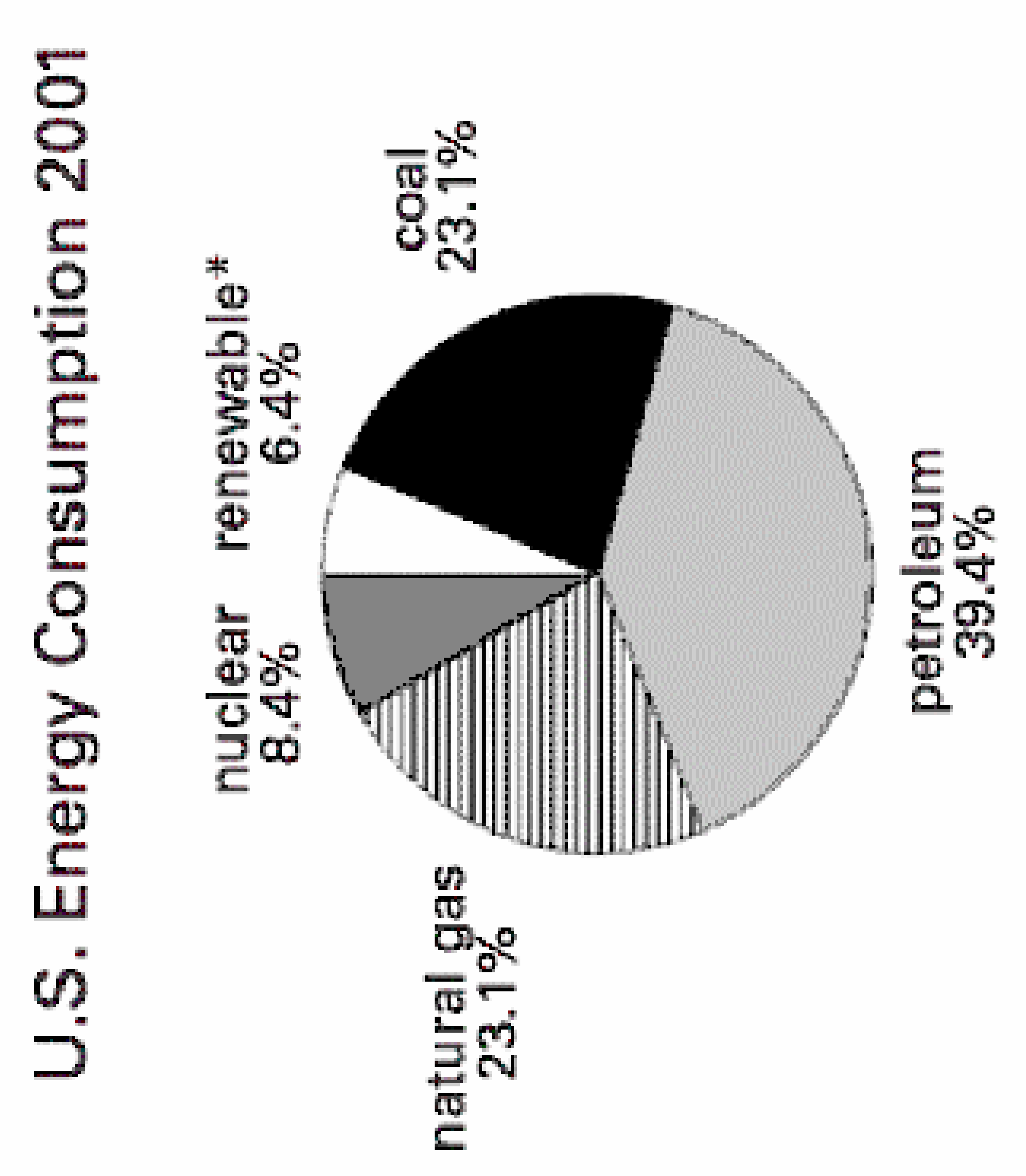
animal energy
food
propane
batteries
gasoline
water
charcoal
human energy
wood

4. Tell the class that their list of energy sources can be placed into two categories: renewable and nonrenewable. Have them brainstorm what they think these terms mean. If they are unsure, you can use the following definitions:

- renewable - energy sources that are replaced by natural processes at a rate comparable to their use
- nonrenewable - energy sources that are limited and can eventually run out; these sources of energy cannot be replaced on a time span of human significance

5. Ask the students to use the definitions to decide which of their energy sources are renewable and which are nonrenewable.

6. Ask students to guess how much of the energy we use in the United States comes from renewable energy sources. Then project on a transparency or draw the pie chart of the U.S. energy supply. It shows that most of our energy comes from oil, coal, and natural gas, which are nonrenewable. Explain that these three energy sources are known as fossil fuels and define the term. The energy stored in fossil fuels comes from the solar energy that was captured in plants millions of years ago, but the formation of fossil fuels is too slow to permit replacement for human use.



Sherman, Robin. *Renewables Are Ready: A Guide to Teaching Renewable Energy in Junior and Senior High School Classrooms*. Union of Concerned Scientists. 2003. Activity: Renew-a-Bean

7. The major categories of renewable energy sources are solar, wind, hydro, and biomass (plant matter).

8. Now it is time to conduct an activity that will demonstrate that conventional energy resources are finite and they will eventually run out.

Renew-A-Bean

This activity introduces students to the difference between renewable and nonrenewable resources. It shows students that nonrenewable sources will be exhausted over time. Moreover, it shows that conservation measures—ways of using less energy—along with increased use of renewables can slow the depletion of fossil fuels. Through the activity, students will gain an increased understanding of:

- the eventual depletion of fossil fuel resources
- the effect of changing rates of energy use on the future
- the need to conserve as well as the need to develop renewable resources

This activity will also give students an opportunity to work with percentages.

Note: The numbers used in this game are approximate and do not reflect actual depletion rates. The actual figures are difficult to estimate. The intent is only to simulate depletion of nonrenewable resources.

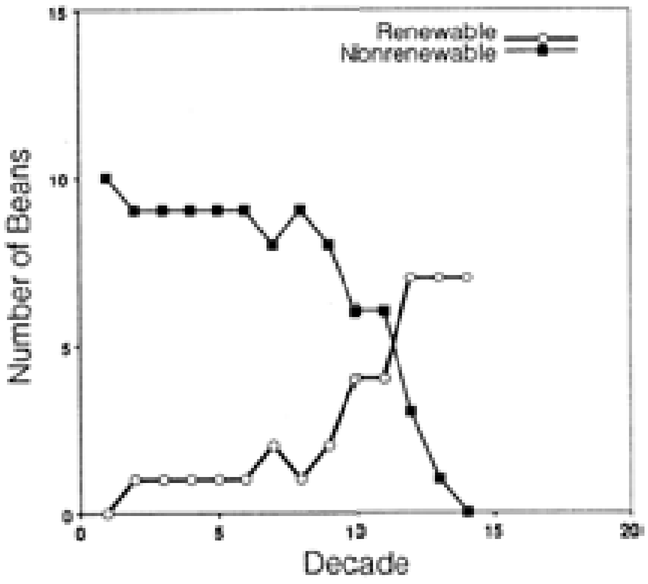
PREPARATION: Fill each bag with 94 beans of one color, six beans of another. This represents the ratio of nonrenewable to renewable energy use in the United States today.

Tell the students that they will participate in a game called "Renew-A-Bean." Explain that the beans in the paper bag represent nonrenewable and renewable resources. They will draw beans from the paper bag in order to simulate energy use over time.

9. Divide the class into groups of five. In the games, students in each group will take turns drawing a given number of beans from the bag. When they pick a "nonrenewable" bean, they should set it aside—it is "used up." When they pick a "renewable" bean, they should return it to the bag. Each drawing represents one decade.

10. Distribute bags. In the first game, have students in each group take turns drawing 10 beans per decade out of the bag. Have them record the number of renewable and nonrenewable beans they drew. Groups should stop picking beans when all the nonrenewable beans are "used up."

11. Ask groups how many decades it took to "run out" of nonrenewable energy. When the nonrenewable energy ran out, was there enough energy to meet the next decade's energy needs (10 beans)? Graph energy use over time. (Sample graph provided here) Ask students how they could make the energy supply last longer. They should come up with two answers—use less energy (conservation) and use more renewables.



Sample Graph [3]

12. Have students look at their graphs. During which decade did each group start using more renewables than nonrenewables? How is this represented on the graph? Which kind of energy will people probably use more of in the future?

13. Introduce the concept of "sustainable use." A sustainable rate of energy use ensures that there will always be enough energy for the next year's needs. Ask groups when, if ever, their energy use was sustainable during the game. (For he purpose of the game, energy use is sustainable when the number of "renewable" beans in the mix is equal to a constant consumption rate, or is growing at the same rate as or faster than a growing energy consumption rate.)

14. Ask students if they think energy use can keep increasing indefinitely. Why or why not? If students answer that the rate of energy use can keep increasing because renewable energy will never run out, discuss limits on the growth of renewable sources of energy (e.g., available land for biomass crops and wind turbines, water sources for hydro).

15. Ask students what they think the ratio of renewable to nonrenewable energy use in the United States is in the current year (see "What Is Renewable Energy?" activity for 2001 figures). Ask how they think the rate at which we use energy changes each year. Is our current use of energy sustainable? What do we need to do to make it sustainable?

16. Ask what a nation could do to become less dependent on fossil fuels?

Estimates vary widely as to how long fossil fuels—oil, coal, and natural gas—will last. These estimates depend on assumptions about how much fossil fuel remains in the ground, how fast it will be used, and how much money and effort will be spent to recover it. However, most estimates agree that, if present rates of consumption continue proven oil and natural gas reserves will run out in this century, while coal reserves will last more than 200 years. Once they are used, these energy sources cannot be replaced.

Long before we actually run out of coal, oil, or gas, however, the environmental and social consequences of extracting, processing, transporting, and burning fossil fuels may become intolerable. In addition, it will not be economically viable to extract all of our fossil fuels, as renewable resources will eventually become competitive. You may choose to discuss these consequences with your students in detail (material included) or just explain that there are negative environmental effects associated with the use of fossil fuels and move on.

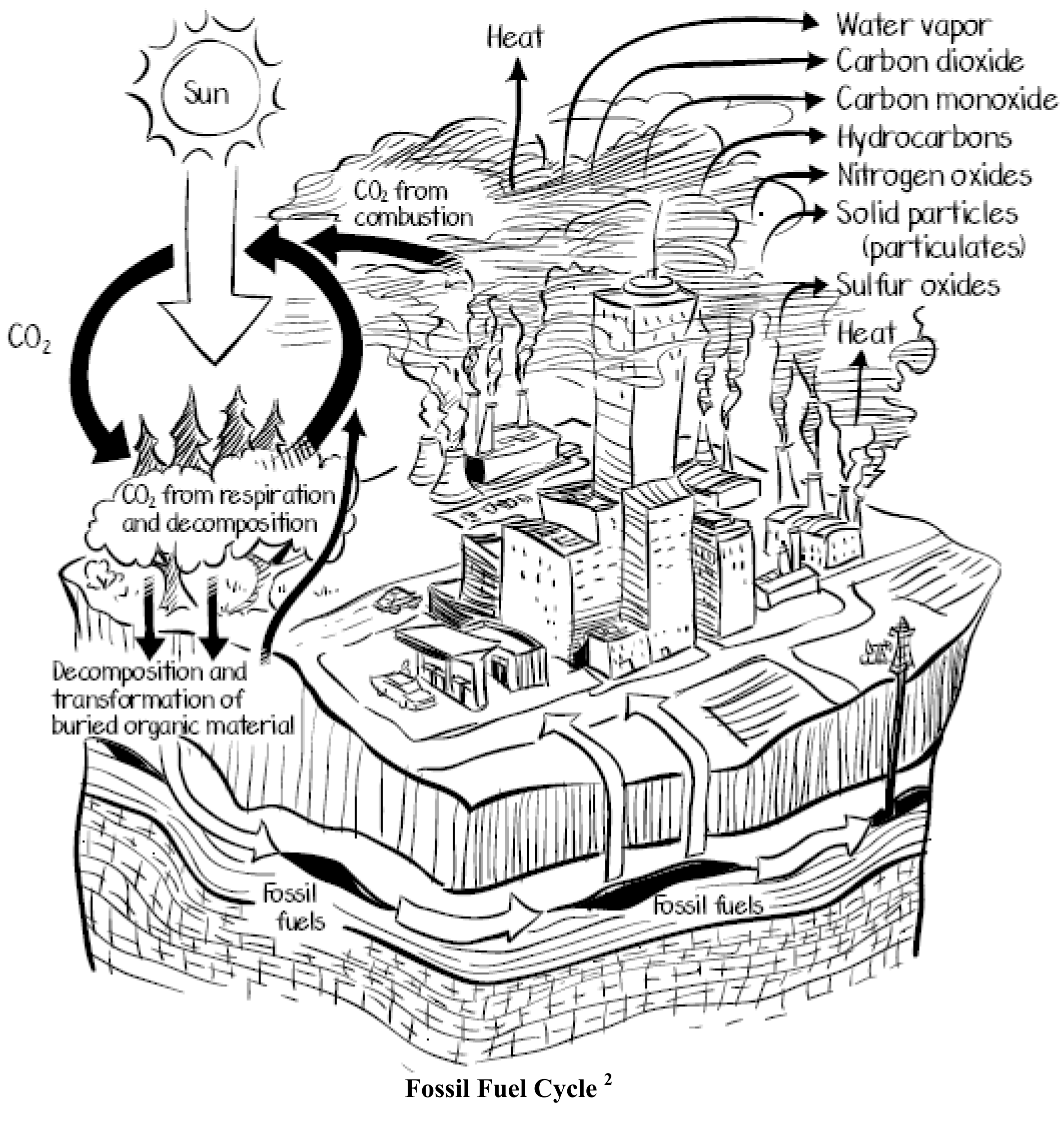
In contrast to fossil fuels, renewable sources of energy produce little or no pollution or hazardous waste and pose few risks to public safety. Furthermore, they are an entirely domestic resource.

ENVIRONMENTAL EFFECTS OF FOSSIL FUELS (POLLUTION SECTION)

The main cause of excess pollution in our air has been the burning (combustion) of fossil fuels — for industrial processes, transportation, and electricity generation.* Fossil fuel combustion contaminates our air with gases, chemicals, smoke, and ashes, pollutants that are ultimately deposited in our water and soil.

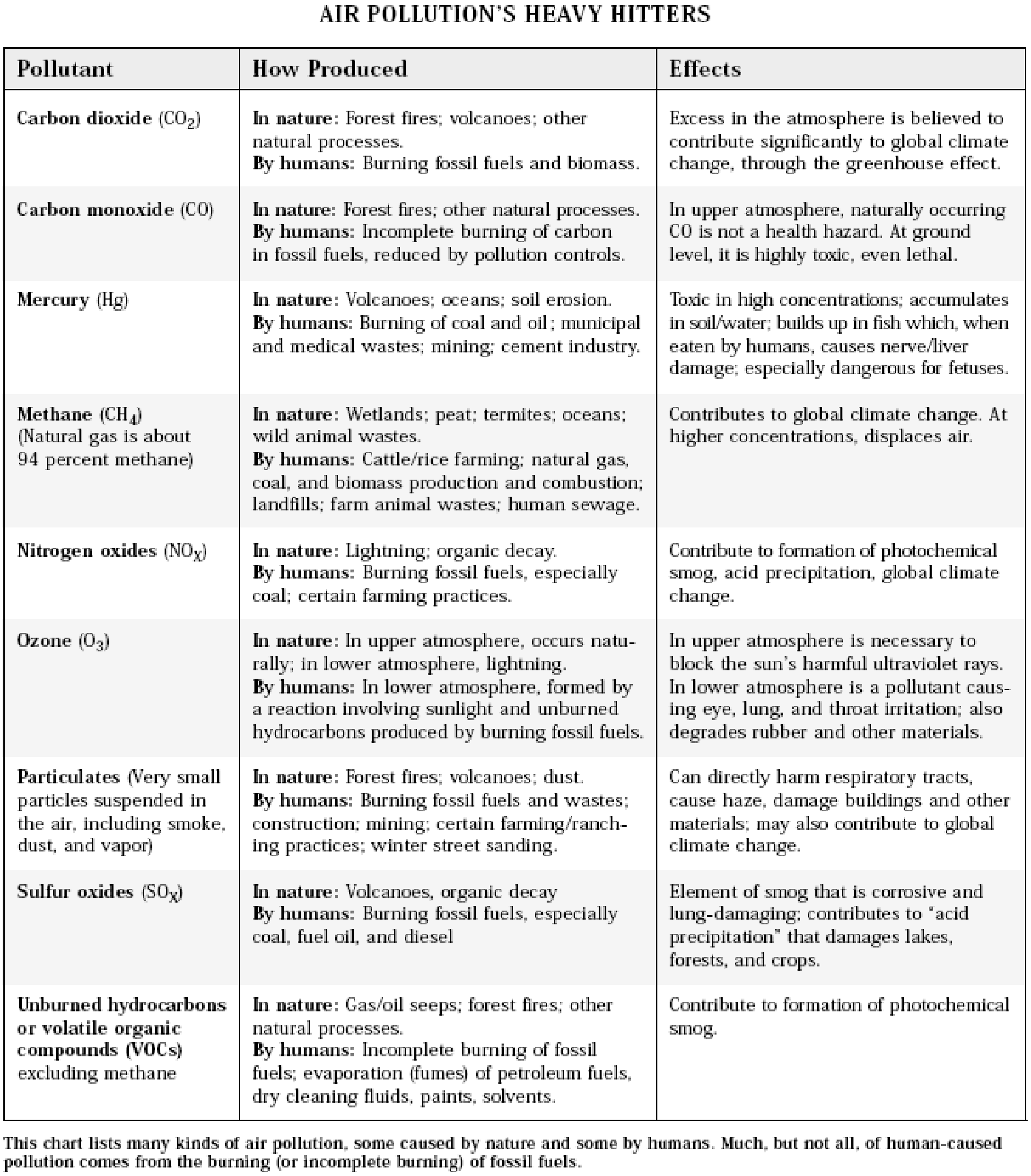
It should be noted that generation of electricity and other human activities cause many kinds of pollution, not just air pollution. They also cause land and water pollution. But pollution of our air from traditional power generation is the main concern, and so it is the focus of discussion in this section.

The fossil fuel cycle shown below demonstrates how pollutants enter the atmosphere



Fossil Fuel Cycle [2]

The most common pollutants, how they are produced and their effects are presented in the table below.



AIR POLLUTION'S HEAVY HITTERS

Pollutant	How Produced	Effects
Carbon dioxide (CO_2)	**In nature:** Forest fires; volcanoes; other natural processes. **By humans:** Burning fossil fuels and biomass.	Excess in the atmosphere is believed to contribute significantly to global climate change, through the greenhouse effect.
Carbon monoxide (CO)	**In nature:** Forest fires; other natural processes. **By humans:** Incomplete burning of carbon in fossil fuels, reduced by pollution controls.	In upper atmosphere, naturally occurring CO is not a health hazard. At ground level, it is highly toxic, even lethal.
Mercury (Hg)	**In nature:** Volcanoes; oceans; soil erosion. **By humans:** Burning of coal and oil; municipal and medical wastes; mining; cement industry.	Toxic in high concentrations; accumulates in soil/water; builds up in fish which, when eaten by humans, causes nerve/liver damage; especially dangerous for fetuses.
Methane (CH_4) (Natural gas is about 94 percent methane)	**In nature:** Wetlands; peat; termites; oceans; wild animal wastes. **By humans:** Cattle/rice farming; natural gas, coal, and biomass production and combustion; landfills; farm animal wastes; human sewage.	Contributes to global climate change. At higher concentrations, displaces air.
Nitrogen oxides (NO_X)	**In nature:** Lightning; organic decay. **By humans:** Burning fossil fuels, especially coal; certain farming practices.	Contribute to formation of photochemical smog, acid precipitation, global climate change.
Ozone (O_3)	**In nature:** In upper atmosphere, occurs naturally; in lower atmosphere, lightning. **By humans:** In lower atmosphere, formed by a reaction involving sunlight and unburned hydrocarbons produced by burning fossil fuels.	In upper atmosphere is necessary to block the sun's harmful ultraviolet rays. In lower atmosphere is a pollutant causing eye, lung, and throat irritation; also degrades rubber and other materials.
Particulates (Very small particles suspended in the air, including smoke, dust, and vapor)	**In nature:** Forest fires; volcanoes; dust. **By humans:** Burning fossil fuels and wastes; construction; mining; certain farming/ranching practices; winter street sanding.	Can directly harm respiratory tracts, cause haze, damage buildings and other materials; may also contribute to global climate change.
Sulfur oxides (SO_X)	**In nature:** Volcanoes, organic decay **By humans:** Burning fossil fuels, especially coal, fuel oil, and diesel	Element of smog that is corrosive and lung-damaging; contributes to "acid precipitation" that damages lakes, forests, and crops.
Unburned hydrocarbons or volatile organic compounds (VOCs) excluding methane	**In nature:** Gas/oil seeps; forest fires; other natural processes. **By humans:** Incomplete burning of fossil fuels; evaporation (fumes) of petroleum fuels, dry cleaning fluids, paints, solvents.	Contribute to formation of photochemical smog.

This chart lists many kinds of air pollution, some caused by nature and some by humans. Much, but not all, of human-caused pollution comes from the burning (or incomplete burning) of fossil fuels.

Air Pollutants [2]

AIR POLLUTION SOLUTIONS

Using Clean Energy Sources

Another solution to the air pollution problem is to create less pollution in the first place by using clean energy sources. Many of the cleanest are renewable energy sources (often referred to as "green" because they are environmentally friendly). Renewable energy sources do not produce many of the air pollutants associated with traditional fossil fuelburning power plants. For example, most renewable energy sources produce very little or no carbon dioxide as they generate electricity.
Note: This is the solution we would like to emphasize, as we are using this introductory lesson to make a case for renewable energy. However, other solutions do exist and they are listed and explained briefly below.

Improving the Technology of Pollution Control

Scientists and engineers are always working on ways to improve pollution control equipment and waste disposal methods. It can be expensive to apply new, cleaner technology to existing equipment. To ensure that pollution controls are implemented, local and federal regulations set standards for air quality and pollution control implementation

Examples of this are
- Catalytic Converters for cars
- Pollution control equipment electric power plants

Conserving Energy

A very important way to help avoid air pollution is by conserving (using less) energy. There are lots of ways we can do this. This is a detailed subject and can be treated as its own topic, but we will not explore it in depth here as our basic goal for this lesson was to make a case and provide a context for renewable energy

ADDITIONAL INFORMATION FOR TEACHERS

SOURCES FOR THIS ADAPTED ACTIVITY:

1. School Power Naturally: Solar Education for New York, *Our Dependence on Fossil Fuels.* (New York State Energy Research and Development Authority - NYSERDA), SPN Lesson # 2.
   Available at <http://www.nyserda.org/schools/2_fossil_fuels.doc>

2. Educators for the Environment. *Energy For Keeps: Electricity from Renewable Energy*. Tiburon, California. 2003. Chapters 1 and 3

3. Sherman, Robin. *Renewables Are Ready: A Guide to Teaching Renewable Energy in Junior and Senior High School Classrooms*. Union of Concerned Scientists. 2003. Activity: Renew-a-Bean

REFERENCES FOR BACKGROUND INFORMATION:

The most up-to-date information about fossil fuel reserves and other data pertaining to energy are available from the Energy Information Administration. The URL of their website is www.eia.doe.gov.

Information on Renewable Energy can be found from a host of sources, a prominent and reliable source is the US Department of Energy – Energy Efficiency and Renewable Energy Division. Their website is http://www.eere.energy.gov/

DAY 3

LEARNING OUTCOME: Through this lecture based session students learn about the different sources of renewable energy and how electricity is generated from these resources (specifically solar.) They learn that the method of generating electricity from solar energy is photovoltaics, and also understand the benefits and drawbacks of photovoltaic systems.

LESSON OVERVIEW: Students are first taught about the different sources of renewable energy and are told that the focus will be on solar energy. They learn about generation of electricity from these resources since electricity is the most common form of energy consumption in our society. They are then led to examine the generation of electricity from solar energy (photovoltaics) in particular. They are led in a discussion of the benefits and limitations of photovoltaic systems and are presented some examples of their application.

GRADES: All Grade Levels. (Students need to know about renewable energy and its context prior to this discussion)

SUBJECTS: Social studies, mathematics

MATERIALS:

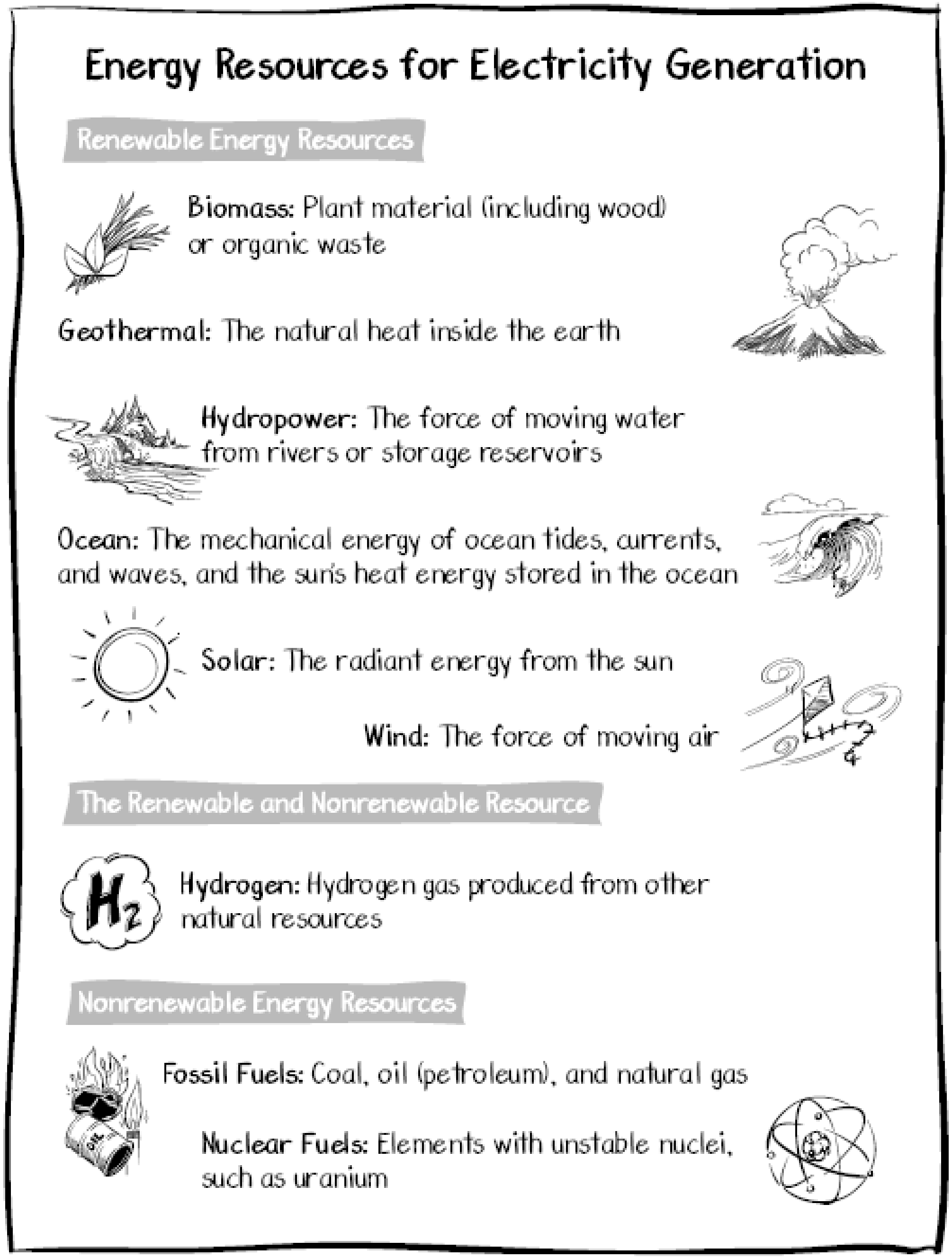
- Student handout with worksheet (Included)

PREPARATION: Ideally should have completed Days 1 and 2 of the education packet. Students should at least have an understanding of renewable energy and its context.

TIME: 60 minutes.

TEACHING THE LESSON:

1. Begin by presenting the chart below. It lists the different sources of energy for electricity generation, separated into renewable and non-renewable resources



Energy Resources for Electricity Generation

Renewable Energy Resources

Biomass: Plant material (including wood) or organic waste

Geothermal: The natural heat inside the earth

Hydropower: The force of moving water from rivers or storage reservoirs

Ocean: The mechanical energy of ocean tides, currents, and waves, and the sun's heat energy stored in the ocean

Solar: The radiant energy from the sun

Wind: The force of moving air

The Renewable and Nonrenewable Resource

Hydrogen: Hydrogen gas produced from other natural resources

Nonrenewable Energy Resources

Fossil Fuels: Coal, oil (petroleum), and natural gas

Nuclear Fuels: Elements with unstable nuclei, such as uranium

Sources of Energy [1]

2. Explain that the focus of this class will be electricity generation, as this is the most common form of energy consumption in our society. Having explained this, ask the students to think about where their electricity comes from. Most students will not have given this too much thought. Explain that this is pretty normal, because most people in industrialized countries like the United States are often many miles of wire removed from the places where their electricity is generated.

3. From previous lessons the students should know that people that have their own way of generating electricity — such as from a wind turbine or solar panels — are still the exception, at least in the United States.

4. Explain that behind the scenes, energy producers work day and night to provide us with a steady supply of electrical power. Using improved technology and know-how, today's electricity suppliers have figured out plenty of different, and sometimes complex, ways to generate electricity. But the most common and widespread method uses an age-old apparatus, the turbine, attached to a much more modern device, the generator. For over 120 years these two seemingly simple machines have worked together in power plants to produce vast quantities of electricity, revolutionizing the way people live, work and play.

5. Now talk about Solar Energy in particular.

THE SOLAR RESOURCE

The sun is the world's most widely used energy resource. Plants began capturing the sun's energy millions of years ago, and members of the animal kingdom have always basked in its warmth. Human dwellings have long included openings that let in the sun's light and heat. Our use of windows to capture the sun's radiation is such a common practice that we don't even think about it. Today we also use the heat of the sun to heat water. And, with technology ranging from tiny solar cells to huge power plants shimmering with rows of curved mirrors, we make electricity.

We all know that our sun gives off radiating waves of heat and light energy. Without these, our planet would not have life. The sun also emits many other kinds of radiation (called the electromagnetic spectrum), such as X-rays and ultraviolet waves. All the waves emitted from the sun move rapidly as tiny bundles of energy called photons. These photons travel vast distances from the sun through the vacuum of space and bathe our planet with solar energy every day.

6. Shedding Light on the Solar Spectrum

The sun emits many kinds of radiation besides X-rays and ultraviolet waves. Altogether, the range of different energy waves from the sun is called the "Solar Spectrum." Forty-five percent of the sun's energy that reaches the surface is what we call light because we can see it. Almost all the rest we do not see (although we can detect and measure it), yet it all delivers energy. For example, ultraviolet radiation, though we can't see it, can tan or burn our skin. A small part of the radiation that reaches the earth as "heat" (infrared radiation) is mostly absorbed in our atmosphere.

7. Some parts of the earth receive more solar radiation than others. In general, the areas at or near the equator receive the most solar radiation. For example, the tropics get about two and a half times more heat, or infrared radiation than the poles. Any area that

receives a steady supply of solar radiation, whether a little or a lot, can make use of the energy transferred from our sun.

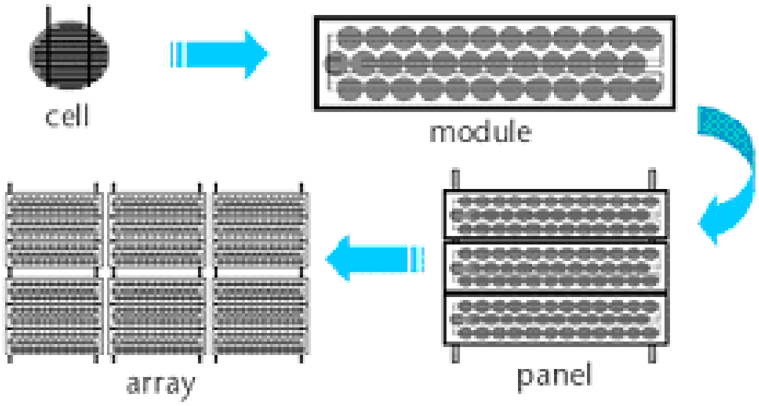
8. We use just a fraction of our enormous solar resource.* The total solar radiation received each year is about 3,000 times all the energy used globally.
Note: The total amount of solar radiation received by the earth is 1.73 x 1017 watts at any one time. This is enough to warm our entire globe, fuel all of the earth's photosynthesizing plants, and create global climatic systems that drive the winds, the waves, and the water cycle.

9. Now talk about generating electricity from solar resources. (Photovoltaics)

In the 1950s, American engineers sought a method to power U.S. space satellites. They found it in an existing process that used energy from the sun called photovoltaics (PV). We still use photovoltaics to energize orbiting satellites, space stations, and the Hubble telescope. Back on the earth, PV is widely used for everything from roadside call boxes to large power plants.

10. In photovoltaics, photons of sunlight react with specially designed materials in a process that results in electricity. *Photo* means light, and *voltaic* refers to the electrical current.

11. The smallest unit is a photovoltaic cell, made of wafer-thin layers that react to sunlight to create electricity. The most common material in use today is silicon, either in crystalline form or thin films, but other materials are being investigated (Photovoltaic Cells and modules are examined in detail in the next activity). Solar cells are wired together to make modules, and modules are combined together to make up a solar panel. A group of solar panels are collectively known as a PV array and can provide enough electricity for a household. Hundreds of arrays (known as an array field) are grouped together for use by a large commercial or industrial facility or by a utility.



PV Components[1]

12. PV systems can be stand-alone (not connected to electric transmission lines) or grid-connected.

Stand-alone PV. Photovoltaic systems are very handy for remote locations where transmission and distribution lines are not desirable or practical. These stand-alone systems are useful for lighting highway signs (energy is stored in batteries for use at night), roadside call boxes, and unmanned research installations in remote areas. They are also frequently found in rural areas or in national parks for lighting, battery charging, driving electric motors, water pumping, and more. The airport at Glen Canyon National Recreation Area, Utah, for example, is powered entirely by PV. Pinnacles National Monument in California uses solar cells for all operations including the ranger station, residences, and campground.

Globally, stand-alone PV is providing electricity in many developing areas without widespread transmission lines. Indonesia, a nation of 17,000 islands, is turning to PV electricity rather than trying to connect all the islands with transmission wires. India supplies hundreds of complete PV “kits” (called Solar Home Systems) to its rural villages. These include everything needed to light up a small home, including solar panels, wiring, and even the lights themselves. In Morocco on the edge of the North African desert, solar panels are often found at bazaars, where they are sold right alongside exotic Moroccan rugs and tin ware.

Grid-connected PV. Grid-connected PV systems range from small rooftop home set-ups to large PV power plants. Today, many U.S. government and privately owned buildings are being fitted with PV as part of the government’s Million Solar Roofs program. Meanwhile, a number of private businesses, such as warehouse- type stores, are making use of their expansive rooftops to install solar panels. Hundreds of utilities are including PV in their operations. The Sacramento Municipal Utility District in California, for instance, has more than 1,100 PV systems (including 800 to 900 homes with PVroofs) that together can produce about 11 MW. The first neighborhood to put PV on the roofs of all of its homes is in Gardner, Massachusetts. These were installed in the 1980s. California is the largest user of grid-connected PV. Arizona, Texas, and Colorado are also making wide use of grid-connected PV systems. Globally, millions of small PV systems are in use. Large-scale PV power plants that generate at least 1 MW or more of solar electricity are operating in the United States, Germany, Spain, Italy, India, and Japan.

Information that explains the quantities referred to

W = watt
kW = kilowatt = 1,000 watts
MW = megawatt = 1,000 kilowatts
1 megawatt serves about 1,000 homes in the United States.

13. **Benefits and Limitations**

Have them brainstorm what they think the benefits and limitations are.

Benefits/Attractive Features

- They are modular (units can be added as needed)
- Make no noise
- Produce no pollution
- Operate during the hours of highest daytime electrical demand.
- PV panels can be mounted on rooftops or even integrated right into the buildings as glass walls, skylights, sunshades, shingles and more. PV panels can also be constructed over parking lots to provide shade and protection from the rain
- Small Concentrating Solar Power units do not take up much space and therefore can be placed in populated areas, especially industrial or commercial locations.

Limitations/ Challenges

- Sunlight supply depends on time of day, the season, the cloud cover, and the location. Today, most of these factors can be controlled with various solar energy storage systems.
- While cost used to be a major barrier with solar technology, it is becoming less so today. While costs have dropped greatly in the past two decades, solar systems are still expensive when compared with other renewables or with fossil fuel sources such as coal or gas.
- The rooftops or land area needed to construct a big commercial PV facility is very large. This may present too great a financial challenge.
- Large installations come with some environmental concerns, especially if sensitive desert habitats are threatened.
- Manufacturing photovoltaic cells takes quite a bit of electricity. It takes two to four years to generate enough electricity from photovoltaic cells to compensate for the original electricity used to make them. However the cells generally last 20 years or more.

14. Present the following data file and example of PV usage

DATA FILE:

California
Almost 400 MW of electricity is currently produced by solar resources in California. Many of California's scenic recreation areas use solar cells for electricity, including national parks such as Death Valley, King's Canyon, Joshua Tree, Mojave, Yosemite, Pinnacles, Lassen Volcanic, and Pt. Reyes.

United States

- Solar energy provides less than 1 percent of the electricity consumed in the United States.
- The top solar electricity producing states are California, Texas, and Arizona.

Worldwide

- Over 1,000 MW of the world's electricity comes from solar. PV production is doubling every three years.
- Some areas making wide use of solar energy are India, Japan, Europe, Indonesia, Australia, Mexico, Northern Africa, and the United States.

Example of PV system use

Lighting the Way on a Foggy Day

On foggy days along the coast of Ventura, California, a lone lighthouse shines its lights and sounds its foghorn for maritime travelers. Though far from the mainland's electrical connections, the Anacapa Island lighthouse operates entirely on electricity. The source of electricity is a large group of solar panels on the roof that converts sunlight into electricity. This electricity also charges batteries to operate the lights even when the sun doesn't shine. Anacapa is part of the Channel Islands National Park system, a series of islands for which diesel generators once provided the electricity.* Now, instead, dozens of solar panels are powering operations around the islands, including a naval installation on Santa Cruz Island.

15. Ask them to complete the worksheet in the student handout for homework

ADDITIONAL INFORMATION FOR TEACHERS

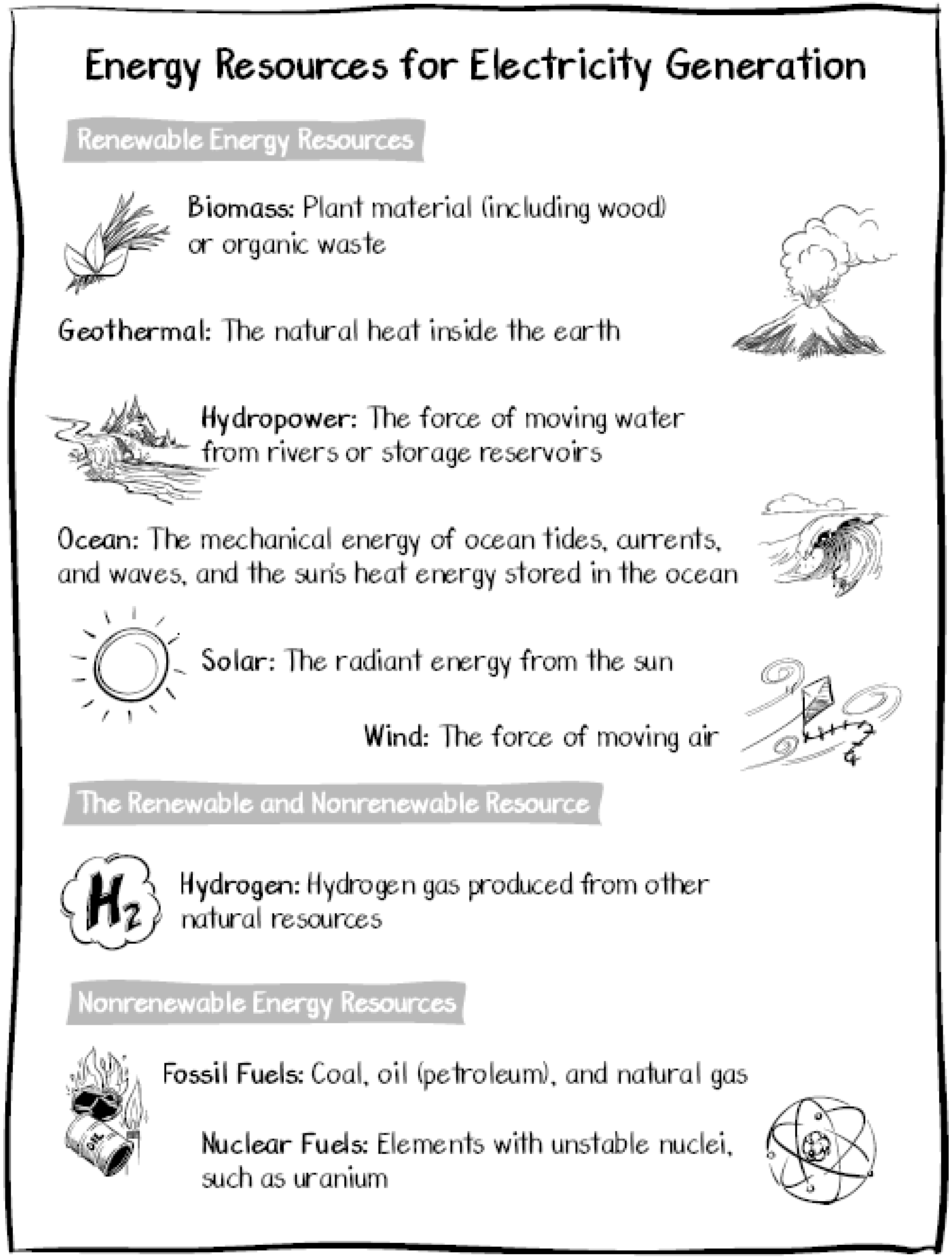
SOURCES FOR THIS ADAPTED ACTIVITY:

1. Educators for the Environment. *Energy For Keeps: Electricity from Renewable Energy*. Tiburon, California. 2003. Chapters 1 and 3
2. Photovoltaics Student Guide. (www.need.org)

REFERENCES FOR BACKGROUND INFORMATION:

Information on all types of renewable energy, including solar and photovoltaics can be found from a host of sources. A prominent and reliable source is the US Department of Energy – Energy Efficiency and Renewable Energy Division. Their website is http://www.eere.energy.gov/

<u>STUDENT HANDOUT</u>



Energy Resources for Electricity Generation

Renewable Energy Resources

Biomass: Plant material (including wood) or organic waste

Geothermal: The natural heat inside the earth

Hydropower: The force of moving water from rivers or storage reservoirs

Ocean: The mechanical energy of ocean tides, currents, and waves, and the sun's heat energy stored in the ocean

Solar: The radiant energy from the sun

Wind: The force of moving air

The Renewable and Nonrenewable Resource

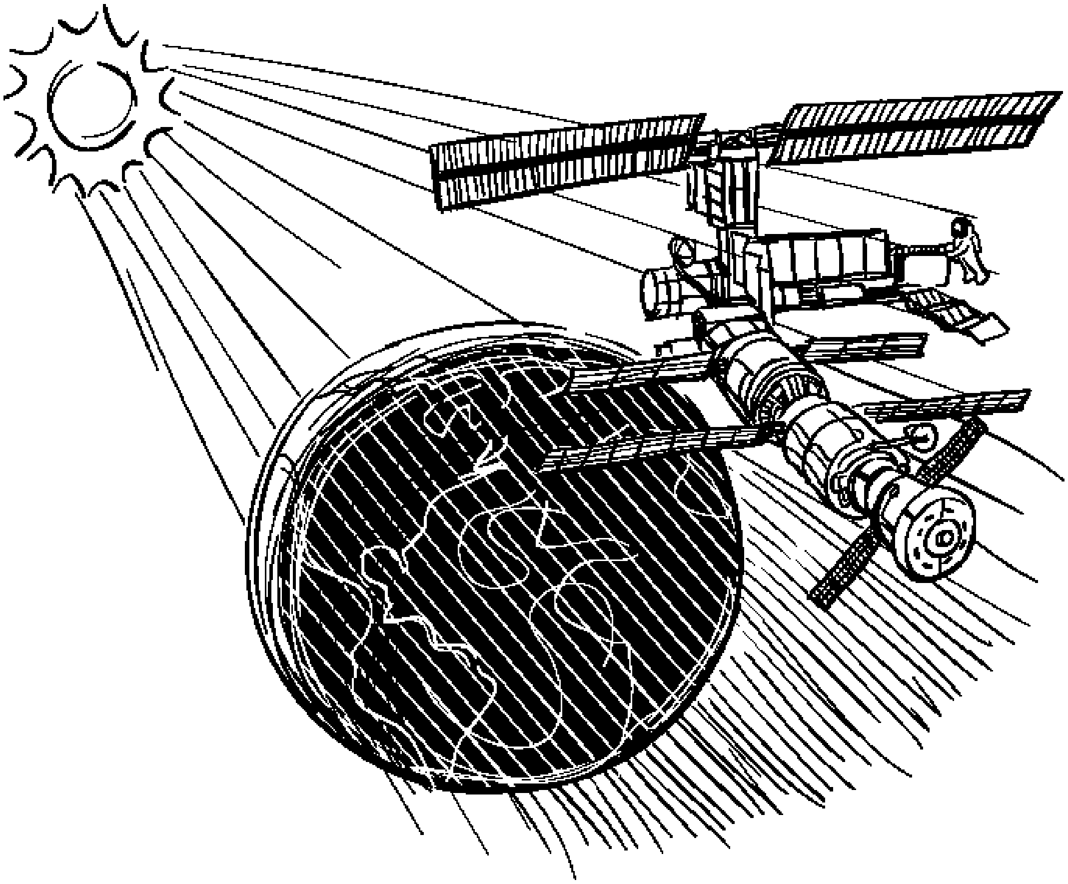
Hydrogen: Hydrogen gas produced from other natural resources

Nonrenewable Energy Resources

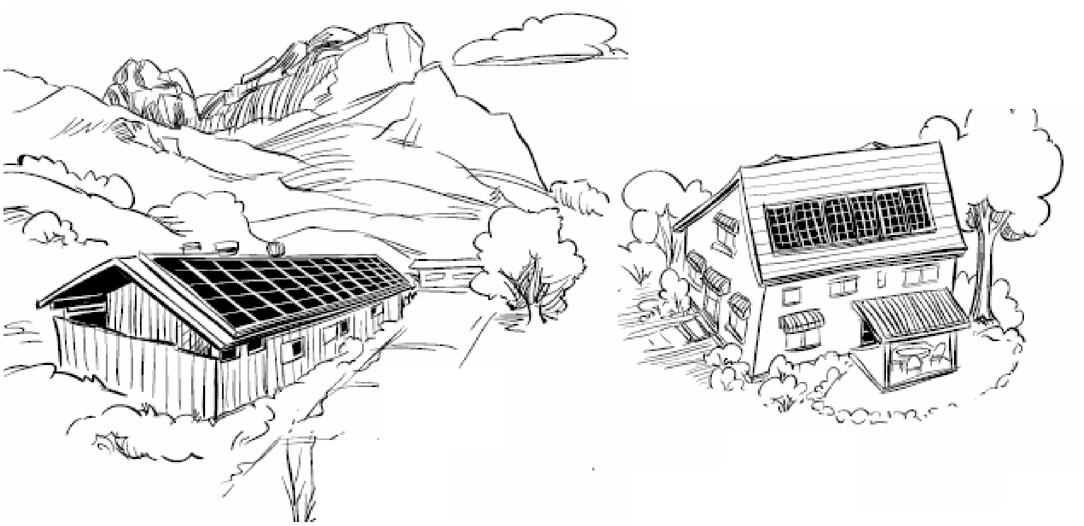
Fossil Fuels: Coal, oil (petroleum), and natural gas

Nuclear Fuels: Elements with unstable nuclei, such as uranium

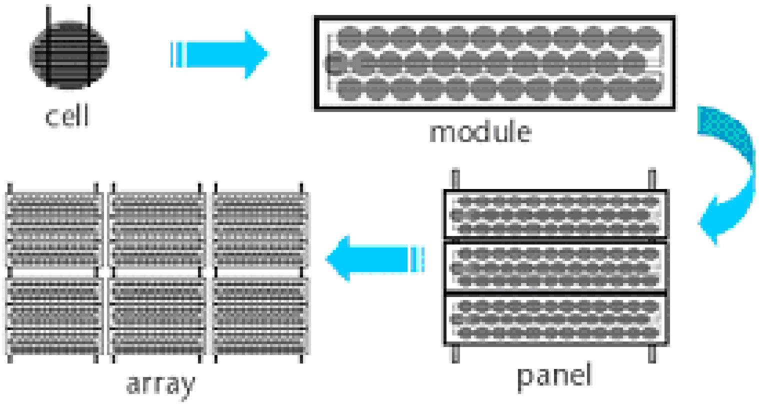
THE SOLAR RESOURCE



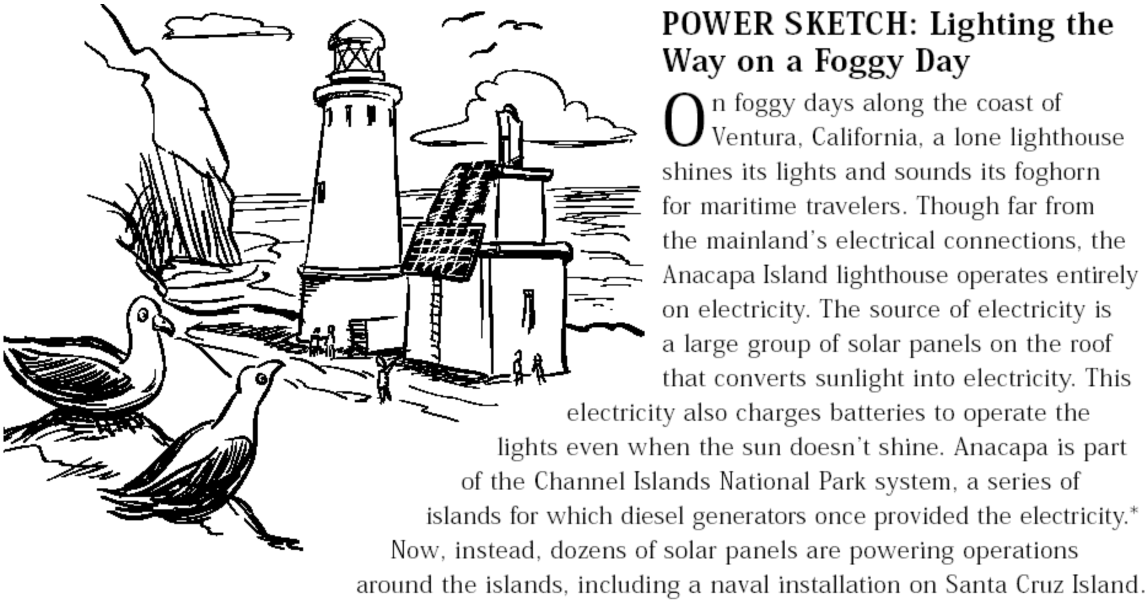
The first use of PV generated electricity was to power satellites [1]



PV systems in use on the roofs of houses [1]



PV Components [2]



POWER SKETCH: Lighting the Way on a Foggy Day

On foggy days along the coast of Ventura, California, a lone lighthouse shines its lights and sounds its foghorn for maritime travelers. Though far from the mainland's electrical connections, the Anacapa Island lighthouse operates entirely on electricity. The source of electricity is a large group of solar panels on the roof that converts sunlight into electricity. This electricity also charges batteries to operate the lights even when the sun doesn't shine. Anacapa is part of the Channel Islands National Park system, a series of islands for which diesel generators once provided the electricity.* Now, instead, dozens of solar panels are powering operations around the islands, including a naval installation on Santa Cruz Island.

Example of the use of PV systems [1]

Worksheet

Short Answers

1. List four renewable energy resources that can be used to generate electricity

3. Name the technology that is used to generate electricity from Solar energy and explain where the name comes from.

4. Rearrange these in increasing order of their size:
   Array, Module, Photovoltaic cell, Array field, Panel

5. How many average United States homes can be powered by a 5.4 MW power plant?

6. List and explain two advantages and two limitations/disadvantages of PV systems

7. Name the three top solar energy producing states in the US.

DAY 4

LEARNING OUTCOME: Students are introduced to how photovoltaic cells work, and understand how varying conditions impact their performance.

LESSON OVERVIEW:
Students are introduced to photovoltaic cells and how they work through an initial brief lecture and discussion based session. They then conduct several experiments to familiarize them with photovoltaics, how they generate electricity, and their performance under varying conditions.

Background: Photovoltaics is a technology for converting light directly into electricity. Most photovoltaic cells have two layers of "semiconductor" material—the same material used in computer chips. When light hits the photovoltaic cell, electrons travel from one layer to the other, creating a voltage (or charge) that can power an electrical device. Photovoltaic cells (also called PV or solar cells) were first developed to power space satellites. Technical advances have steadily increased PV cell efficiencies, and their cost has dropped significantly. Solar cells are widely used in calculators and for remote power applications not connected to an electricity grid (such as rural villages, communications relays, and emergency lights, signs, and telephones). They are not yet economically competitive for large-scale electricity generation.

GRADES: 8–12

SUBJECTS: science, technology, mathematics

TIME: two 45-minute class periods for all the experiments below; less time if you do fewer

MATERIALS: Divide students into groups of two to four.

Each group needs:
- small solar PV cell with at least a 0.4 V output (these can be obtained from most scientific supply companies and electronics stores)
- 30 cm of wire (approximately 22 gauge)
- DC ammeter with a range of approximately 0–10 amps
- DC voltmeter with a low rating (1 or 5 VDC minimum rating is fine)
- Graph Paper

Depending on which experiments you do, you may also need:
- a strongly directional light source, such as a shaded desk lamp or flashlight
- magnifying glass
- cardboard
- aluminum foil
- glue
- small motor (approximately 1.5 V DC) or flashlight bulb

Note: Complete Solar educational kits with most of these materials can easily be purchased online.

http://www.plastecs.com/solar_kits.htm

Educational Solar Kits
SDK 1 - Introductory - $ 9.50
SSK 1 - Intermediate - $ 18.95

PREPARATION:

1. If you have not studied electricity in your class, you may want to discuss the basic concepts of electricity before proceeding.
2. Unless your school already owns some, you need to order PV cells in advance. Buy as many cells as you can afford; you can divide the class equally according to how many PV cells you have. Since each PV cell will be attached to an ammeter and voltmeter, the number of ammeters and voltmeters your school owns may be a limiting factor, but they are reusable in future years.
3. Attach 15 cm of wire to each node of the PV cell, to connect it to the ammeter, voltmeter, bulb, or motor. Some cells come with clips or hooks around which you can manually twist wire; some do not. If yours does not, you may need to solder the wire ends to the cell before class. If yours does have a clip, you can have the students attach the wire themselves.
4. You will need a sunny day to do most of these experiments. Alternatively, you could do Experiments 1, 2, and 3 in the classroom, using fluorescent lights, but you will need an ammeter that will measure accurately between 0 and 1 amp to do this.

PROCEDURE:

1. Discuss with students the technology of photovoltaics and describe how a PV cell works. Distribute the handout “Photovoltaic Cells” (attached). You might have students read about photovoltaics before the class period from internet resources they find themselves.
2. Distribute the solar cells. Tell students to be careful; PV cells are fragile. You may want to attach the cells to a stiff backing before class.
3. First, show students that PV cells can generate electricity. Ask each group to attach the two wires to the end of a flashlight bulb or a small DC motor. Put the cells under an intense lamp or in sunlight.
4. Have students attach their PV cell to an ammeter. Make sure the positive and negative ends of the PV cell wires match up with the ammeter. Assign one student in each group to measure and record current for the experiments below.
5. Run one or more of the experiments. Write on the board the scientific question for each experiment. You might want to write the results (in amps) of each group’s findings on the board. These can be averaged, and the class can draw conclusions from the data.

EXPERIMENT 1: How does light intensity affect how much electricity a solar cell can produce?

Procedure: Have students place the PV cell at distances of 4 cm, 12 cm, and 25 cm from a strongly directional light source other than the sun (a shaded desk lamp is good). The solar cell should be held facing directly at the light source. Ask students to measure the current of the cell at 4 cm, 12 cm, and 25 cm from the light source. Have students graph the results.

Follow-up: Have students draw conclusions from their measurements. Ask them if their graphs represent a linear or exponential function. Point out to students that what is being tested is the effect of *intensity* of light on PV cells. Point out that light is more intense on a sunny day than on a cloudy day. What does this say about the best conditions for using PV cells? What time of day do they work best?

EXPERIMENT 2: How does the angle to the light source affect how much electricity a solar cell can produce?

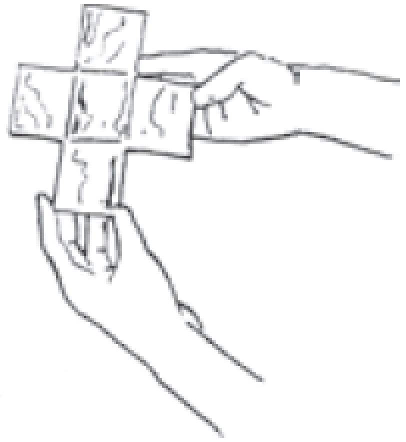
Procedure: Have students place their PV cells on a horizontal surface in direct sunlight (either outside or on a sunny window sill). Measure the current. Then, have them point the PV cell directly at the sun: slant it so that its shadow is directly behind it, with the cell's face perpendicular to the sun's rays (one way to discover the sun's direction is to insert a stick in the ground and tilt it until it has no shadow). Measure the current. Students might also measure the PV cell's current at decreasing 15° intervals from the perpendicular (90°, 75°, 60°, 45°, 30°, and 15°), then graph the measurement. The result should be a sinusoidal curve.

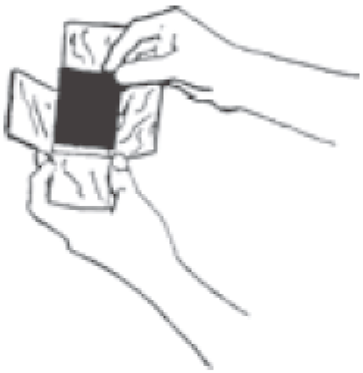
Follow-up: Have students draw conclusions from their measurements. Ask them: How could you increase the output of a PV cell during the day, when the angle of the sun's rays is constantly changing?

EXPERIMENT 3: How does concentrating the light affect how much electricity a solar cell can produce?

Procedure: Have students measure the current of a PV cell under a light source (a lamp or the sun). Then, have them concentrate the light source on the cell with a magnifying glass (move the magnifying glass around until a bright area appears on the cell). Measure the new current. Alternatively, students can make a cardboard reflector. Cut out a cardboard shape and glue aluminum foil on the four flaps. Place the solar cell in the base and fold up the four side flaps to reflect light on the cell. Measure the new current.

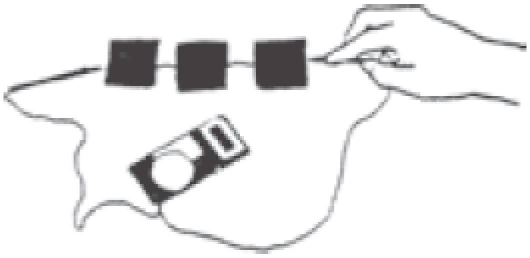
Follow-up: Have students draw conclusions from their measurements. Ask: Does it make sense to concentrate sunlight on a PV cell? Point out that many PV cells today have concentrators on them.





EXPERIMENT 4: How does putting several PV cells in a series affect how much electricity they can produce?

Procedure: Measure the voltage of a PV cell under a light source. Then connect several PV cells in series and measure the voltage produced under the same light source. Now repeat the measurement by connecting several cells in parallel, and measure the *current* and *voltage* produced under the same light source.



Follow-up: Have students draw conclusions from their measure- ments. Ask: How much more voltage was produced, in comparison to the voltages produced by individual cells? How much more current was produced with the cells connecting in parallel, in comparison to the current produced by individual cells? You can point out that most modern PV systems have cells connected in series strings to raise the voltage to a useful level, and grouped in parallel to provide the desired power (current).

FOLLOW-UP: To conclude the activity, you may want to do one of the following:

1. Summarize your findings by averaging together the measurements of all the groups.
2. Review the technology of photovoltaics, adding in information gained through the experiments.
3. Describe recent improvements and discoveries in photovoltaic technology (such as thin film or amorphous silicon cells).
4. Assign individual or group research projects in the following areas:
   a. photovoltaic efficiency
   b. kinds of PV cells, such as thin film or amorphous silicon
   c. technology of manufacturing PV cells
   d. costs of manufacturing PV cells
   e. new developments in PV technology
   f. current uses of PV cells

ADDITIONAL INFORMATION FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY:

1. Sherman, Robin. *Renewables Are Ready: A Guide to Teaching Renewable Energy in Junior and Senior High School Classrooms*. Union of Concerned Scientists. 2003. Activity: Photovoltaics

Note: Almost all material directly cut and pasted from above source.

REFERENCES FOR BACKGROUND INFORMATION:

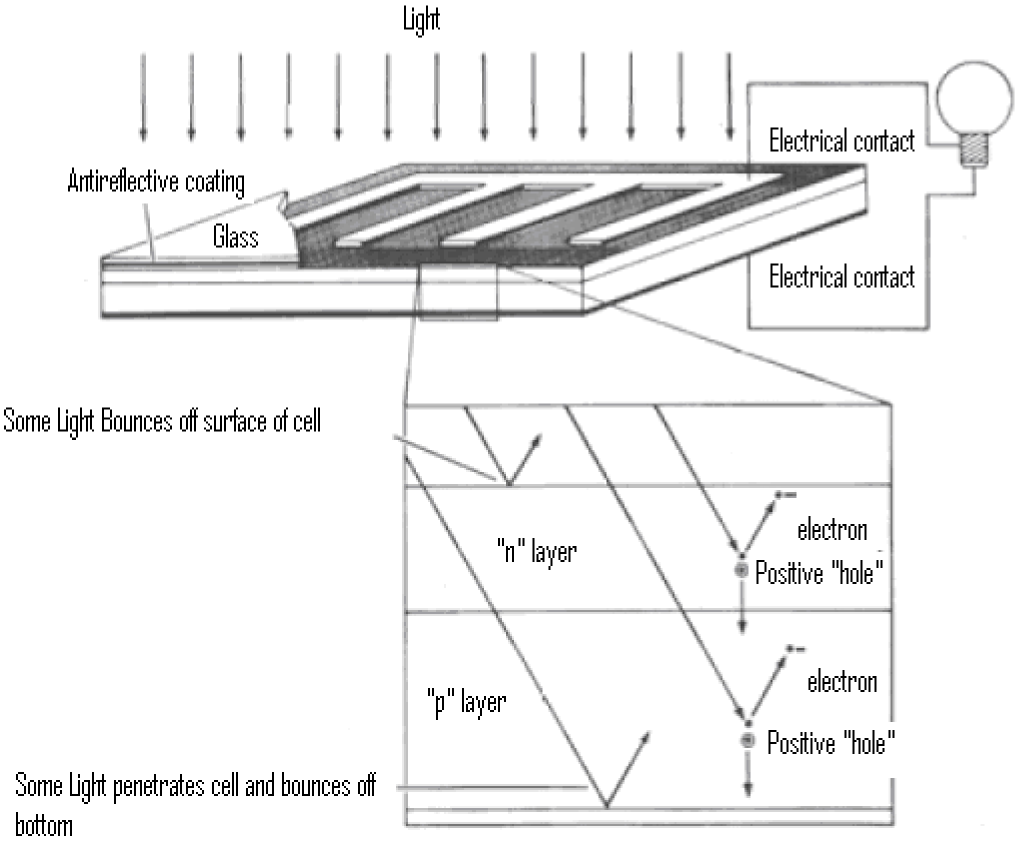
Information on Photovoltaics can be found from a host of sources. A convenient and reliable source is the US Department of Energy – National Center for Photovoltaics. Their website is http://www.nrel.gov/ncpv/

PHOTOVOLTAIC CELLS – STUDENT HANDOUT

A photovoltaic cell turns light directly into electricity.

Photovoltaic cells (also called PV or solar cells) are made of two ultrathin layers of silicon that are contaminated (or “doped”) by two different substances. One layer is called the “n” layer and the other is called the “p” layer. There is a slight electrical difference across the two layers—that is, one layer is more positively charged, the other more negatively charged.

When light hits the cell, it knocks electrons off atoms in both layers. Since there is a difference in charge between the layers, electrons flow from one layer to the other. When an electrical device is attached to the cell, creating a circuit, these electrons flow through the circuit, creating electricity.



OPTIONAL DAY AFTER 4

This activity is to be used if you elect to include a field trip to WPI as one of your activities, or simply if you want to introduce them to elements of an educational PV system. This could be completed either on the WPI campus or at your school. Being at WPI would probably enhance the experience as the students could possibly have the opportunity to interact with Photovoltaic systems first hand.

LEARNING OUTCOME: Students will learn the basic components of their solar electric system, how it generates electricity, and what information is provided to them (data) to understand how it works.

LESSON OVERVIEW: Students will be led through a step by step lecture to learn how WPI's solar electric system works (typical of educational solar systems), and answer questions in a worksheet to test their understanding.

GRADES: Varies, can apply to all grade levels

SUBJECTS: Integrated physics and chemistry, math

MATERIALS:

- Worksheet (included)
- WPI's educational PV system (will be present if field trip is chosen.)

Alternatively could use computer and Heliotronics' SunViewer software, or photographs of the installation.

PREPARATION: This section really does not have much value if it is taught independently. It is strongly recommended that students have been led through activities on Days 1-4.

TIME: 45 minute class period. Could be significantly longer and more enriching if WPI field trip is chosen

TEACHING THE LESSON:

1. Review the information provided in the System Description section below to understand how the school's solar electric system works and how the system's performance and output are measured.
2. Then have the students answer the questions in the attached Worksheet using all the information provided.

System Description

Worcester Polytechnic Institute has an electric generating system powered by the sun that provides electricity to the school.

The WPI solar electric system consists of 4 solar modules located on the roof of one of the residence halls (Morgan hall.) Each module consists of many different solar cells that are semiconductor materials capable of generating electricity in the presence of sunlight. Each solar module measures about 6.5 feet long by 4.5 feet high, and the entire system covers an area approximately 15 feet wide by nearly 10 feet long. These solar modules are similar to the solar cells that provide energy for solar calculators and other electronic devices, only they are much larger! They convert sunlight directly into electrical current, which is conducted along wires into the building. Inside the building, the current is conditioned to match the voltage and current type present inside the residence hall. The energy output from the system can then be used by WPI for lighting, computers, air conditioning, or any application powered by electricity. The solar electric system does not even come close to produce enough energy to power all the buliding’s needs, but it does reduce the amount of electricity the school needs to purchase from the electric company.

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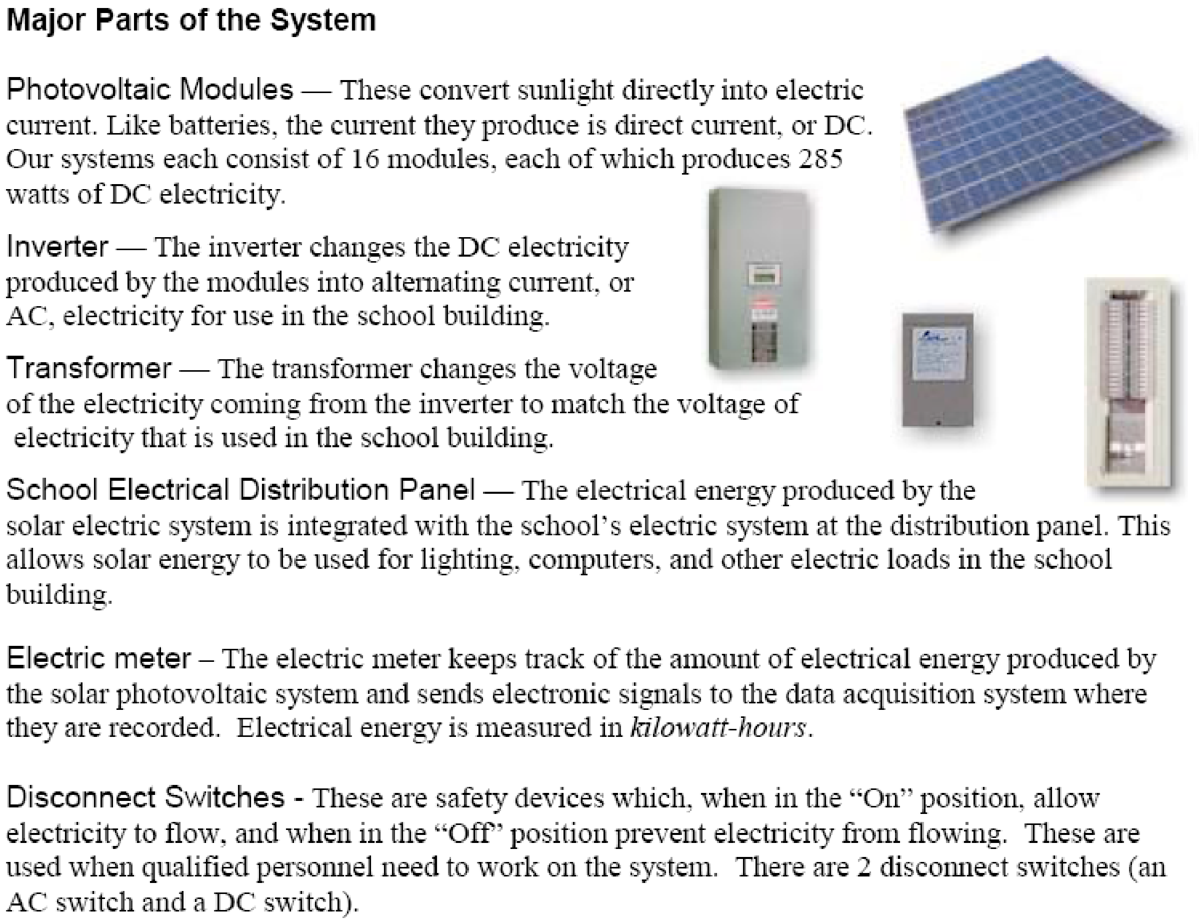


Major Parts of the System

Photovoltaic Modules — These convert sunlight directly into electric current. Like batteries, the current they produce is direct current, or DC. Our systems each consist of 16 modules, each of which produces 285 watts of DC electricity.

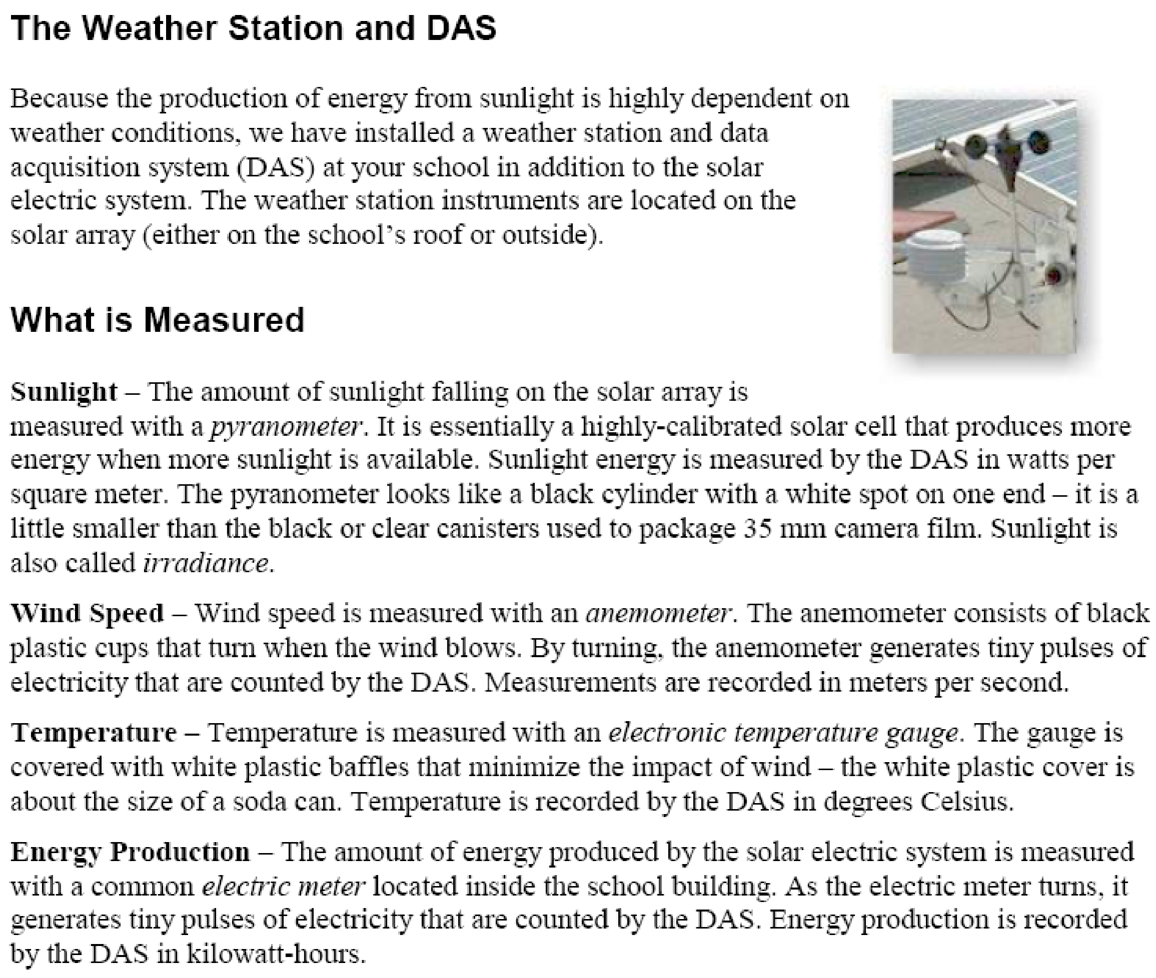
Inverter — The inverter changes the DC electricity produced by the modules into alternating current, or AC, electricity for use in the school building.

Transformer — The transformer changes the voltage of the electricity coming from the inverter to match the voltage of electricity that is used in the school building.

School Electrical Distribution Panel — The electrical energy produced by the solar electric system is integrated with the school’s electric system at the distribution panel. This allows solar energy to be used for lighting, computers, and other electric loads in the school building.

Electric meter – The electric meter keeps track of the amount of electrical energy produced by the solar photovoltaic system and sends electronic signals to the data acquisition system where they are recorded. Electrical energy is measured in *kilowatt-hours*.

Disconnect Switches - These are safety devices which, when in the “On” position, allow electricity to flow, and when in the “Off” position prevent electricity from flowing. These are used when qualified personnel need to work on the system. There are 2 disconnect switches (an AC switch and a DC switch).



The Weather Station and DAS

Because the production of energy from sunlight is highly dependent on weather conditions, we have installed a weather station and data acquisition system (DAS) at your school in addition to the solar electric system. The weather station instruments are located on the solar array (either on the school's roof or outside).

What is Measured

Sunlight – The amount of sunlight falling on the solar array is measured with a *pyranometer*. It is essentially a highly-calibrated solar cell that produces more energy when more sunlight is available. Sunlight energy is measured by the DAS in watts per square meter. The pyranometer looks like a black cylinder with a white spot on one end – it is a little smaller than the black or clear canisters used to package 35 mm camera film. Sunlight is also called *irradiance*.

Wind Speed – Wind speed is measured with an *anemometer*. The anemometer consists of black plastic cups that turn when the wind blows. By turning, the anemometer generates tiny pulses of electricity that are counted by the DAS. Measurements are recorded in meters per second.

Temperature – Temperature is measured with an *electronic temperature gauge*. The gauge is covered with white plastic baffles that minimize the impact of wind – the white plastic cover is about the size of a soda can. Temperature is recorded by the DAS in degrees Celsius.

Energy Production – The amount of energy produced by the solar electric system is measured with a common *electric meter* located inside the school building. As the electric meter turns, it generates tiny pulses of electricity that are counted by the DAS. Energy production is recorded by the DAS in kilowatt-hours.

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ADDITIONAL INFORMATION FOR TEACHERS

SOURCES FOR THIS ADAPTED ACTIVITY:

1. Watts On Schools. *Introduction To Your School's Solar Electric System.* Available at http://wattsonschools.com/pdf/wos-1.pdf

2. Heliotronics Inc., *Solar Learning Lab Users Guide*.

REFERENCES FOR BACKGROUND INFORMATION:

The most detailed information about WPI's installation can be found from Solar Team 2's project report. This report is available from WPI's library. Typical Installation information can be found at the website of Heliotronics Inc. http://heliotronics.com/products/prod_main.html

STUDENT HANDOUT [1]

Worksheet

Part A

Match the following PV system components on the left with the proper function on the right:

_______ Inverter
_______ Photovoltaic Module
_______ Electric Meter
_______ PV Cells
_______ Disconnects/Switches
_______ Photovoltaic Array
_______ Anemometer
_______ Datalogger
_______ Thermometer
_______ Transformer
_______ Pyranometer

a. Device that measures how much energy is being generated
b. Device that measures sunlight
c. A group of photovoltaic modules
d. Converts DC electricity into AC electricity
e. Device that measures temperature
f. Device that measures the wind speed
g. Increases (steps up) or decreases (steps down) the voltage
h. Made of semiconductor material that produces electricity when light hits it
i. Safety devices that immediately stop the flow of electricity
j. A group of photovoltaic cells
k. Device that measures and stores data output by the system

Part B- *Multiple Choice*

Solar Electric systems do which of the following?
a. Heat water b. Generate electricity

What type of electrical current do photovoltaic (PV) modules generate?
a. AC (Alternating Current) b. DC (Direct Current)

What type of electrical current is used in your school?
a. AC (Alternating Current) b. DC (Direct Current)

DAY 5

LEARNING OUTCOME: Students will learn about various topics related to Photovoltaic systems. Using software they will learn how much pollution is prevented by PV installations and how much energy is being generated by the panels. They will learn how to read a line graph and will understand that solar energy production is dependent upon the weather. Thus they will learn the key skills of observation, inference and validation that are an essential component of the scientific method and are needed to interpret data that constitutes most scientific results.

LESSON OVERVIEW:

Students will be led through SunViewer software, with particular emphasis being paid to the power generated and avoided emissions sections. Students will look at graphs of the power output (generated by the SunViewer software from Heliotronics) of a solar energy system and will make inferences about the weather. They will then compare the inferences they made about the weather with actual data of weather at that time and explain possible discrepancies

GRADES: Applicable to all grades that have been introduced to graphs.

SUBJECTS: science, math, social studies.

TIME: 60 minutes

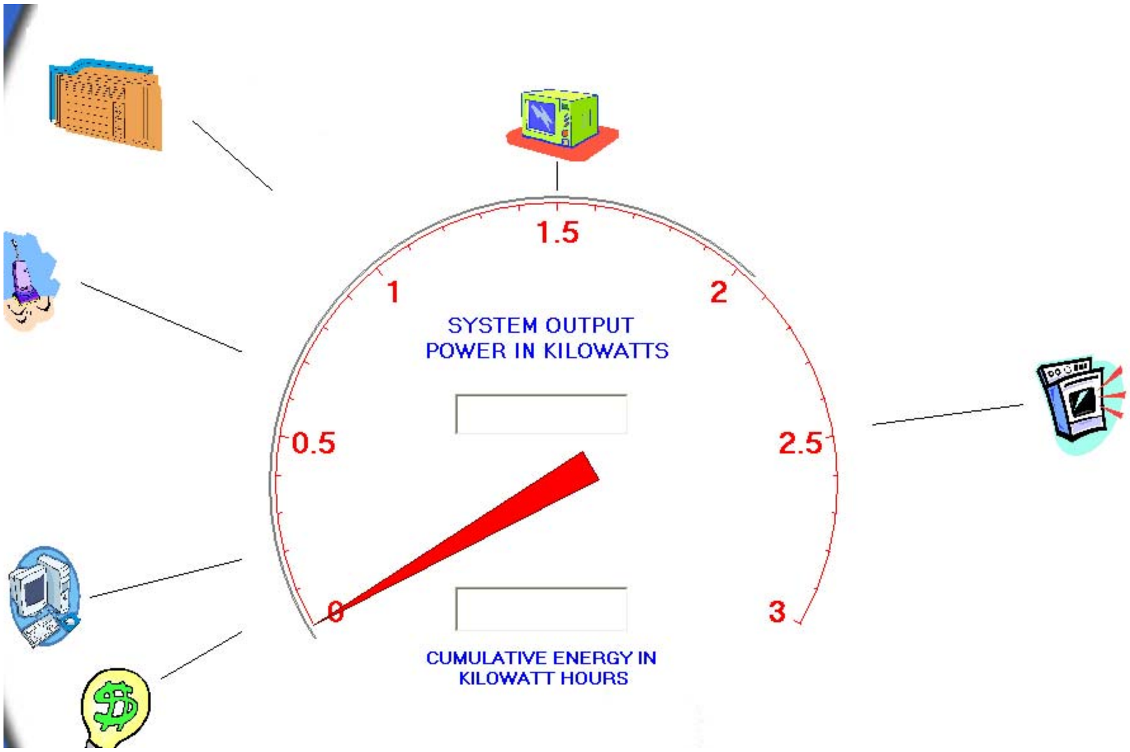
MATERIALS:

- Computer with Internet access or Heliotronics Inc. Data Acquisition System (DAS)
- SunViewer software and computer/s.

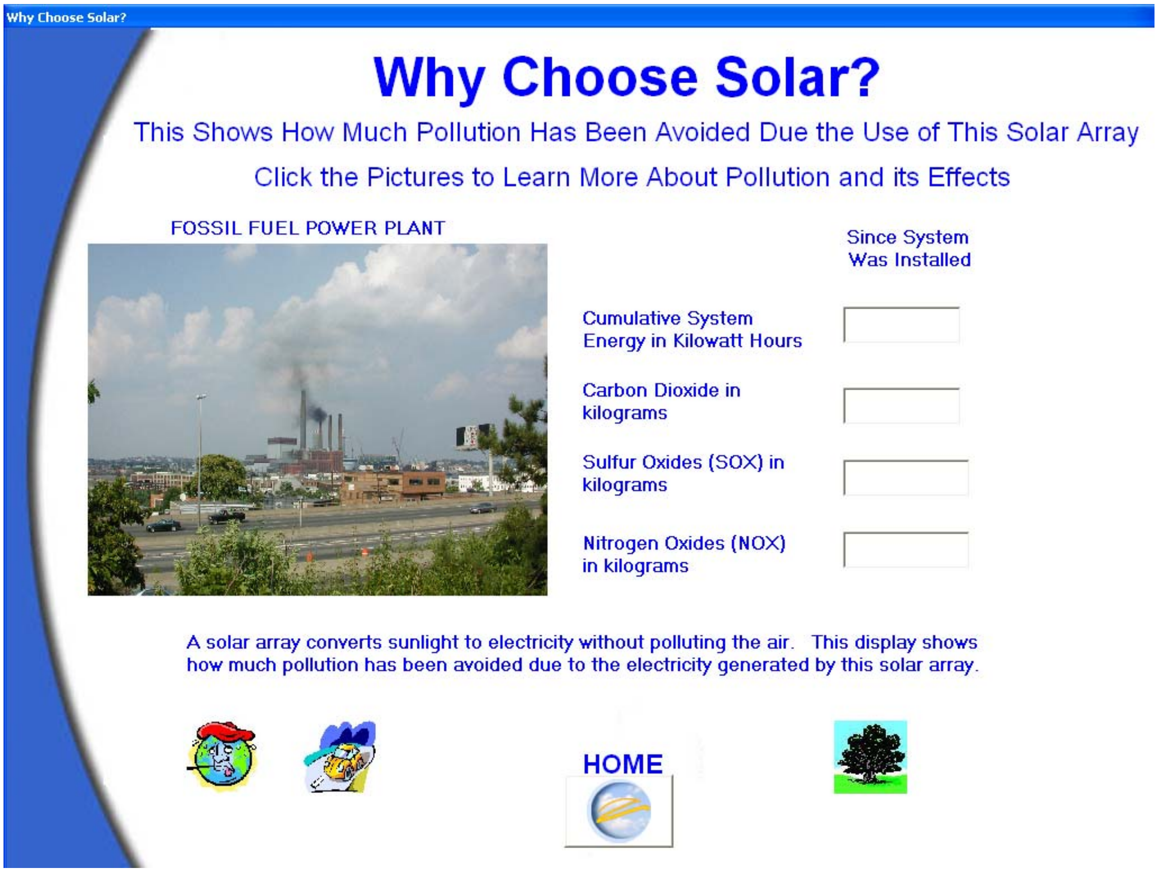
PREPARATION: Parts 1 – 4 of this educational packet

PROCEDURE:

1. Lead the students through the SunViewer software interface focusing primarily on the power/energy generated and the avoided emissions screens. Explain the importance and relevance of each of these displays



Power Generated by System



Why Choose Solar?

This Shows How Much Pollution Has Been Avoided Due the Use of This Solar Array

Click the Pictures to Learn More About Pollution and its Effects

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	

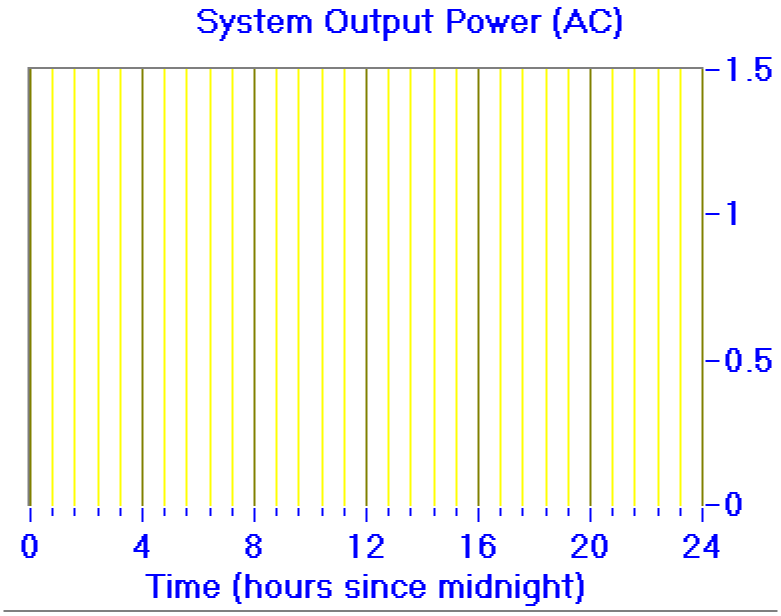
A solar array converts sunlight to electricity without polluting the air. This display shows how much pollution has been avoided due to the electricity generated by this solar array.

Avoided Emissions

2. Then conduct a discussion about the solar energy system at WPI, asking students to discuss what would happen on a sunny day, a partly cloudy day, and an overcast day.

3. Instruct students in how to make a chart of solar energy production over time.

4. Obtain and present to students a time-series plot of the power produced by the school's solar energy system over 3-7 days (this can be obtained from the DAS or the SunViewer software).



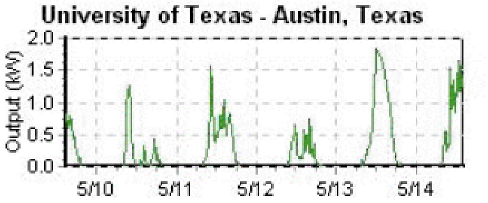
Plot of System Output Power over time

5. Ask them to make inferences about the weather during each day. The following questions can be used to guide students' thinking:
   - Was the day sunny, partly cloudy, or overcast?
   - Did the weather change at some point during the day? If so, how?

6. Directed the students to discuss their findings with the class. What do they remember about the recent weather? Does it match with what the data is showing

The performance of the solar energy system at any given time depends primarily on the amount of sunlight available to it. On bright, sunny days, the system gradually produces more and more energy throughout the day until the sun is directly overhead. A graph showing the energy production of the solar system (y-axis) over time (x-axis) on a sunny day will resemble a smooth, tall, bell shaped curve. On consistently overcast days, the curve will have the same width but will be much lower, showing that the system produced less energy throughout the day. And on partly cloudy days, with patches of clouds intermingled with bright sun, the curve will no longer be smooth, but instead will tend to be bumpy or spiky, showing that the system produces more energy during sunny periods and less energy during cloudy periods. This exercise is intended to give both teachers and students experience with connecting to the solar energy system with the DAS or with the SunViewer software. Graphs of the system's power output over the past several days (like the one shown in the example below) are available by either method.

Example 1. Solar energy production graph available from website (www.wattsonschools.com).



Using current graphs from the DAS or website, students can make inferences about the weather conditions on that day. In Example 1, above, the only day that appears to have been consistently sunny was 5/13, and even then the morning looks like it may have been overcast for a while before the sun came out. Energy production peaked at about 1.8 kW on this day. 5/10 had some bright sunshine in the early morning, and then became very overcast, resulting in almost no energy production for the rest of the day (though it appears there were two times when the sun poked through the clouds for a short while). 5/11 was a brighter day overall, but energy production still appeared spiky throughout the day, indicating a partly cloudy day. The highest energy output on 5/12 was only about 0.75 kW; given that on the very next day energy production reached about 1.8 kW, we can assume that the sun never really came out at all on 5/12, even though there were some periods when it was brighter than others.

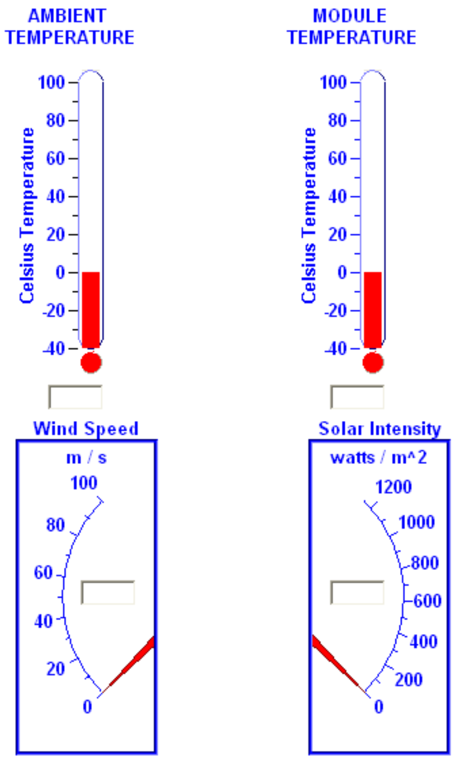
Students should be encouraged to discuss or write about each day on the plot in small groups. Students should be reminded that the graph is not a graph of weather or sunlight, but of the power production of the solar energy system. Although a plot of sunlight would look very much the same, an important lesson is that we are able to gain knowledge about something we are interested in (in this case, the weather) by observing other easily observable phenomena (solar energy output) that are related to what we are interested in (again, the weather).

When encouraged to make observations about the weather, students often will try to relate temperature to the energy production of the solar system. Although there is a relationship between temperature and energy production, it is not strong, and in fact the relationship is inverse (when other variables are controlled, the colder the temperature, the higher the energy production). It should at least be pointed out to students that graphs of energy output tell us far more about the amount of sunlight falling on the system than they tell us about the temperature (after all, there can be lots of sunlight on very cold days, too).

A variation on this activity is to assign different groups of students a chart from a different school (obtained from the website), and have each group find the needed chart on the website.

Note: Example directly sourced from Reference 1 for this activity

7. Now ask them to compare their inferences about the weather for those days and times with actual data from the weather monitoring section of SunViewer software. Ask them to explain possible discrepancies or flaws in their reasoning.



Weather condition measurements

ADDITIONAL INFORMATION FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY:

1. Watts On Schools. *Exploring Solar Energy Data.* Available at http://wattsonschools.com/pdf/wos-7.pdf

REFERENCES FOR BACKGROUND INFORMATION:

Information on the DAS and the data from the graphs and the information can be found in Heliotronics Inc.'s Solar Learning Lab™ User's Guide.

DAY 6

LEARNING OUTCOME: Students will learn how to calculate the instantaneous energy conversion efficiency of a solar electric system and contrast the energy conversion efficiency to that of other energy conversions.

LESSON OVERVIEW: Students will use data from the WPI solar electric system to learn how to calculate system efficiency. They will then verify their calculations against the efficiency data from the SunViewer software.

GRADES: 8-12

SUBJECTS: Math, Science

MATERIALS:

- Computer (with internet access or connected to solar electric system and SunViewer software)

PREPARATION: Parts 1-5 of educational packet

TIME: 45 minute class period.

TEACHING THE LESSON:

1. Explain that solar electric energy systems, like those we use, convert the sun's radiant energy directly into electricity. The question is how well does the solar electric system do its job? Or, more precisely: How much of the sun's energy is actually converted into usable electricity by the PV system? The answer to this question is best expressed by calculating the "efficiency" of the solar electric system. The efficiency reveals the percentage of sunlight that is converted into usable electricity by the solar electric system.

2. ***Sounds Easy, What Makes it Hard?***

   Efficiency is expressed as a percentage. To calculate efficiency, we need to divide the amount of energy actually produced by the amount of energy that could have been produced, then multiply the result by 100.
   As examples,
   Example 1: If you were trying to collect some water to add to your sandcastle, but the pail you were collecting water in had a leak such that from the time you took the water from the ocean to the time you got to your sandcastle only half the water was left in the pail, the efficiency would be calculated as:

   = (Amount of water left / Amount of water collected) x 100
   = (0.5 / 1) x 100
   = 50%

Example 2: If you ate only one hamburger for every two hamburgers you were given, your eating efficiency would be calculated like this:

(1 hamburger actually eaten / 2 hamburgers that you could have eaten) x 100
= (1/2) x 100
= 0.5 x 100
= 50%
So your eating efficiency in this example is 50%. You are only making use of 50% of the hamburgers that are available to you.

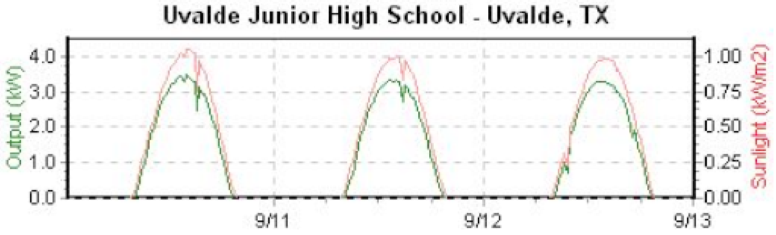
Calculating solar electric system efficiency is a little harder, because we have to figure out:
- How much energy the system actually produced at a certain time, and
- How much energy the system could have produced during that time.

3. Go through this sample efficiency calculation, with students in teams of 2 and you leading them.

Sample Efficiency Calculation

Data for use in this activity can be derived from the daily graphs of system performance available on the schools pages or from the raw historical data files available on the data page. We'll use examples of both in this activity.

For the graph data, we'll use the following graph from our system at Uvalde Junior High School that was made on September 13, 2000. At the peak hour on September 12, the graph shows that energy output from the Uvalde system was about 3.25 kW while the solar irradiance was about 1000 watts per square meter.



For the raw historical data, we'll use data from our system at Fayetteville High School. We'll look at the data at 1:00 pm on January 1, 2000. You can find and download this record and lots of other data on our data page. Here is the actual data record we will use:

```
1,1,2000,1,1300,19.25,861,2.356,3.279,2205,9.81
```

We are interested in the data on time, solar irradiance, and energy output. According to the data file description we provide on the data page, the time is given in the 5th field (1300, or 1:00 p.m.), the solar irradiance data is given in the 7th field (861 watts per square meter), and the energy output is given in the 9th field (3.279 kW).

To summarize, here are the data points we will use:

Location	System Output (kW)	Solar Irradiance (w/m2)
Uvalde	3.25	1000
Fayetteville	3.729	861

You can use any data from any system for this activity.

Since we are using just one data point or measurement for our calculation of efficiency, the efficiency value that we derive is called the "instantaneous energy conversion efficiency" of the system. The conversion efficiency may change over time or with different weather conditions, so the value we calculate will be valid instantaneously, or just for the time period from which our data is derived.

To calculate the efficiency at each school, we need to know two things:

- The amount of energy actually produced by the system, and
- The amount of energy that could have been produced by the system.

Step 1. Calculating the Amount of Energy Actually Produced by the System

The first part is easy, since we already know the amount of energy produced by the system just by looking at the graph or by reading the raw data. For Uvalde, the amount of energy actually produced is 3.25 kW; for Fayetteville, it is 3.279 kW.

Step 2. Calculating the Amount of Energy that Could Have Been Produced by the System

The second part, calculating the amount of energy that could have been produced by the system, is harder. How do we know how much energy could have been produced? Well, let's start with what we know.

We know that in Uvalde, the amount of solar radiation available to the system was 1000 watts per square meter. If we knew how many square meters of solar panels the solar electric system contained, we could calculate exactly how much sunlight energy was available to the panels. This would be the amount of energy that could have been produced by the system!

So all we need to know is how many square meters of solar panels are on the system at Uvalde. Every Watts On Schools system is the same and consists of 16 photovoltaic (PV) modules. According to the module specifications, each of these modules measures 1.892 meters in length by 1.282 meters in height. Let's multiply these dimensions to obtain the area of each module:

$$1.892 \text{ m} \times 1.282 \text{ m} = 2.4255 \text{ m}^2$$

But there are 16 modules, so the area of all the modules is:

$$2.4255 \times 16 = 38.8087 \text{ m}^2$$

Now, if we multiply the area of the modules by the amount of sunlight available for each system, we get the amount of energy that could have been produced:

Note: Example directly sourced from Reference 1 for this activity

For Uvalde,

$$38.8087\ m^2 \times 1000\ w/m^2 = 38{,}808\ \text{watts, or } 38.808\ kW$$

For Fayetteville,

$$38.8087\ m^2 \times 861\ w/m^2 = 33{,}414\ \text{watts, or } 33.414\ kW$$

Step 3. Calculating the Efficiency

Now we go back to our equation for calculating efficiency. We need to divide the amount of energy actually produced by the amount of energy that could have been produced, then multiply the result by 100.

So, for Uvalde, we have:

$$\begin{aligned}&(\ 3.25\ kW\ /\ 38.808\ kW\ ) \times 100\\ &= 0.0837 \times 100\\ &= 8.37\%\ \text{Efficiency}\end{aligned}$$

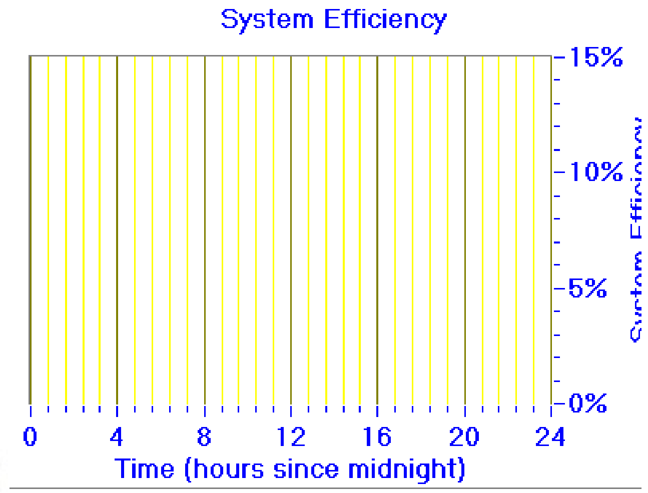
For Fayetteville, we have:

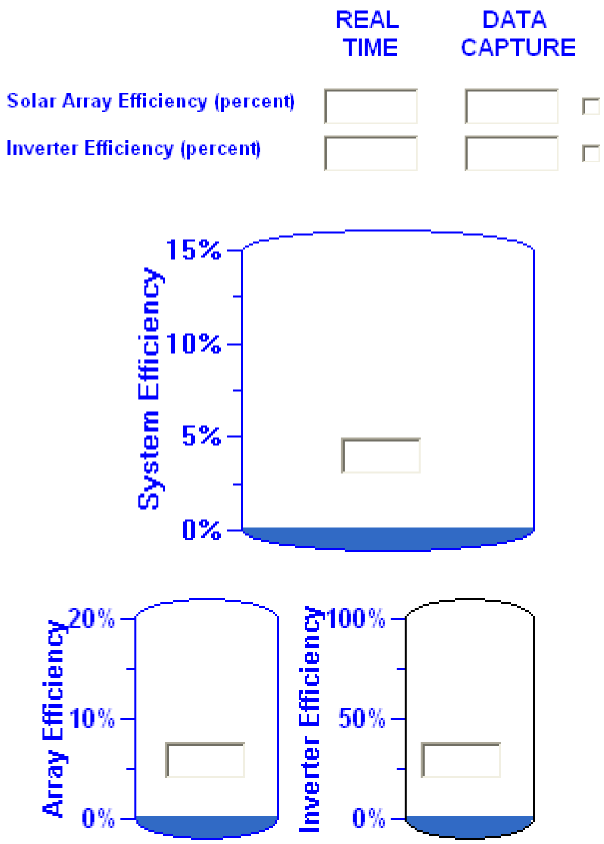
$$\begin{aligned}&(\ 3.279\ kW\ /\ 33.414\ kW\ ) \times 100\\ &= 0.0981 \times 100\\ &= 9.81\%\ \text{Efficiency}\end{aligned}$$

Note: Sample Efficiency Calculation directly sourced from Reference 1 for this activity

5. Based on the sample calculation, calculate the efficiency of the system for a day with very low temperatures and for a day with high temperatures, compare and discuss.

6. Compare the answers you obtain with the numbers and plots for efficiency from the SunViewer software. Have the students explain possible discrepancies





Efficiency from SunViewer Software

7. Review: If we lived in a perfect world, we would expect our solar energy systems to convert every bit of available solar energy into usable electricity. This would be 100% energy conversion efficiency. But we don't live in a perfect world, and it turns out that no conversions of energy from one form to another form can be done with such perfect efficiency.

ADDITIONAL INFORMATION FOR TEACHERS

SOURCES FOR THIS ADAPTED ACTIVITY:

2. Watts On Schools. *Calculating the efficiency of a Solar Electric System.* Available at http://wattsonschools.com/pdf/wos-5.pdf

2. Heliotronics Inc., *Solar Learning Lab Users Guide*.

REFERENCES FOR BACKGROUND INFORMATION:

Information on the efficiency of PV systems can be found at the US Department of Energy's website. http://www.eere.energy.gov/RE/solar_photovoltaics.html

DAY 7 - OPTIONAL

Additional Ideas, Projects and resources

This is a section in which students are informed about various existing solar projects and resources, so that they can continue to pursue their interest in solar energy and phototvoltaics if they choose to do so.

In a lecture and discussion based format students are pointed towards various existing solar programs and resources. At the end students are asked which programs seem most appealing to them and if they would like to attempt to participate in any.

We recommend one 45-minute class period to guide interested students

You could choose to present this material in any way you choose. We recommend that you read the through list of resources presented and decide which ones would be suitable to emphasize for your classroom.

RESOURCES:

Schools Going Solar (http://www.irecusa.org/schools/)

Many schools across the country are already equipped with solar energy systems in an effort to provide the benefits of sustainable energy to the school building and also to help the students augment their math and science studies. There currently exists a program called Schools Going Solar that considers bringing solar energy to schools an important first step to increasing the overall use of solar energy. The rationale cited on the website is as follows, "Schools make excellent showcases for displaying the benefits of solar energy. Students learn about solar energy, and then can educate their parents and other adult member of the community about these technologies." [39]

Schools Going Solar states that many of these projects in schools came about through the interest and impetus of a student and/or a teacher in the school. The Schools Going Solar movement and their website are intended to build a network – a community of people who can share experiences with solar energy in schools. Their hope is that teachers, students, community officials, and the general public should find the information contained in their website helpful in establishing a project.

The website is owned by the Interstate Renewable Energy Council (IREC)**.** The IREC was formed in 1980 and is a non-profit organization whose mission is to "…accelerate the sustainable utilization of renewable energy sources and technologies in and through state and local government and community activities."[39]

Members of the IREC include state energy offices, city energy offices, other municipal and state agencies, national laboratories, solar and renewable organizations and companies, and individual members. IREC works with many partners including the federal government, national environmental and municipal organizations, regulatory commissions, state-appointed consumer representatives, energy service providers, utility groups, universities and research institutes.

The Schools Going Solar website has a database of schools in Massachusetts where solar energy installations have been successfully integrated into curricula. The teachers and other personnel associated with the solar installations from these schools present a valuable resource for information and feedback.

The website also has an online monthly newsletter that publishes articles related to solar projects and their implementation in schools across the nation. This is a resource that can be used to stay in touch with developments all over the country.

Another section on the schools going solar website is a collection of tips to help establish solar facilities at a school. They state these tips are a product of experience with literally hundreds of school projects. These tips are presented below:

Overall

- Find at least one enthusiastic “champion.”
- Obtain buy-in up front
- Be sure the school’s custodial and maintenance staff are engaged and educated.
- Establish partnerships with business.
- Even with many participants, make sure that a single office or individual has project responsibility.
- Create community ownership.

Hardware Hints

- Choose an established, reliable solar contractor.
- Make sure the roof is not due to be replaced in the next few years.
- To get the most out of PV, be sure the school uses electricity as efficiency as possible.

Inside the School

- Provide teachers with a curriculum, lesson plans, and/or experiments.
- Make it easy for the teachers to teach solar energy.
- Be sure materials meet standards.
- Computer hook-ups and real-time date are great learning tools.
- An educational display brings the project to many.”

These tips are the product of numerous experiences, and can be looked to as guidelines for the establishment of similar facilities elsewhere. The schools listed in the database can also be contacted to get first hand advice and suggestions on establishing and subsequently operating and generating programs for these facilities.

Watts on Schools (www.wattsonschools.com)

Watts On Schools is a program by American Electric Power designed to bring solar power to schools in communities throughout Texas, Arkansas and Louisiana. Through Watts On Schools, AEP has installed nineteen solar energy systems at public elementary, middle, and high schools located within the service areas of three of their electric utility operating companies.

The rationale behind this program is as presented on their website below:

“Why provide schools with solar energy? Because the communities we serve are centered around their schools, and schools hold the key to educating not only children, but also families and entire communities about the benefits of solar energy.”

Each system is capable of producing enough energy each month to power a typical Texas home. Participating schools receive the energy produced by the systems for free, lowering the schools' electric bills every month. In addition, participating schools receive solar energy educational materials and conduct solar energy events on an annual basis.

This program is a direct result of AEP’s customers consistently telling them that they value clean, renewable sources of energy in their communities. AEP decided to respond to their customers' wishes by bringing solar energy closer to them through public schools.

It contains very useful information, downloadable data, activities and suggestions.

National Energy Education Development (www.need.org)

The NEED Project is a nonprofit association dedicated to promoting a realistic understanding of the scientific, economic and environmental impacts of energy, so that students and teachers can make educated decisions.

The NEED program includes curriculum materials, professional development, evaluation tools, and recognition. NEED teaches the scientific concepts of energy and provides objective information about energy sources - their use and impact on the environment, the economy and society. The program also includes information to educate students about energy efficiency and conservation, and tools to help educators, energy managers and consumers use energy wisely.

NEED provides curriculum materials, professional development, evaluation and recognition programs to help students prepare for the future. The energy industry faces labor shortages in the coming years. Energy choices and challenges will become increasingly complicated as the nation and the world balance the need for energy supply with the importance of increasing energy efficiency and conservation. The world energy market grows daily, with new players, new resources and greater challenges. The energy world is ever-expanding, and NEED exists to prepare future leaders, train teachers to teach energy from a balanced perspective, and to reach parents and community decision makers through energy outreach and education.

School Power Naturally (http://www.nyserda.org/schools/)

School Power....Naturally is an innovative program from the New York State Energy Research and Development Authority (NYSERDA) that is designed to educate New Yorkers about energy, and, in particular, the role solar electric power - photovoltaics, or PV - can play in providing clean energy for our homes, schools and workplaces.

The $2.1 million *School Power....Naturally Program* was offered to schools as part of NYSERDA's New York Energy $mart^{SM} Schools Program. Each of 50 schools, which were competitively selected in 2003, receives a solar energy and data collection system, worth about $24,000, for a school contribution of $1,500, or over 90 percent of the cost to the school.

All schools in New York can participate in *School Power...Naturally* by using the curricular materials and data - they are available on our website www.SchoolPowerNaturally.org to anyone.

Education is the heart of this program. We've teamed up with professional curriculum writers to create multidisciplinary materials to meet NYS education standards. These lesson plans for grades 5 through 12 describe creative, interactive ways for students to learn more about the sun and solar energy.

Students in 50 schools across the state are learning hands-on how PV works. Each of these schools is having a 2 kilowatt (kW) grid-tied PV system installed on its roof, as well as additional features to link the hardware on the roof with lessons in the classroom.

Students are discovering not only that a 2 kW system can meet about 25 to 30 percent of the energy needs of a typical home, but also how solar electricity works, and why it is an important option for producing clean, reliable and inexhaustible energy.

As another feature of this project, the 50 schools are being outfitted with instrumentation and educational software that provides computerized, real-time performance data on-site. Information is also posted on NYSERDA's website in 15- minute averages so that each PV school can monitor the performance of its system and the PV systems of other schools.

The most exciting feature of the program is that any school in New York can log on and use the data from any or all of the 50 schools, either alone, or in conjunction with the lesson plans available on the website.

This program also features *community education* - NYSERDA is helping the 50 schools host open houses in which members of the public can learn how they, too, can "go solar," and in some cases even tour the installation. In addition, the "Solar Buddies" program has each of them partnering with another school in its region for tours and educational activities.

It is all part of NYSERDA's commitment to help New Yorkers learn how to use the power of the sun at school and at home.

School Power....Naturally is a multiyear effort intended to continue through 2006. The 50 schools chosen to receive solar energy systems were competitively selected based on criteria that included a statewide geographical distribution mix, involving a mix of urban, suburban, and rural demographics. A large emphasis was placed on the action plan that was submitted by each entrant, showing how the school proposed to incorporate the solar energy systems into educational planning and community outreach. Eligible schools were limited to those contributing to the State's System Benefits Charge on the transmission and distribution of electricity throughout the State.

Solar Energy in Competitions

As evidenced by the success of programs like FIRST robotics and the FSAE collegiate design competition, competitions are a popular way to engage students in productive learning activity. This can be specifically applied to activities related to solar energy as most experts agree that competitions serve to spread awareness in an atmosphere that is exciting and conducive to self motivated learning. There are various competitions for college and high school student teams built around the use of solar energy. These programs were created to help promote and educate the usefulness of renewable energy technology. These competitions are intended to provide a greater understanding of solar energy technology, its environmental benefits and its promise for the future and, a "hands-on" opportunity for students and engineers to develop and demonstrate their technical and creative abilities. Some examples of such events are discussed below.

National Junior Solar Sprint (http://www.nrel.gov/education/student/natjss.html)

The U.S. Department of Energy's National Junior Solar Sprint (JSS) Program is a classroom-based, hands-on educational program for 6th, 7th, and 8th grade students. JSS student teams apply math, science, and creativity to construct model solar-powered cars and race them in interscholastic competitions hosted within their schools or within their states or regions. JSS began in 1990 as a single demonstration race and expanded to 10 regional competitions in 1991. The program now uses public and private sector support to improve education in middle/junior high schools across the nation. In recent years, the event grew to 83 host sites in 26 states involving 100,000 students and 15,000 teachers.

The primary goals of the JSS program are to:

1. generate enthusiasm for science and engineering at a crucial stage in the educational development of young people.
2. improve students' understanding of scientific concepts and renewable energy technologies; and
3. encourage young people to consider technical careers at an early age.

American Solar Challenge (http://www.formulasun.org/asc/)

The US Department of Energy [DOE] sponsors the American Solar Challenge, a 10-day solar powered car race from Chicago to Claremont, California; the longest solar powered car race in the world. Teams from universities must construct vehicles that can travel the 2,300 miles that are powered solely be the sun. Secretary of Energy Spencer Abraham states that, “The American Solar Challenge will advance renewable energy and electric vehicle technologies, promote educational and engineering excellence, and encourage environmental consciousness and teach teamwork”

Solar Decathlon (http://www.eere.energy.gov/solar_decathlon/)

The US Department of Energy, through its National Renewable Energy Laboratory [NREL] and Energy Efficiency Renewable Energy Network [EREN], has also created the Solar Decathlon contest for teams of college students. The purpose of the contest is to promote public awareness and future consideration of renewable energy in the design of homes. The goal of the Solar Decathlon is to design and build an entire house, which will be powered by only solar power, in eight days. These solar houses will not only provide a working demonstration of the possibilities of solar power but may also spawn design innovations. This contest also integrates the schools of architecture and engineering and promotes the thought of solar power integration in common homes.

These competitions are examples of how solar and renewable energy is being brought to students nationwide. They provide an insight into the current view of renewable energy and an example of a successful method of bringing renewable energy into education at various levels.

Renewables Are Ready: A Guide to Teaching Renewable Energy in Junior and Senior High School Classrooms

Available at: http://www.ucsusa.org/documents/Renewablesready_fullreport.pdf

This manual, created by the Union of Concerned Scientists [UCS], is a teacher's guide and is intended to help teachers introduce their students to renewable energy technologies and the political and economic conditions necessary for their implementation. It contains a set of classroom activities with detailed instructions, an expanded list of project suggestions, ideas for student-led education and action campaigns, and a bibliography of resources for further investigation.

It includes detailed descriptions of activities that can be designed and explains their educational value. The activities included are multidisciplinary and investigatory. Most of the projects emphasize group work and cooperative learning. The activities can be taught independently or as a unit. The manual suggests that teachers use them in the context of a comprehensive unit on energy and energy-related environmental issues. Several resources on energy and the environment are listed in the bibliography.

To quote the preface of the manual it “…is intended to help school teachers provide their students with an understanding of the technologies and the political and economic systems that must be understood to work towards a clean, sustainable energy future.”

Energy for Keeps: Electricity from Renewable Energy

Available at: http://www.energyforkeeps.org/

Energy For Keeps: Electricity from Renewable Energy is a school textbook currently being used in California's public school system with the aim to educate children in grades 6-12 about renewable energy technologies like solar, wind, geothermal, hydroelectric, ocean energy, and hydrogen.

The publication of the 233-page book was prompted by a competitive grant from the state's Energy Commission. The book is published by the group Educators for the Environment [EE]. To insure objectivity and accuracy, the publishing house consulted over 75 technical and educational experts from all over the U.S. The CEO of the EE group says that the "…next step is to publish a shorter version – one without the extra information for teachers – as a sort of handbook for everyone who uses electricity; then we'd like to publish a version that includes energy data for all 50 states". The group cites positive reviews of the book, and it is currently being looked at for integration into curricula in other states, specifically Hawaii.

Appendix P: PCET Satellite program - Professional Development Program Info

June 28th

PCET SATELLITE PROGRAM: WEEK 1

	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5
8:00	PCET Overview: Projects, speakers, etc.	TEMI Mentor Presentation/Discussion	TEMI Mentor Presentation/Discussion	TEMI Mentor Presentation/Discussion	Field Trip Day: Plastics Engineering Speaker during Field Trip
9:00	Introduce Someone Else	Environmental Engineering Speaker	Accoustics Speaker	EE/Windpower/Renewable Resources Speaker	
10:00	Minorities in Engineering Speaker	Pringle Shipping Activity	Timing Device Activity	Coffee Stirrer Construction Activity	
11:00	Card Tower Activity				
Lunch	Lunch	Lunch	Lunch	Lunch	
1:00	working Tour of WPI	Design Process with "Renewable Resources": Research the Problem	Design Process with "Renewable Resources": Develop Solutions	Design Process with "Renewable Resources": Select a Solution	
2:00	Design Process with "Renewable Resources" Identify Problem & Constraints	Intro/Start Capacitor/Windchimes Project	Work on Capacitor/Winchimes Projects	Finish Capacitor/Windchimes Projects	
3:00	Presentation of Project Descriptions				
4:00	TEMI Mentor Presentation/discussion				
4:30		Discussion Bob, Tim, Richard V.	Discussion Bob, Tim, Richard V.	Discussion Bob, Tim, Richard V.	

PCET SATELLITE PROGRAM: WEEK 2

		DAY 6	DAY 7	DAY 8	DAY 9
8:00	July 4th Observed Holiday	TEMI Mentor Presentation/Discussion	TEMI Mentor Presentation/Discussion	TEMI Mentor Presentation/Discussion	TEMI Mentor Presentation/Discussion
8:30		Coffee Stirrer Testing			
9:00		Assistive Technology Speaker	Aerospace Engineering Speaker	Biomedical Engineering Speaker	Civil Engineering Speaker
10:00		Larry Bob's Blocks/Water Quality Testing	Solar/Fuel Cell Activity??	NEED ACTIVITY	Cement Structures Activity
11:00					
Lunch		Lunch	Lunch	Lunch	Lunch
1:00		Design Process with "Renewable Resources": Construct a Model	Design Process with "Renewable Resources": Test/Evaluate	Design Process with "Renewable Resources": Share your Solutions	Design Process with "Renewable Resources": Redesign
2:00		Intro/Start Assistive Tech/Water Filter Projects	Work on AT/Water Filter Projects	Work on AT/Water Filter Projects	Finish AT/Water Filter Projects
3:00					
4:00					
4:30		Discussion: Richard S, Luis	Discussion: Richard S, Luis	Discussion: Richard S, Luis	Discussion: ALL

Appendix Q: Professional Development Program Guide

Design Process with Solar Energy Professional Development Program Guide

Written by WPI Solar IQP Team 2
Devin Brande
Michael LaBossiere
Sid Rupani
Ye Wang

Table of Contents

1 Introduction

The purpose of this guide is to provide the information necessary to conduct a professional development program on the design process using solar energy as the basis for the design. The program is divided into eight sessions, each of which will last about an hour. The goal of the program is to provide teachers with a basic background in solar energy emphasizing the use of the design process. The program progresses through this basic outline:

- Discission 1: Identify Problem and Constraints
- Discussion 2: Research the Problem
- Discussion 3: Develop Solutions
- Discussion 4: Select a Solution
- Discussion 5: Construct a Model
- Discussion 6: Test/Evaluate
- Discussion 7: Share Solutions
- Discussion 8: Redesign/Wrapup

The first four discussions will each consist of a short lecture to provide information and guidance, and then some time will be devoted to allow the groups to pursue their own tasks. The last four discussions will be mostly spent with the teachers working together with their groups to implement solutions they have devised. The last discussion is especially important, because this is the discussion that the teachers will be given packages to bring back to their schools and, if they choose, use to teach lessons to their students on solar energy. It is crucial that the teachers know how valuable these lessons can be, especially if it sparks an interest in a few students who want to pursue even more knowledge.

2 Program Sessions

This section will outline each of the eight discussions of the program in greater detail. This document is not meant to be a hard and fast rulebook that must be followed to the letter. It can be followed, or it can be adapted to the particular needs of whoever is running the program. Different resources may be available, or the program could be adapted to a group other than teachers. This is simply a guide that will help direct efforts in the right direction.

2.1 Discussion 1: Identify Problem and Constraints

The purpose of Daiscussion 1 is to introduce the teachers to the problem being addressed, and give a basic outline of what the process will be. This discussion should progress as follows:

- Divide teachers into small groups (3 or 4 per group is good). This is because the design process is much easier to coordinate in small groups, rather than in a group of 20 or 30 people. It also makes it easier for everyone to give their input on the problem.
- Talk with the group about energy and photovoltaics. The basic information that should be covered is:
    - Fossil fuels and nuclear power accounted for 89 percent of the electricity generated in the US in 2001
    - Nuclear waste is difficult to dispose of safely, stays radioactive for a very long time.
    - Fossil fuels endanger environment through mining, waste disposal, and vulnerable delivery systems (such as oil tankers).
    - Fossil fuels are non-sustainable due to finite reserves
    - Average household consumes about 1-2 Kilowatts (1000-2000 Watts)
    - Replacing conventional fuels with clean, renewable sources can reduce reliance on non-renewable sources.
    - Solar panels could partially or completely replace grid-generated electricity.
- Additional information can be added if it is relevant.
- Give the problem: Design a PV system for a typical Worcester residence (house or apartment building) that will produce at least 50% of the power needed by that residence. If doing a house, assume about ½ acre of land. If doing an apartment building, assume little to no land, but a good amount of roof space, either flat or slanted.
- The rest of this discussion should be devoted to discussion among the entire group and/or within the individual groups. Focus on what the problem is, and what constraints are placed on possible solutions (cost, size, weight, etc.)

2.2 Discussion 2: Research the Problem

The purpose of this discussion is to do some research on photovoltaic systems, particularly ones intended for use on residential buildings. One good way to do this is to use a projector connected to a computer and perform some Internet searches on the subject. This should be demonstrated at first if any teachers are unfamiliar with Internet searching. The point of this is not only to get some information, but also to involve all of the teachers in the research process. If the facilities are available, teachers could even separate into their individual groups and do research on their own. Suggest that teachers with the Internet available at home spend some more time researching the subject, and bring notes or printouts of their findings to share with their groups. Give example research questions (shown below) to help give ideas on what to research.

Suggested resources:

http://www.google.com – Very good Internet search engine
http://www.massenergy.com - Massachusetts Energy Consumers Alliance, helps provide PV installations to Massachusetts residents and schools
http://www.mtpc.org/RenewableEnergy/index.htm - Massachusetts Technology Collaborative renewable energy information.

Questions to consider:
How much energy do solar panels generate? Consider size, angle, facing direction, shading…
How much does a solar installation cost? How does price relate to the kWh rating of the installation?
What incentives are available to residential customers who want to install solar panels?
What procedure do homeowners need to go through to get a solar installation put up on their home?

Materials needed:

Projector and computer with Internet access

2.3 Discussion 3: Develop Solutions

By now, the teachers should have a firm grasp of what the problem they are addressing is, and some background information on photovoltaics. Have them restate the problem to reinforce this concept. Now it is time for them to do some brainstorming on possible solutions to the problem. A Powerpoint presentation is provided. This presentation outlines why brainstorming is a good idea, and gives an example brainstorming method that works well in small groups, the Idea Trigger method. Other methods can be substituted if desired. The presentation should last no more than 15 minutes, after which the teachers should ask any questions if they have any, then go to work on their brainstorming. Be sure to emphasize that brainstorming should be unhindered by any criticism. All ideas are valid, and seemingly crazy ideas could spark another idea in someone's head that could be very good.

Materials needed:

Projector and computer with Powerpoint
Lots of paper to write ideas on
Pencils or pens

2.4 Discussion 4: Select a Solution

After producing as many ideas as possible, it is time to select one of them based on some design criteria. The method which will be used to do this is a value matrix. The Discussion 4 Powerpoint presentation contains a sample value matrix, as well as the procedure that should be followed. The value matrix can be adapted to make it simpler if desired. For example, the ranges for evaluating each criteria could be replaced with a simple "Yes/No" or "1/0" scheme. The main point to get across on this discussion is that decision making is an inherently subjective process, but this value matrix method is helpful for making the process as objective as possible and coming up with a numerical representation of the quality of a solution. Once the presentation is completed, let the teachers go to work producing their own value matrices within their groups.

Materials needed:

Projector and computer with Powerpoint
Paper and pencils

2.5 Discussion 5: Construct a Model

From this discussion forward, the program will be largely unstructured. Teachers will work together with their groups to work towards a final solution to the problem. On Discussion 5, their goal will be to construct a model to represent their chosen solution. Since it is impossible to actually go out and build a complete PV installation in an hour, a smaller-scale solution needs to be used. One good example is a kit from Lego that includes small PV panels. Whatever solution ends up being used, instruct the teachers to produce a model that represents their chosen solution as accurately as possible. Another good idea is to have them draw a diagram of a full-scale version of their solution.

Materials needed:

Model building kits
Poster paper
Pens, markers

2.6 Discussion 6: Test/Evaluate

This discussion will be devoted to testing and evaluating the chosen solutions. Teachers should thoroughly and objectively go over their designs and evaluate how well they fit the criteria they chose. The testing will be mostly theoretical, since the models they are building are not full-scale.

After testing, have the teachers review the design steps used so far.

2.7 Discussion 7: Share your Solutions

Once all of the groups have built and tested their solutions, it is time for the group as a whole to come back together and share solutions. Let each group come to the front and give a short explanation of their model and how it provides a good solution to the problem, as well as any tradeoffs they had to make. Allow the other groups to give suggestions and feedback on the solutions given.

2.8 Discussion 8: Redesign/Wrapup

On this last discussion, the groups should take the suggestions given to them during the presentation on Discussion 7 and make any changes they think would improve on their design. Make sure they keep track of the changes they make, and why they think they are good changes.

After the redesign is finished, it will be time for the wrapup portion. Be sure to provide every teacher with copies of the educational activities developed by WPI Solar IQP Team 2, with the suggestion that they take them back to their students and use them. Also be sure to mention the installation on the roof of Morgan Hall, and go to the website below to show them pictures and information related to the installation.
Morgan Hall installation pictures: http://[to be determined]

Materials needed:

Projector with computer and Internet access
Copies of WPI Solar IQP Team 2 educational modules

3 Conclusion

At the end of this program, the teachers should have a good understanding of the reasons why renewable energy is an important topic, and why photovoltaic installations are a good possibility for reducing consumption of fossil fuels. Through this short design process, they should have gained the knowledge and skills necessary to go back to their respective schools and speak knowledgeably about solar energy. By providing the educational modules to the teachers, chances are at least a few students will become interested in solar power, and pursue more knowledge on their own.

Appendix R: Environmental Aspects of Alternative Energy (An Independent Study Project Report by Nicholas Seifert)

Environmental Aspects of Alternative Energy

By: Nicholas M. Seifert

ISP: JIB-0404
D-Term, 2004

In Fulfillment of a Self Designed Minor in The Environment and Technology

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Table of Figures

1 – Introduction

Today, expansions in all areas of technology continue in the United States. The U.S. excels in development of technologies from toasters to pharmaceuticals. A necessary component of expansion of any type is energy. Increased awareness about the impact human actions have on Earth has caused an increasing demand for sustainable energy technologies. One of these technologies, windmills, has been around for hundreds of years; others, solar panels and fuel cells to name two, have been around and usable for only a few decades. If development and expansion is to continue in the way U.S. citizens, and increasingly world citizens, have grown accustomed to a shift towards sustainable technology is imperative. However, before making that shift it is important to understand the consequences. If Henry Ford had known that the automobile would eventually threaten all life on Earth would he still have created it? Similarly, it is necessary to understand all costs associated with a shift towards a sustainable energy source.

This report examines the “cradle to grave” impact of a photovoltaic (PV) array. This means that all aspects of the life of these PV panels are considered, analyzed, and quantified as much as possible to establish its associated costs. These costs are not solely financial, but ecological as well. As much as possible it details the processes involved in mining the materials necessary for mass production, which for most panels currently produced are silicon, and phosphorous and boron for doping. The manufacturing process required to create the finished product. For PV arrays that are installed a benefit analysis is presented detailing how much power is generated over its lifetime, the pollution it is preventing, and other important costs and factors. Lastly, an examination of what happens to these PV panels once they have become obsolete was performed and its results discussed.

The collection of the information mentioned above facilitated an informed analysis of the benefits of photovoltaic arrays. Though it is nearly indisputable that solar technology is a clean way to generate electricity it is important to ask “at what price?” If the ecological impacts outweigh the social benefits, this technology has been falsely dubbed “clean”, if not this report only emphasizes the reasons for the transition. This is an essential piece of research that is being conducted at an opportune time. A time when the citizens of Earth still have the luxury of choosing their energy sources based solely on financial cost, not their ecological impact. This information will help to determine which technologies should be implemented when this luxury is no longer an option.

2 – Background Information

2.1 – A Brief History of Photovoltaics

Though the focus of this report is on the cradle to grave impacts of photovoltaics it is always important to understand the history of a technology. This history can often put things into perspective and provide insight into future developments. The history of solar photovoltaics dates back to 1838 when physicist Edmund Becquerel published observations about the photovoltaic effect[1]. These observations remained as theory until the 1870's when the effect was studied in various solids, including selenium. This led to the development of selenium cells with an efficiency of 1-2%[2]. Little further development was made until the 1950's when Bell labs technicians discovered the light sensitive properties of silicon doped with impurities. This led to the first development of silicon photovoltaic panels with an efficiency of 4-6%. Photovoltaics received credibility when NASA successfully used them in the Vanguard space satellite to power its radio. The utilization of PV technology in space applications has continued to this day, and has even led to contemporary development of panels with efficiencies greater than 25%. Due to the high cost of manufacturing, as well as inefficiency, PV panels saw little use or development beyond high cost applications until the 1970's. Rising energy costs sparked renewed interest in the technology, which spurred investments into research that continues to this day. The cost of generating PV panels has dropped 15-20 fold in its history, and at least 5 fold occurring in the last 20 years[3]. In the past 20 years the

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[1] http://www.bigfrogmountain.com/solarhistory.htm
[2] http://www.sandia.gov/pv/docs/PVFOverview.htm
[3] http://www3.interscience.wiley.com/cgi-bin/fulltext/70001636/PDFSTART

efficiency of crystalline silicon cells has increased by 50%, as the figure below illustrates. This would seem to indicate that further efficiency developments could be produced using silicon doped panels, which would be advantageous from an environmental standpoint. This topic is discussed in more detail in the section titled "Material Considerations".

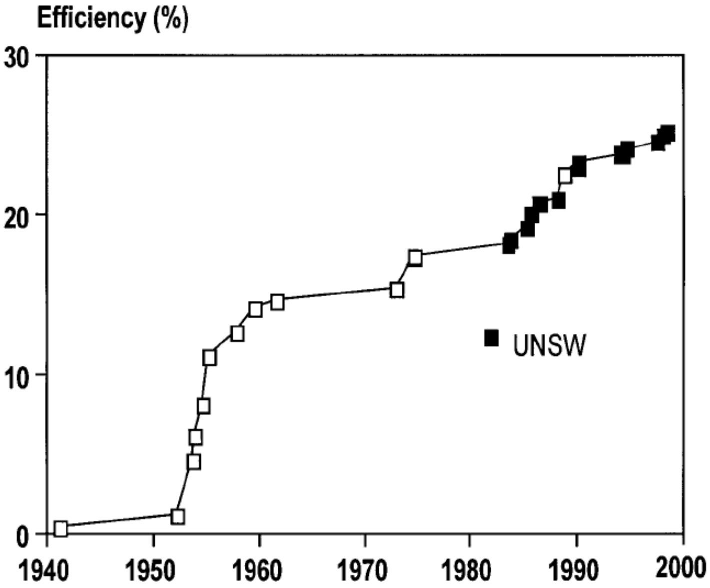

Figure 1: Plot of photovoltaic panel efficiency versus time[4]

2.2 – How photovoltaic panels work

PV panels work by taking advantage of imperfections in silicon and other materials. These imperfections can be combined with several other components to induce a current, and generate power. One of the most common materials used in the generation of power is, as previously mentioned, silicon. For the purpose of this discussion I will only address silicon. It should be understood however, that other materials can be used with equal, and sometimes greater, success. Some new

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[4] http://www3.interscience.wiley.com/cgi-bin/fulltext/70001636/PDFSTART

technologies, and many experimental ones, use different materials with great improvements in efficiency.

There are two types of silicon that are used in the construction of most PV panels, what are referred to as N-type, and P-type. These names refer to the positive or negative nature of the material. N-type has an extra electron, while P-type is short one electron. Silicon can be found with certain impurities in nature, or it can be "doped" to create the impure materials needed for PV panels. N-type can be created by doping silicon with phosphorous, while P-type is created by doping silicon with boron[5]. This is useful because when these two types of silicon are put together an electrical field is formed. This electrical field essentially acts as a diode, allowing electrons to flow only in one direction. When sunlight strikes these panels its photons free electron-hole pairs, which causes a current to flow. This current, and the voltage created by the electrical field of the different types of silicon creates power.

This becomes useful when you place these materials into a cell, and connect several cells into a panel. These cells are formed by wafering thin films of N-type, called the emitter, and P-type, called the base, on top of a metal backing. Electrical contacts are placed on the top of the silicon wafers, and typically consist of a thin conductive grid. This grid needs to allow as much sunlight as possible to contact the cell. An anti-reflection coating is applied to the top surface of the emitter to prevent loss of usable energy. Glass is then placed over this assembly and sealed to the housing of the panel. A diagram of the layers of a cell can be seen below.

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[5] http://science.howstuffworks.com/solar-cell.htm/printable

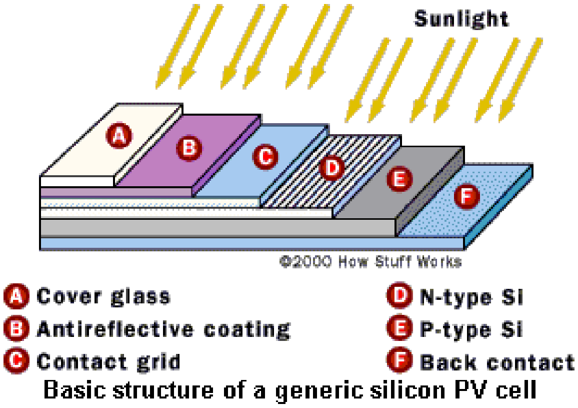

Figure 2: Illustration of PV panel assembly levels[6]

Unfortunately, the picture the above text paints isn't quite as pretty as the actual situation. Several things must be mentioned which are an essential part of performance and operation of PV panels. The power density of sunlight is around 1350 W/m^2 outside of the earth's atmosphere, and about 1000 W/m^2 on the ground[7]. Most of this energy cannot be captured by PV panels. In fact, most contemporary panels are between 10% and 15% efficient[8,9]. Part of this efficiency loss stems from the fact that not all of the photons that come into contact with the panel have the correct energy. The energy needed to knock an electron loose is called the "band gap energy". These different energy levels are due to the fact that light has different wavelengths, of which visible light is only a small part of the spectrum. This efficiency can be improved upon by utilizing two or more different layers of PV which operate at different band gap energies. This type of panel is called a "multijunction" panel, and is utilized by organizations such as NASA, as well as satellite manufacturers. An efficiency of 34% has been obtained by the National Renewable Energy Laboratory by using a multijunction panel consisting of

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[6] http://science.howstuffworks.com/solar-cell.htm/printable
[7] Solar Cells, Page 1
[8] http://www.windsun.com/PDF_Files_Solar/SP150A.pdf
[9] http://www.bullnet.co.uk/shops/test/siemens.htm

three layers: Gallium Indium Phosphide (GaInP), Gallium Arsenide (GaAs), and Germanium (Ge)[10]. This increase in efficiency has a very high production cost, which means that it is only feasible for high tech applications with large budgets, such as space devices.

2.3 – Material Considerations

Several materials have been mentioned in connection with solar panels. Of these the most common for low-cost commercial applications are silicon with phosphorous and boron. Silicon is the second most common element on earth after oxygen[11]. It is very common in various forms and is highly inert. Health problems caused by exposure to silicon are typically caused by long term exposure to finely powdered dust. Boron is not considered a toxic compound and requires no special handling considerations. Phosphorous has fairly serious health risks which will be discussed later. Gallium Arsenide is a compound consisting of gallium and arsenic, of which arsenic is considered a toxic compound[12]. Germanium also has certain toxic effects on some bacteria, as well as low toxicity for mammals[13]. Little information about the toxicity of indium could be found. The phosphorous used in GaInP is actually considered a poisonous element, with an average dose of 50mg being fatal[14]. Of these materials, however, gallium seems to be one of the least offensive, with little to no indication of toxicity. Other materials used in experimental applications include Copper Indium Diselenide, and Cadmium Telluride.

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[10] http://www.nrel.gov/ncpv/higheff.html
[11] http://en.wikipedia.org/wiki/Silicon
[12] http://en.wikipedia.org/wiki/Gallium_arsenide
[13] http://en.wikipedia.org/wiki/Germanium
[14] http://en.wikipedia.org/wiki/Phosphorus

Further development of silicon is also taking place: single crystal, as opposed to multi-crystalline, silicon cells have been found to reach 24% efficiency[15]. Due to manufacturing costs most of these materials are not realistic for commercial production of solar cells.

2.4 – Future PV Technologies

PV use is becoming increasingly prevalent as the cost of panels drops. A significant increase in efficiency of PV cells in combination with the development of a cost effective manufacturing process would stimulate their use to levels possibly comparable to conventional power generation technologies like coal and natural gas. Development in new areas may make this possible. Between 20-40% of the cost of traditional silicon PV panels comes from the silicon. Even though silicon is relatively abundant, it is costly to produce it purely, and in high volume[16]. A new relatively new technology that alleviates this problem is thin film PV panels, which are discussed below. This means that if the efficiency of thin film technologies, presently around 8%, can be increased this would result in decreased overall cost. An additional technology that has been paid little attention is solar concentrators. These are especially effective when used for passive solar applications, but have received little attention for active solar applications. Solar concentrators work by focusing a large amount of sunlight, a large area, into a small area. This is accomplished using Fresnel lenses, which have concentric rings of prisms around a magnifying lens[17]. These concentrators are able to bolster the

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[15] http://www.solarexpert.com/pvbasics2.html
[16] http://www.pv.unsw.edu.au/info/thininfo.html
[17] http://www.qrg.nwu.edu/projects/vss/docs/Power/1-how-do-solar-concentrators-work.html

efficiency of commercially viable silicon PV panels to around 20%. They can have an even greater impact on the cost per kWh of higher efficiency panels[18].

Thin film PV panels hold potential as a low-cost alternative to traditional panels. The materials used in their construction are similar, silicon being a major component. These thin film panels have several advantages, fabrication is relatively simple and requires low temperatures, little material is used, and high voltages can be easily obtained. The main problems with thin film panels is that their production cost is still high, they need to become more reliable over a longer period, and their efficiency needs to be improved[19]. This is illustrated by the figure below.

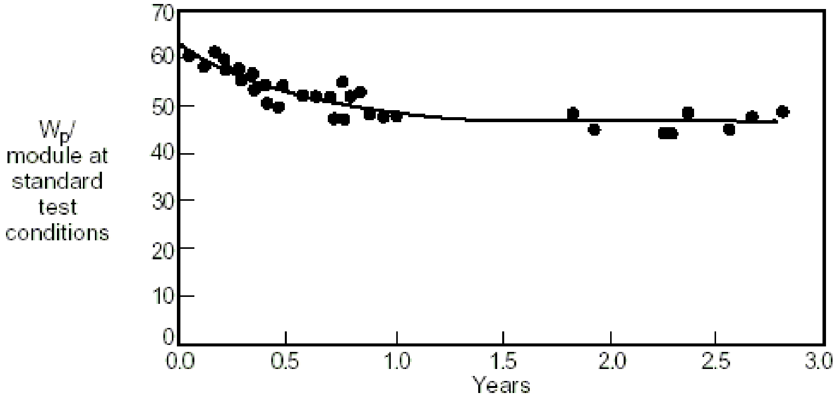

Figure 3: Peak Watt (Wp) production versus time[20]

2.5 – Environmental Considerations

The term "world community" has been coined in recent decades and is especially applicable to several areas of contemporary life. Information sharing occurs on a global scale nearly instantaneously with the use of the World Wide Web and the internet. The

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[18] http://www3.interscience.wiley.com/cgi-bin/fulltext/70001631/PDFSTART
[19] Solar Cells and their Applications, Page 282.
[20] http://www.nrel.gov/ncpv/pdfs/tf_nrel.pdf

example considered in this section is with regard to ecological and biological functions and their inhibition by various factors. One environmental issue, global warming, connotes in its title that it affects the world community. Other issues not directly related to global warming, such as the pollution of air and water, may affect people thousands of miles away from their origin. An example of this is the hole in the ozone layer above Antarctica. Briefly, ozone depletion is caused by a chemical reaction often involving Chlorofluorocarbons (CFCs). The hole in the ozone located over Antarctica was not caused by CFC emissions in that country. Emissions of ozone depleting compounds in other countries affect that region because of the Coriolis Effect and weather patterns[21]. An environmental impact closely associated with energy generation is global warming and is discussed in detail below.

Global Warming (GW) is a problem that has many names including, global climate change, and the greenhouse effect. The greenhouse effect conveys the principles at work, but not the exact implications, which can be explained fairly easily. The earth's atmosphere acts like the windows of a greenhouse. That is, it allows solar radiation from the sun in and some of the heat it produces out, but keeps most of it in; this is necessary for life on earth to exist. There are several atmospheric gases responsible for this effect on earth, but the major contributors are CO_2, methane, N_2O, and ozone (tropospheric). The reason that GW has become an issue is attributable to the increase in production of greenhouse gases following the industrial revolution.

> "Researchers have also been able to document that the increased concentration of such gases in the atmosphere results from human activities

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[21] http://www.theozonehole.com/ozone.htm

> such as the burning of fossil fuels, deforestation and land degradation, cattle ranching, and rice farming." [22]

The scientific proof that should be consulted to decide if GW is happening continues to become more and more abundant. Such startling statistics as: During the past 40 years the mean surface temperature of the earth has risen by .5 degrees; warming in the 20th century is greater than any other time during the last 400-600 years. Though a 0.5 degrees F increase in global average temperature does not seem very great, in the last 10,000 years the earth's temperature has varied only as much as 1.8 degrees F. At the end of the last ice age average temperatures were only 5-9 degrees F cooler than present temperatures[23]. A small change in temperature can create a huge change in global climate.

Global Warming is an important consideration when discussing energy generation because of the processes typically used for energy production. Coal, petroleum, and natural gas are extremely common energy generation fuels. The United States contributes 25% to world wide CO_2 production, and of those emissions, 40% comes from power plants[24]. This is illustrated by the figure below.

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[22] http://www.ucsusa.org/global_environment/global_warming/page.cfm?pageID=964
[23] http://www.ucsusa.org/global_environment/global_warming/page.cfm?pageID=963
[24] http://www.sierraclub.org/cleanair/factsheets/power.asp

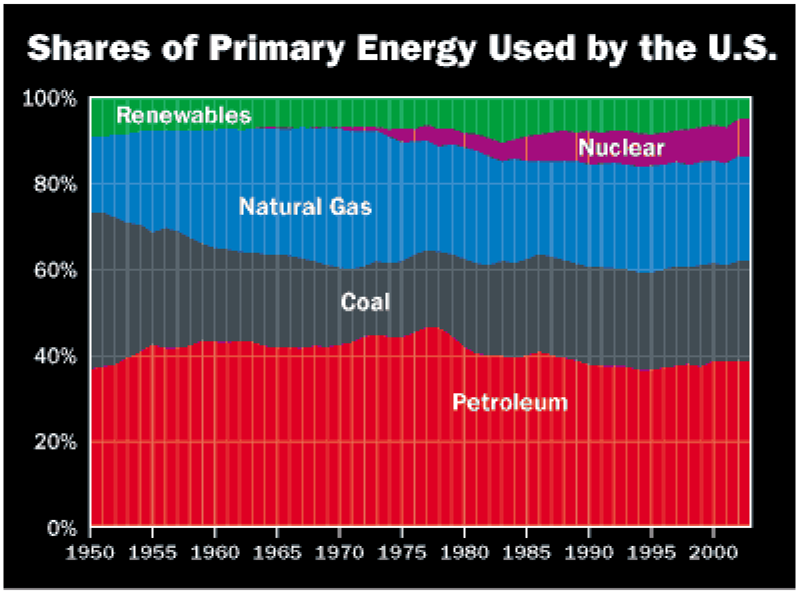

Figure 4: Plot of energy sources versus time[25]

Because PV panels are a sealed system, once they have been installed they are not responsible for emissions of any sort. This means that energy being generated by a PV array would not cause any detrimental environmental effects. What is important to analyze is the environmental impact associated with the construction and eventual disassembly of PV panels and their associated components. If the problems associated with those processes are lesser than those associated with traditional power generation the case for photovoltaic use is strengthened.

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[25] http://www.newamericancentury.org/global-20030923.htm

3 – Photovoltaic Panel Life Cycle

3.1 – Mining and Refining of Silicon

The first area of discussion in the area of PV panel life cycles is the mining of materials necessary for the production of commercially available units. Though the mining processes of the materials for experimental panels is important to consider, the scale of commercially available panels is larger, and therefore of greater concern. Silicon does not occur in nature by itself, but it is quite prevalent in oxides and silicates. By weight it composes over 25% of the earth's crust[26]. Silicon is present as an oxide in materials such as sand, amethyst, agate, quartz, rock crystal, and flint to name a few. Granite, clay, asbestos, and mica are some of the silicate minerals. Sand is readily available and is typically the material used for production of pure silicon. Silica is contained in sand and can be reduced to a pure form of silicon using different methods.

The mining of sand is so prevalent and uncomplicated that it seems to warrant little discussion. A cursory explanation, however, will reveal the essential facts. Sand is typically mined from dunes, which are typically located near bodies of water. Michigan, for example, ranks third in the U.S. for sand production[27], all of which occurs near, or on the coast of Lake Michigan. Though sand is prevalent in this and other similar areas, its use, or overuse, can be aesthetically problematic. With a freshwater lake such as Michigan this may not cause as many ecological problems, as in other situations. Sand removal from oceanic coasts can lead to erosion, loss of vegetation, and other unsought effects. A picture of a mining operation can be seen below. The physical extraction of

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[26] http://en.wikipedia.org/wiki/Silicon

[27] http://www.geo.msu.edu/geo333/sand.html

sand typically is accomplished with simple surface removal. A conveyor is used to gather and move the sand into transport vehicles. These vehicles can then centrally collect the material, at which point it can be distributed.

Figure 5: A Surface mine in Saskatchewan, CA[28]

The term "metallurgical grade silicon" (MGS) is used to describe silicon that is at least 99% pure. Sand, SiO_2, is reduced to MGS using a several step process. The first step of this process involves a fairly simple chemical reaction whereby:

$$SiO_2 + 2C \longrightarrow Si + 2CO^{[29]} \quad (1)$$

This results in 2-3% impurity, which is further purified at 300 to 400 ^{o}C by transferring it to $SiHCl_3$. This is described using the following reaction:

$$Si + 3HCl \longrightarrow SiHCl + H_2 \quad (2)$$

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[28] http://interactive.usask.ca/ski/mining/search/mining_types.html#Surface

[29] http://www6.ww.uni-erlangen.de/~bicki/scriptum/lecture03.pdf

MGS is actually obtained by reversing equation 2 at extremely high temperatures, 1000 to 1150 °C. The difficulty in this stage of the purification process is that it is necessary for the Si to be deposited on a material that will not affect the purity. This is accomplished by using what is referred to as the Siemens process, whereby an already purified Si rod is used as the deposit medium. This process can be referred to generally as polymerization[30], and the purified silicon is referred to as "polycrystalline" silicon.

Further refining to single crystal Si is generally accomplished using two methods: the floating zone method, or the Czoralski method. These processes are illustrated below. The floating zone method produces silicon with a purity of about .1 part per million (ppm), and the Czoralski method produces a silicon with a 1ppm purity.

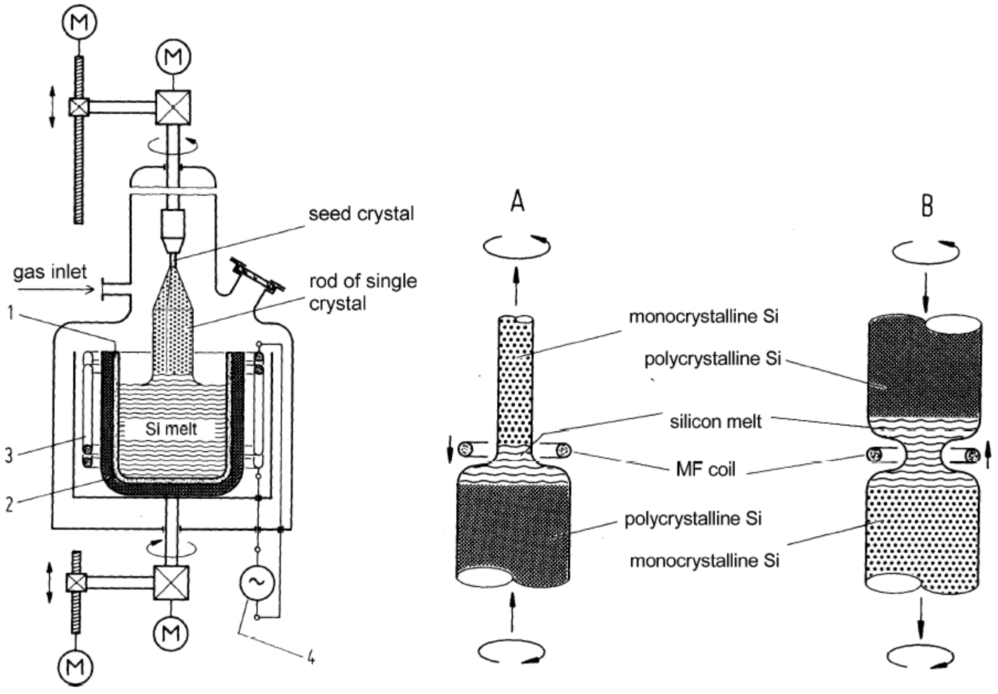

Figure 6: Schematic drawings of popular growth methods for silicon single crystal fabrication. Left: Czochralski method. 1: quartz crucible, 2: graphite crucible, 3: heater, 4: current supply. Middle and right: Floating zone melting according to the platform method (middle) and the pinhole method[31]

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[30] http://www.dowcorning.com/content/sitech/sitechbasics/siloxane_polymerization.asp

[31] http://www6.ww.uni-erlangen.de/~bicki/scriptum/lecture03.pdf

The purification processes above have several aspects which may have potentially detrimental health affects. Crystalline silica occurs as a powder that, according to the Occupational Safety and Health Administration (OSHA), if inhaled can cause silicosis. This has been linked to bronchitis, and tuberculosis and possibly lung cancer[32]. These risks can be reduced by refining silicon in a closed environment, providing adequate ventilation, or using appropriate respiratory protection. In formula 2 above it can be seen that HCl, hydrochloric acid, is an essential component of the refining process. HCl is dangerous in liquid form, as in equation 2, as well as in a gaseous form, called hydrogen chloride, which is produced when equation 2 is reversed and the temperature is increased. Though hydrogen chloride is less concentrated than HCl, human exposure to hydrogen chloride gas in high concentrations can lead to laryngitis, bronchitis, and pulmonary edema. Neither HCl nor hydrogen chloride gas will be discussed with regard to their impact on the environment because the purification process explained above are closed systems and should not result in the release of either.

3.2 – Manufacturing of Photovoltaic Panels

Now that the process involved in mining and refining the materials necessary for commercial silicon PV panels has been discussed it is appropriate to proceed to the next stage in the process. The manufacture of a commercially available PV panel requires that the results be reproducible at a low cost in large volumes. How this is accomplished varies with each manufacturer, however the assumption that silicon cells are the prevalent

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[32] http://www.osha.gov/SLTC/semiconductors/substratemfg/polysiliconprod.html

commercial technology will continue. Panels currently available typically have a stated 20 year, or more, “power output warranty”. The specification sheets for several large manufacturers can be viewed in the Appendix to this report. What is detailed in the discussion below are the processes used to put the various components of a PV panel, discussed in the “How Photovoltaic Panels Work” section of this report, together. This discussion will include general information, information about any relevant environmental considerations, as well as considerations when manufacturing a panel that will be guaranteed to produce power for 20+ years.

Once high purity silicon has been obtained it is necessary to put it in a shape which will allow multiple wafers of the material to be cut and assembled. This is accomplished by casting blocks or ingots of the different types, n or p, of silicon. The reason that the type of cast varies is that mono-crystalline Si is cast in ingots, whereas multi-crystalline or polycrystalline Si is cast into large blocks and then cut into ingots[33]. As discussed in the previous section, the difference between mono and poly-crystalline Si is a single process. This additional process adds time, and subsequently cost to the process. The reason that a mono-crystalline structure would be used is that it is more efficient. This translates to a greater required area for the same amount of energy production when using poly-crystalline processes[34]. The advantage of poly-crystalline Si usage is that the casting process can reduce the amount of waste. Mono-crystalline Si is formed in cylinders, which when cut for use gives circular wafers, which can be trimmed square to increase the surface area exposed. Poly-crystalline Si, however, can be formed

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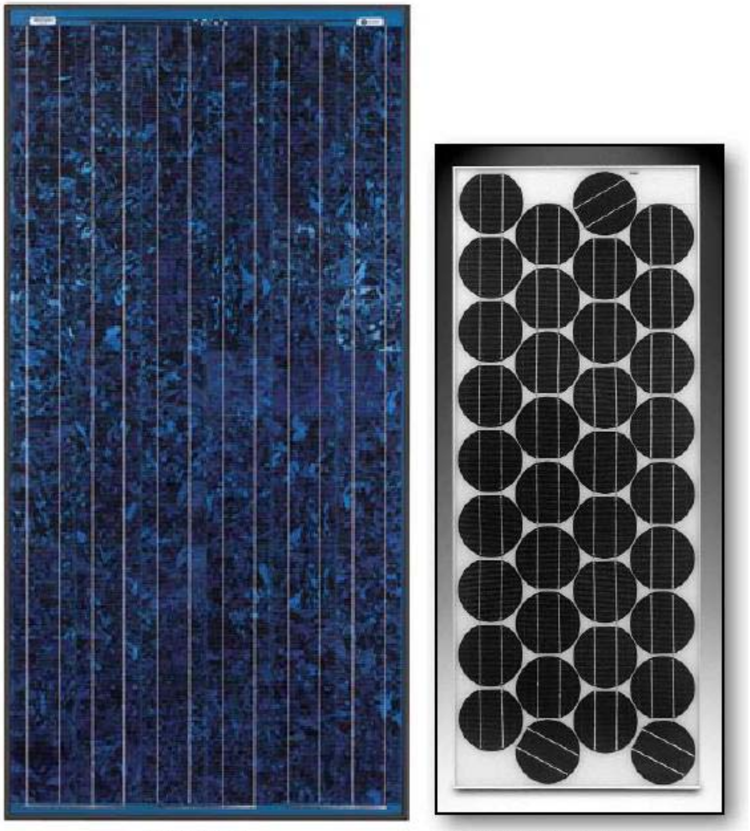
[33] http://www.chem.uu.nl/nws/www/publica/95057.pdf

[34] http://www.affordable-solar.com/thphtesicrpo.html

into square ingots instead, which maximizes the exposed area for a rectangular enclosure. Both instances are pictured below.



BP 3160B SunWize SW85 & SW90

Figure 7: Polycrystalline PV panel (left), and monocrystalline PV panel (right).

The thickness of the wafers used for these modules has decreased as the technology matured, with a current overall thickness of 200-300μm being somewhat standard[35]. A thickness of 0.3-0.8μm is typical for the emitter, while the base thickness ranges from 100-300μm[36].

After wafers of appropriate thickness have been cut it is necessary to remove any surface imperfections caused by the cutting device. This is accomplished by chemically

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[35] http://www.chem.uu.nl/nws/www/publica/95057.pdf

[36] Solar Cells: An Introduction to Crystalline Photovoltaic Technology, Page 83.

etching them with sodium hydroxide (NaOH) in water. They are then rinsed with water and sulpheric acid, which causes a release of H_2, H_2O, Na_2SO_4, and Na_2SiO_3. These reactions are described by the following equations below.

$$2NaOH + Si + H_2O \longrightarrow Na_2SiO_3 + 2H_2 \, (1)$$

$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O \ (2)$$

It is possible to use a different etching material that results in less noxious material release; however etching is an essential part of the manufacturing process as it increases the efficiency of the panels.

Creating the emitter is a process that differs from base creation. The base is typically created by adding doping agents to the molten Si prior to casting of ingots. The emitter is created by high-temperature diffusion from a gaseous or liquid source into that base material[37]. This means that while the base has a uniform distribution of boron, the emitter has an average concentration of phosphorous. This essentially means that there is a phosphorous gradient in the emitter, where at the leading edge the surface concentration can be greater than the solid solubility of the dopant. This concentration uniformly decreases with depth until the concentration of n-type dopant equals that of the p-type dopant.

Once these wafers have been sliced, surfaced, and had emitter characteristics added to some, assembly into a module can begin. Modules can be seen quite easily in the mono-crystalline panel above: each circle represents one module. Modules are assembled individually, and then connected to form a panel with a certain voltage and power characteristic. These modules are similar in their construction, which is largely

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[37] Solar Cells and their Applications, Page 60.

thanks to the Department of Energy (DOE), which contributed significant research to manufacturing of PV panels during the early 1980's[38]. A necessary requirement for modules, and panels, is that they have a medium for conducting the power they generate. This is accomplished using a grid or plate of conductive material, such as copper or silver. This conductor is then soldered[39] or screen-printed onto the bottom of the base wafer, and to the top of the emitter wafer[40]. On the top layer this conductor needs to impede the transmission of sunlight as little as possible so it typically takes the form of a grid. The bottom of the panel does not have this consideration and can be created by alloying a metal with the silicon. Using aluminum this can be accomplished by heat treating those two materials at a temperature above their eutectic temperature of 580°C[41]. An antireflection coating is applied to the top layer to increase performance. This step can have an impact of about 4%. Materials used include TiO_2, or Silicon Nitride. This completes the creation of a photovoltaic module.

Once each module has been created it is necessary to sort them by their electrical properties. This sorting allows cells that produce similar current at a fixed voltage to be combined into a module string. In a panel the module with the lowest current producing capability limits the other modules, possibly causing a great decrease in efficiency. An attachment tab is soldered to each module; the modules are then laid face down and connected to each other[42]. The covering glass is cleaned, and a thin sheet of Ethylene Vinyl Acetate (EVA) is applied to it to prevent moisture transmission by providing

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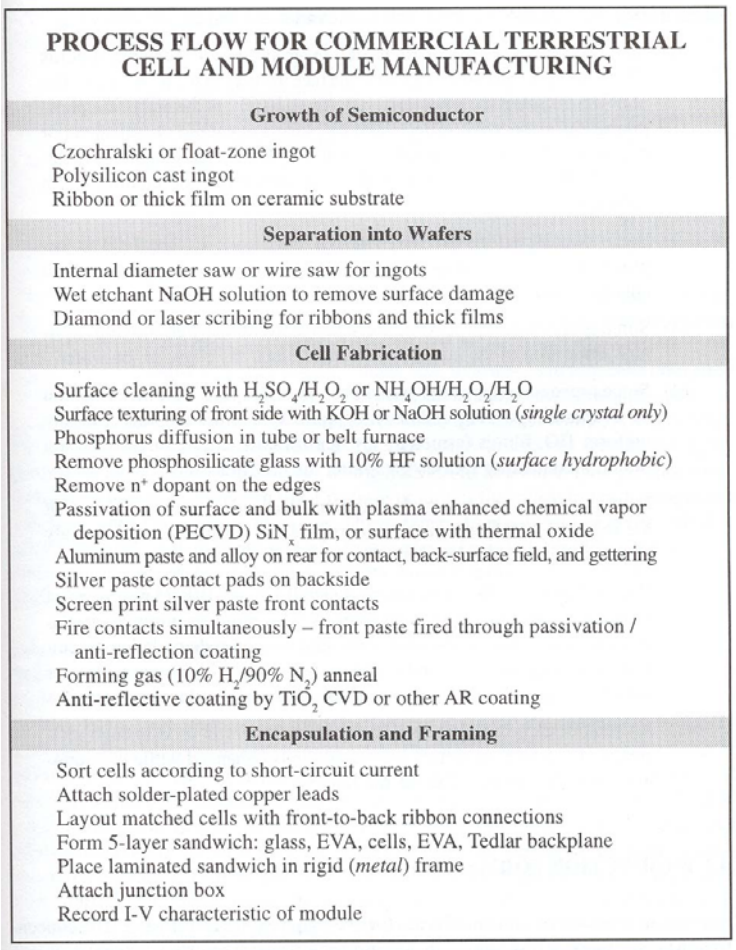
[38] Solar Cells and their Applications, Page 213.
[39] Solar Cells and their Applications, Page 214.
[40] http://www.chem.uu.nl/nws/www/publica/95057.pdf
[41] Solar Cells: An Introduction to Crystalline Photovoltaic Technology, page 84.
[42] Solar Cells and their Applications, Page 216.

encapsulation[43]. The modules are then placed onto this assembly followed by an additional layer of EVA. A final layer of film is applied to cover the back of the module. This entire assembly is then placed in a laminator and exposed to very controlled conditions to properly melt and cure the EVA, which acts as the "glue" for the module. After testing the solidity of the EVA bonding junction boxes are connected to the outputs and frames are attached and sealed. The figure below this text summarizes the processes discussed above, including crystal growth, wafer separation, cell construction, and encapsulation.



PROCESS FLOW FOR COMMERCIAL TERRESTRIAL CELL AND MODULE MANUFACTURING

Growth of Semiconductor

Czochralski or float-zone ingot
Polysilicon cast ingot
Ribbon or thick film on ceramic substrate

Separation into Wafers

Internal diameter saw or wire saw for ingots
Wet etchant NaOH solution to remove surface damage
Diamond or laser scribing for ribbons and thick films

Cell Fabrication

Surface cleaning with H_2SO_4/H_2O_2 or $NH_4OH/H_2O_2/H_2O$
Surface texturing of front side with KOH or NaOH solution (*single crystal only*)
Phosphorus diffusion in tube or belt furnace
Remove phosphosilicate glass with 10% HF solution (*surface hydrophobic*)
Remove n^+ dopant on the edges
Passivation of surface and bulk with plasma enhanced chemical vapor deposition (PECVD) SiN_x film, or surface with thermal oxide
Aluminum paste and alloy on rear for contact, back-surface field, and gettering
Silver paste contact pads on backside
Screen print silver paste front contacts
Fire contacts simultaneously – front paste fired through passivation / anti-reflection coating
Forming gas (10% H_2/90% N_2) anneal
Anti-reflective coating by TiO_2 CVD or other AR coating

Encapsulation and Framing

Sort cells according to short-circuit current
Attach solder-plated copper leads
Layout matched cells with front-to-back ribbon connections
Form 5-layer sandwich: glass, EVA, cells, EVA, Tedlar backplane
Place laminated sandwich in rigid (*metal*) frame
Attach junction box
Record I-V characteristic of module

Figure 8: Process flow for commercial terrestrial cell and module manufacturing[44]

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[43] http://www.nrel.gov/ncpv_prm/pdfs/33586018.pdf
[44] Solar Cells: An Introduction to Crystalline Photovoltaic Technology, Page 119.

3.2.1 – Brief Discussion of Manufacturing Economics

Though PV panels are relatively expensive to produce the cost has decreased significantly in recent years. This is at least partially attributable to development and advances in the semiconductor industry. This fact, combined with the increased total manufacturing capacity of the PV industry has led to reduced costs per kW. This is illustrated by the figure below.

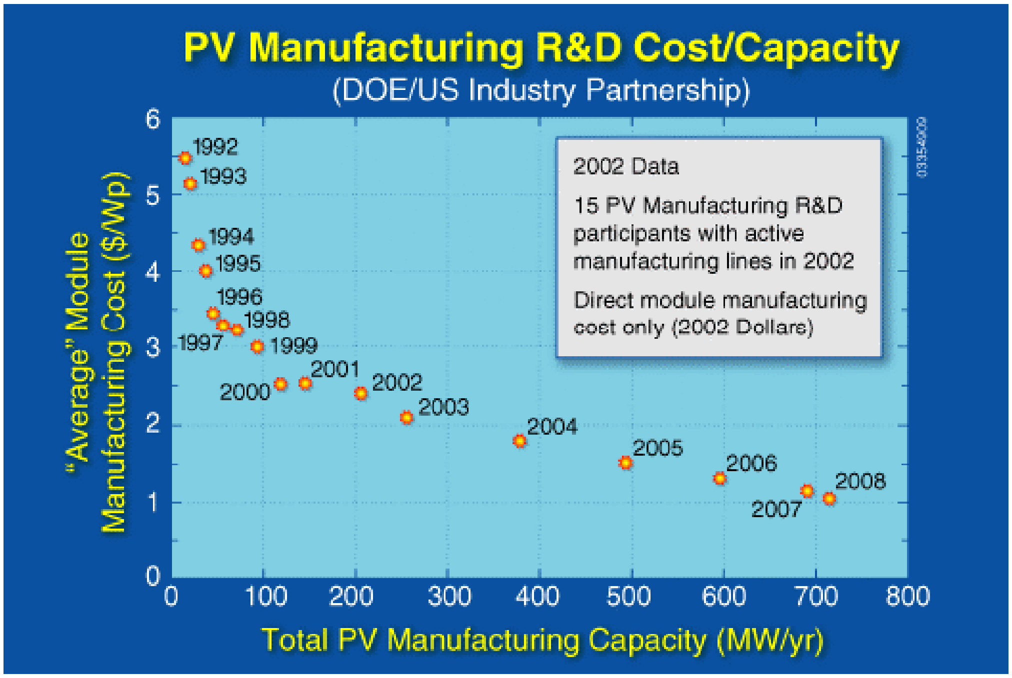

Figure 9: Manufacturing cost versus manufacturing capacity

While this figure seems to indicate an extremely favorable situation, it is a bit deceiving and requires a bit of an explanation. The vertical axis is a weighted average based on the contribution of the manufacture to the total manufacturing capacity. These costs do not include secondary or tertiary costs to the manufacture, such as research and development, or marketing and sales[45]. The horizontal axis represents the total manufacturing capacity

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[45] http://www.nrel.gov/pvmat/pvmatcost.html

of all of 15 participants; this is not the actual quantity of PV modules that have been manufactured. The costs shown are also representative of this full production, which benefits the manufacturer because of economies of scale. However, this graph is useful since it indicates that an increased demand in PV production would reduce the cost per kW, a necessary development if photovoltaic panels are to increase their share of total energy production.

3.3 – Photovoltaic Panel Useful Life Analysis

Looking at the benefits of photovoltaic panels during their useful life is, quite possibly, the most important aspect of this report. If the benefits realized from the use of these panels during their lifetime does not offset the harm done during their creation their use as a sustainable technology is doubtful. However, depending on the results of that analysis, it is possible that their offset is better than other energy sources, which would give them relative strength.

For the purpose of this discussion a hypothetical installation will be discussed, including panel location, size, weather, equipment efficiency, and other relevant information. There are geographic advantages that are important when considering the installation of a large-scale PV facility. As should be intuitively expected southern and southwestern United States are excellent locations for PV arrays. The solar radiation for the United States can be seen in the figure below.

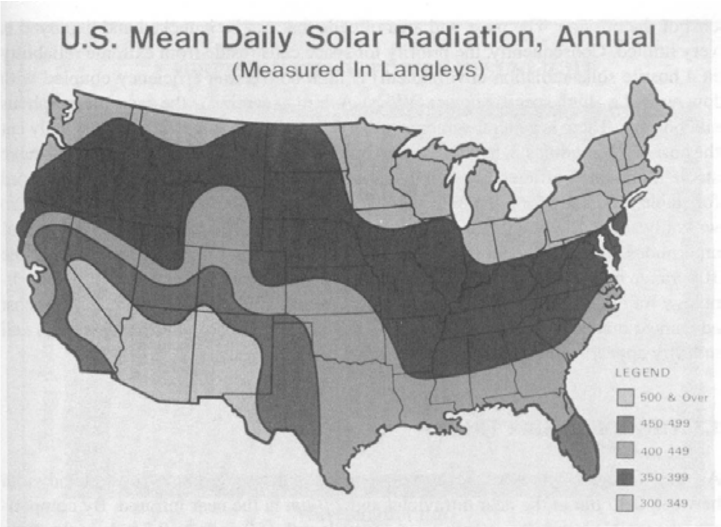

Figure 10: U.S. Annual mean daily solar radiation measured in langleys. 1 langley = 1 cal/cm^2=4.19 J/cm^2

This figure illustrates that the solar radiation for Massachusetts and Vermont is approximately equal, as well as showing the potential for southern and southwestern states. To give an idea of just how much power can be generated in similar regions of the U.S. actual data obtained from the University of Vermont's (UVM) solar project web page[46], and the Chicago Solar Partnership web page[47] will be discussed. Both sites have archived data concerning power output. The data available on these pages can be corroborated using archived weather information from various websites. Unfortunately, neither of the sites discussed above have a long term history of data, because they have been installed in the last five years or less. However, an organization called Solar Now, located in nearby Beverly MA, has a 100kW PV array that has been in use since the early 80's. All of this information will be discussed and analyzed to predict the potential benefits during the lifetime of a theoretical array. A picture of the UVM array and the Beverly, MA array can be seen below.

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[46] http://www.uvm.edu/~solar/
[47] http://www.chicagosolarpartnership.com

Figure 11: PV Installations - Left: UVM[48], Right: Solar Now[49]

3.3.1 – Weather Considerations

Two of the states with arrays that will be analyzed, Vermont and Massachusetts, have four distinct seasons. This means that solar exposure can vary due to cloud cover or other environmental factors. This can be illustrated by the figure below this text. This figure displays production data for the 5kW array installed on the roof of one of UVM's buildings. This data is for 2003.

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[48] http://www.uvm.edu/~solar/?Page=images/roof_full.jpg

[49] http://www.solarnow.org/beverly.htm

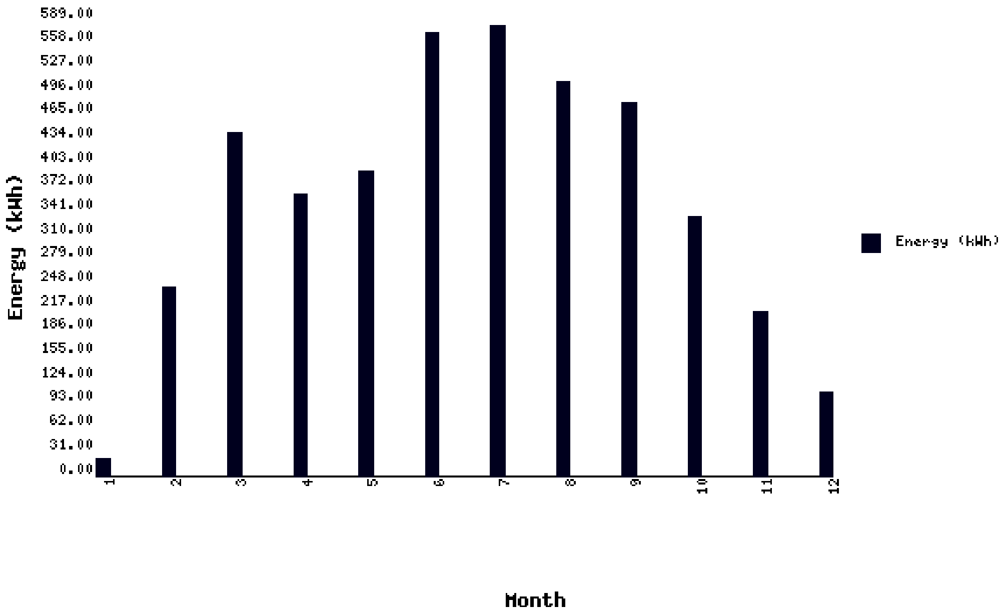

Figure 12: Energy History Per month for 2003[50]

The vertical axis displays the power generated by the array in kilowatt hours (kWh), while the bottom axis represents the month. As is clearly illustrated, peak production occurs in the sunniest months of the year, May through September.

For more accurate understanding of power production, a specific day, or a few days can be examined. For example, during the week of April 12th to April 18th there were several cloudy and rainy days in Burlington, VT. This impact can be seen in the plot of energy production for the month of April below. The vertical axis again represents the energy production in kWh, while the horizontal axis represents the day of the month.

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[50] http://www.uvm.edu/~solar/?Page=energytotals.html

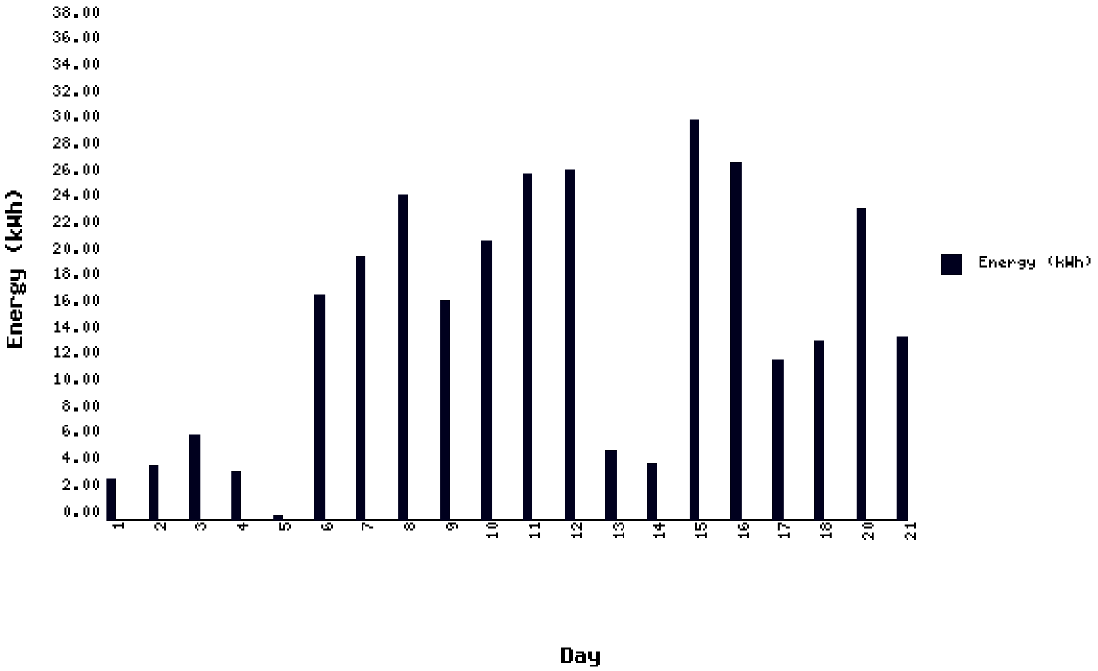

Figure 13: Power generation in kWh during April, 2004[51]

Clearly, on the 13th and 14th, something affected the production of power. The cause can be obtained by looking at the archive of weather data available for Burlington, VT at www.accuweather.com or other similar sites. On April 13th in Burlington 0.54 inches of precipitation fell, and on the 14th 0.23 inches fell[52].

The above discussion was meant to illustrate the weather sensitivity of PV installations to weather conditions. It is not, however, meant to prove that these arrays are impractical in locations with less than year-round peak sunlight exposure. It was more meant to point out the effect so that it can be understood how energy production can be increased, or reduced.

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[51] http://www.uvm.edu/~solar/?Page=energytotals.html

[52] http://www.accuweather.com/adcbin/public/climo_local.asp?partner=accuweather

3.3.2 – Energy Production in Perspective

The benefits of installing a PV array are discussed below. This is the "meat and potatoes" of this report, in that up to now only relatively negative aspects of photovoltaic arrays have been discussed. However, their purported function as a source of clean energy requires further analysis and discussion. Understanding just what the environmental benefits are for a specific array, extrapolating that to a larger array, and making judgments based upon that theorizing will help to establish the net impact PV panels have during their cradle to grave cycle.

One of the direct consequences of installation of a PV array comes from CO_2 emissions that are prevented. UVM claims that for a 5kW array approximately 18,000 pounds of carbon dioxide gas are prevented from entering the atmosphere[53]. This is equal to driving a car that averages 24 miles per gallon approximately 23,000 miles. The Chicago Solar Partnership includes a real-time calculation of the amount of CO_2 production avoided through their website[54]. This figure seems a bit high, however, for the 4852 kWh produced for UVM's 5kW array last year. The actual figure is more likely near 10,000 pounds of CO_2[55]. For a 49kW array installed on the Museum of Natural History in Chicago, IL 10 tons of CO_2 emissions have been avoided this year. The amount of CO2 "prevented" above assumes that the power produced by the PV arrays is directly offsetting power generated by sources utilizing combustion. This is a reasonable assumption based on the sources of energy that the figure presented in the "Environmental Considerations" section of this report outlines. Nearly 90 percent of our energy comes from sources which require combustion: petroleum, coal, and natural gas.

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[53] http://www.uvm.edu/~solar/?Page=why.html
[54] http://www.chicagosolarpartnership.com/pv/index.htm
[55] http://www.infinitepower.org/calc_carbon.htm

Combustion of natural gas is less of a cause for concern than the other two sources. Nuclear power has zero carbon dioxide emissions, though it has its own troubling environmental implications[56].

3.3.3 – PV Array Lifetime Estimates

Due to the lack of long-term data available regarding power production for a PV array, it is necessary to extrapolate lifetime production of energy. Similarly, the amount of CO_2 that is prevented is also estimated. These estimates will be limited to 25 years, which is typically the duration of the manufacturer warranty. It is likely that the panels will operate and produce power for a longer time than this, though the efficiency of that system may be somewhat poor. Environmental variations, as well as efficiency degradation will be estimated based on archived data from UVM's solar program website. Hopefully a more accurate picture can be obtained if the data from the 100kW array run by Solar Now can be obtained.

During 2003 the power generated by the array at UVM was approximately 4260kWh. As previously mentioned this amounts to approximately 5 tons of CO_2 that was prevented. Simple multiplication will give a rough estimate of the benefits this system provides during its life: 4260x25 and 5*25. This results in 106,500kWh of energy production, and 125 tons of CO_2 prevention. Putting these numbers into perspective is important for conveying the magnitude of the benefits. 125 tons of CO2 prevention would be equivalent to not driving approximately 320,000 miles. 10.6MWh is enough energy to run two computers continuously for 25 years. Unfortunately, these estimates

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[56] http://www.epa.gov/cleanenergy/natgas.htm

are probably too high. The reason is that the efficiency of PV panels often decreases as its time of exposure to sunlight increases. The degradation of efficiency varies for different types of panels, but can be estimated to be 0.25-0.5% per year for crystalline silicon panels[57].

An important concept is that of energy payback (EP). Simply described this is the amount of energy that must be produced by a PV array, or any power generating technology, in order to offset the energy inputted for its creation. For a crystalline panel currently on the market the EP length is approximately 4 years. This assumes a 12% conversion efficiency and 1700kWh/m^2 of available solar energy[58]. Though the energy needed to create single-crystal panels is larger, their efficiency is greater, resulting in approximately the same EP duration. A 4 year EP time for a panel that can be used for 30 years means that approximately 87% of the energy produced by the panel is “clean”. This is definitely good news for PV proponents.

3.3.4 – Discussion of PV Installation: Economics and Other Factors

One of the major problems for PV systems that are currently connected to the power grid is that they are categorized statically or improperly. What is meant by this is that PV panels should not be directly compared to grid power because of the very nature of its energy generation. This has two main points, the first being that it is a clean energy source, which is becoming increasingly important, especially in the United States. If the

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[57] http://www.gaiam.com/retail/gai_content/learn/gai_learnArticle.asp?article_id=1330&category_id=168
[58] http://www.nrel.gov/ncpv/pdfs/24596.pdf

United States were to sign an international agreement to reduce CO2 production, such as the Kyoto Protocol[59], it would face quite a challenge. The figure below illustrates.

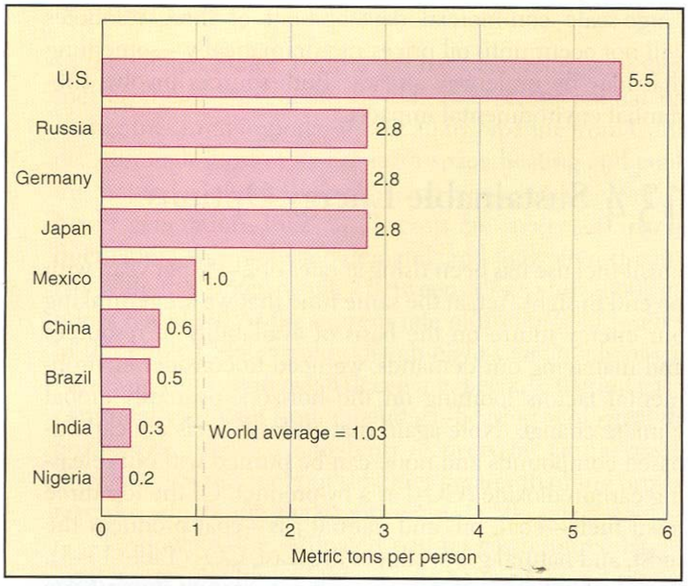

Figure 14: Annual carbon emissions per capita from burning fossil fuels, selected countries, 1998[60].

This figure serves to illustrate the extreme disparity in CO_2 production between the United States and other countries. PV panels would be a great start to reducing this.

Another reason for implementing large-scale PV installations is to reduce dependence on foreign imports of petroleum products. The energy plan laid forth by the current presidential administration is incongruous with its aims to stop terrorist activity. A nation whose power production is not reliant on foreign sources is likely much safer than one dependent. Unfortunately this is not the trend that the U.S. has been following, as the figure below illustrates. This is an excellent example of why PV is not given the credit it deserves. Its use as a source of energy independent from foreign products increases its value, as does its decreasing CO_2 production.

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[59] http://unfccc.int/resource/docs/convkp/kpeng.html

[60] Environmental Science: Towards a Sustainable Future, Page 336. Richard T. Wright, Prentice Hall.

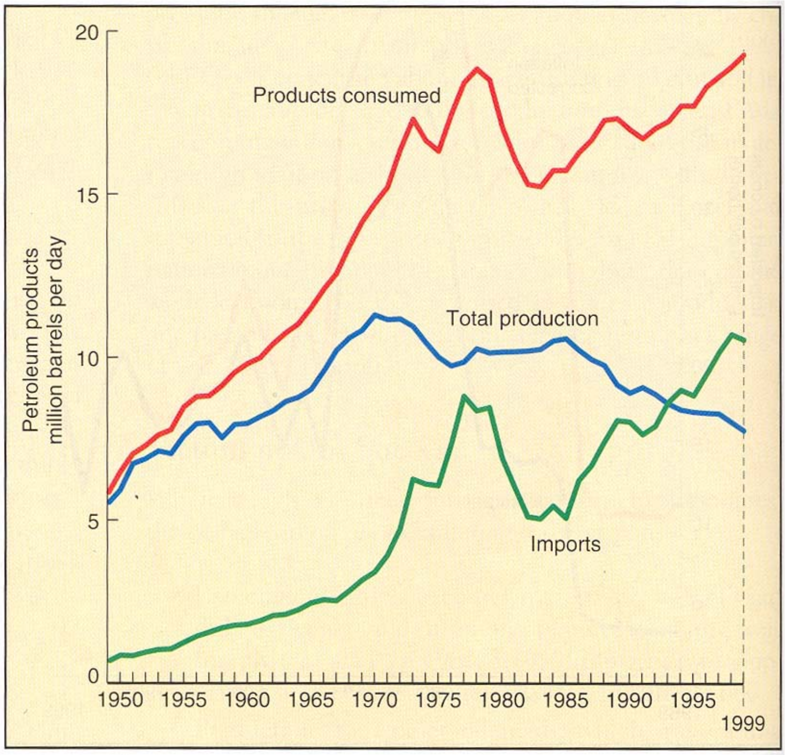

Figure 15: Consumption, domestic production, and imports of petroleum products[61].

Another example of PV being put into an unfair category is in terms of power production credits. PV systems that are connected to local utilities and feed power back are called "grid intertied" systems. These systems can track production using at least two methods. One of these methods is a fixed rate for each kW hour of production; another is matching the produced amount of energy exactly. For systems with a flat rate, this credit varies. However, for a case analyzed in White Plains, NY the rate is 15 cents/kWh[62]. When examining the economics of PV this rate is not very advantageous for swift system payback. However, this is the best example of unfairly categorizing PV systems. The peak power production months, and daily times for PV are practically identical to the peak demands placed on utilities: May, June, July and August from noon until 6:00pm.

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[61] Environmental Science: Towards a Sustainable Future, Page 330. Richard T. Wright, Prentice Hall.

[62] http://www.millionsolarroofs.com/articles/static/1/binaries/Quantifying_Residential_PV_Economics.pdf

Because of the demand placed on the utilities during these times grid intertied PV systems provide power that is worth more. In the case of the White Plains site discussed in the study this resulted in more than a 9 cent increase in the value of generated power, a 60% increase in the cost returned to grid intertied system owners. This is no small figure, and should be taken into account in deciding future PV regulations and rates.

3.4 – Removal and Disposal or Recycling of PV Arrays

The purpose of this section is to examine contemporary and potential methods for disposal of PV arrays. Large scale disposal concerns for PV panels won't be realized until around the year 2020[63], due to their 25+ year life expectancy. However, this is an incredibly important aspect of this report. If a PV panel is created that becomes classified as a hazardous waste, this is disadvantageous. The reason for this is that the amount of energy, and therefore associated chemical and thermal effluents, needed to properly recycle or dispose of that panel will be great. This also means that disposal will be extremely costly financially. For these reasons it would be highly beneficial for PV manufacturers to design their products for easy disassembly into component systems. The figure below illustrates cost estimates associated with various disposal methods. Environmental concerns are not as much of a problem with silicon panels, because of the relatively benign nature of silicon. This section will address disposal concerns, waste classification, current recycling methods, and potential recycling methods for PV panels.

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[63] http://www.pv.bnl.gov/abs_142.htm

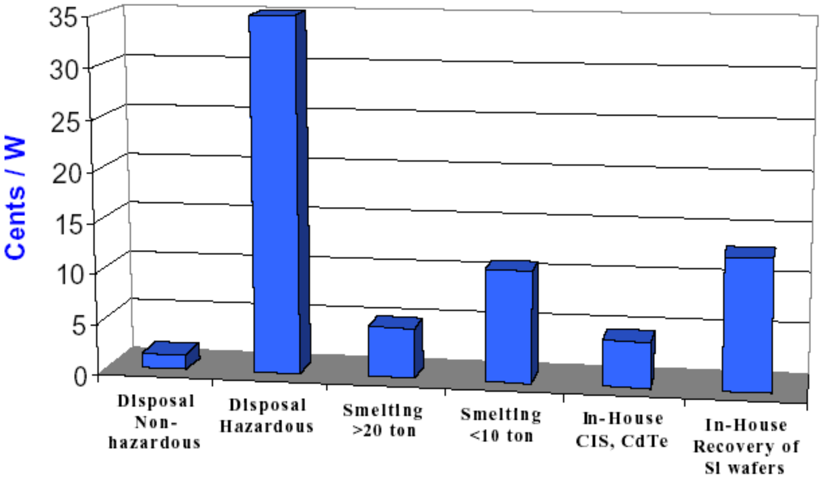

Figure 16: Cost of recycling PV panels versus disposal[64]

3.4.1 – Disposal and Recycling Issues

Things that are created are generally disposed of. This is true for PV panels, and it is an excellent reason to engineer panels to be easily disposed of when they have been decommissioned. Though silicon technology panels are relatively benign, they do contain some metals which are potentially problematic. These metals include copper and silver. Since silicon, glass and EVA are considered non-toxic materials they could be disposed of in a landfill. However, the copper and silver exist in a concentration that may be problematic. The above figure illustrates that the cost for smelting would be only slightly higher than disposal if the quantity were greater than 20 tons. For an expanding market this would suggest the economic feasibility of a large-scale operation specializing in constituent separation.

An alternative to smelting materials is reusing the solar modules. This is possible because individual modules sometimes have little to no decrease in voltage output after

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[64] http://streference.jrc.cec.eu.int/pdf/Present_Recycl_WS/13)%20Ken%20Zweibel.pdf

their use[65]. This process would begin by gently peeling off the backsheet of the panels, followed by vaporization of the EVA layers at a temperature of around 500°C. Another method that could be used would involve chemically stripping the EVA and metals from the modules. This would allow for a high percentage of metal recovery in most cases. Because the reuse of modules and materials reduces the cost of producing new PV panels, this is a great incentive for manufacturers to create panels that can easily be recycled. Costs of reusing PV modules would be around 13 cents/W, for an operation of 150,000 cells/year, while the reclamation of metals would be around 9 cents/W.

Because the recycling industry for PV panels is a new area it is difficult to tell the state that it is in. However, some general principles can be applied to it based on other industries or sectors. Contemporary computer "take back" campaigns are an effort to hold manufacturers accountable for the products they produce and force them to take their PC's back at no additional cost to the consumer. Though this may seem unfair, the purpose is to spur design of PC's whose components can easily be removed, reused, or recycled. PV has a distinct advantage in this arena. Because it is a technology that is "green" or "clean" it seems quite possible that manufacturing companies have ecological ideologies imbedded in their missions. While this is not enough to ensure creation of recyclable PV panels it is a big help in combination with other facts. One such fact is that it is possible to create materials from, nearly entirely, environmentally benign materials without significant performance loss[66]. Because hazardous materials are costly to dispose of the incentive for using these benign materials is even greater.

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[65] http://www.pv.bnl.gov/keystone.htm
[66] http://www.pv.bnl.gov/keystone.htm

4 – Conclusions and Recommendations

The situation outlined in the previous sections should leave the reader with a positive impression about the prospect of photovoltaic energy production. The concept of energy payback easily illustrates that the amount of energy needed to offset the production of PV panels is able to be produced within four years or less, depending on the type of panel. The manufacturing costs of PV panels have been decreasing, and predictions indicate this trend will continue. An important aspect for financial viability that did not receive mention in this paper was incentives being provided through local and national legislation. These incentives are often substantial and may reduce the cost of PV panels to a level that makes their purchase feasible.

The future of photovoltaic panels is in a state of positive flux. Prices per watt are dropping, while the efficiency of the technology is improving. An interesting cost comparison would be to estimate the increasing price of petroleum into the future, and how that would impact the PV market. As oil becomes scarcer this may raise the cost of power production to a point where PV is as cheap, or cheaper. Prices for conventional energy prices are in the 6-10 cent/watt range, a figure that is biased because it does not reflect environmental costs. Solar power currently costs around 22 cents/watt, a cost that is faced entirely at the initial installation of the PV array[67]. This means that the actual cost per watt is initially around $4.50. Getting PV production prices into the same range as conventional technologies would greatly bolster its market share. This differential may also be decreased by technological incentives, including commercial production of thin-film technology. Current thin-film technologies have a payback in the range of 1-3

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[67] http://www.nrel.gov/ncpv/hotline/08_00_keller.html

years, and it is likely that in the near future that will be reduced to 1 year or less[68]. As mentioned previously, the cost for conventional power is extremely unrealistic and does not include the cost needed to offset the detrimental environmental effects.

This cursory examination of the cradle to grave cycle for a PV array has revealed that these panels have a positive energy production, and should indeed be called a "green" or "clean" technology. Several areas associated with these panels were not examined, including the secondary technologies necessary for the use of PV power production, the energy associated with mining the necessary minerals, and the amount of energy necessary for recycling of the panels. However, one fact remains: simplicity of material used in construction makes many aspects an easier matter. The use of silicon makes the mining of that material relatively non-energy intensive. The recycling of PV modules, illustrated by "In-House Recovery of Si Wafers" in Figure 16 can be considered an initial energy input for a new panel. The cost associated with recovery of Si modules is 13 cents/watt, whereas for creation of new Si modules this cost is approximately $1.50/watt[69]

The topics discussed above serve to illustrate the fact that the PV industry is expanding, and that the costs associated will only continue to decrease while simultaneously the technology improves. Continuing widespread use of PV panels will assist this by providing economy of scale, and increased monies for research and development. When the "first generation" of PV panels is ready to be decommissioned in 2020 proliferation of the technology will have made its continued use feasible, and practical, as well as being an even greater ecologically necessity.

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[68] http://www.nrel.gov/ncpv/pdfs/24596.pdf

[69] http://www.pv.bnl.gov/keystone.htm

Appendix S: WPI Installation Case Study for Heliotronics

Solar Learning Lab™ Case Study

Worcester Polytechnic Institute

Worcester, Massachusetts

The University of
Science and Technology.
And Life.™

Worcester Polytechnic Institute is one of the nation's premier educational institutes. WPI's unique curriculum takes a 'learn by doing' approach to education. WPI students obtain a firm grounding in science and technology and then learn to apply their knowledge by tackling real problems through the intense project based curriculum. The twin principles of theory and practice are interwoven to in a curriculum that thoroughly prepares students for life and work in today's technological world.

Solution:

By installing a Heliotronics data monitoring system, the WPI Community Solar Initiative has created an exciting Solar Learning Lab™ at the WPI Campus. The system includes the Heliotronics' *Feynman* monitoring system and large plasma display screens for the software. The data from the Solar Learning Lab™ is accessible throughout the school network and thus making it available for educational use. The WPI Solar Learning Lab™ also includes the SunViewer.net web portal.

Background:

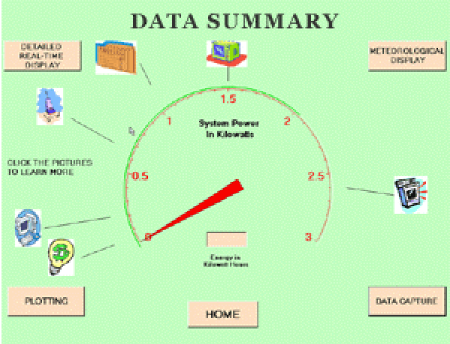
This installation and the WPI Community Solar Initiative was the product of WPI's unique project-based curriculum. Two teams of four students participating in their Interactive Qualifying Project (a required part of the WPI curriculum), set out on the mission to promote solar education and awareness at WPI and in the Worcester area. Establishing a solar installation at WPI designed for educational purposes was one of their goals. Their goals also included implementing educational programs about renewable energy topics in Worcester Public Schools and WPI K-12 Outreach Programs.

Funding:

Funding for the The Solar Learning Lab™ came from a donation of $10,000 from the WPI Class of 1975. Additional funding was provided by Mass Energy through grant money from the Massachusetts Technology Collaborative.

Location and Access:

The photovoltaic installation resides on the roof of Morgan Residence Hall. The plasma display screens that display the SunViewer software can be found on the first floor near the entrance of Morgan Hall. The SunViewer.net web portal can be accessed through WPI's webpage, www.wpi.edu.



Heliotronics, Inc.
1083 Main Street
Hingham, MA 02043-3961
Info@Heliotronics.com
617-730-5436

Insert Photo of WPI Installation

Project Snapshot

Data Monitoring System: Heliotronics *Feynman* Package

System Specs: monitors real-time PV power and energy output, system efficiency, array efficiency, inverter efficiency, AC/DC current and voltage, avoided emissions, irradiance, PV module temperature, ambient temperature, and wind speed.

User Interface: Heliotronics' SunViewer™ educational display software accessible through presentation computer and exhibited on plasma display screens

PV Installation: 4 RWE Schott Photovoltaic Modules

PV System Capacity: 1.08 kW AC
Estimated Annual Energy Production: 1296kWh/year

Installation team: WPI Plant Services, WPI Network Operations, and WPI project team members.

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