

SOLAR ENERGY AND PHOTOVOLTAICS EDUCATIONAL PROGRAM

Created in partial fulfillment of an Interactive Qualifying Project

By students of

WORCESTER POLYTECHNIC INSTITUTE

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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 photovoltaics 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

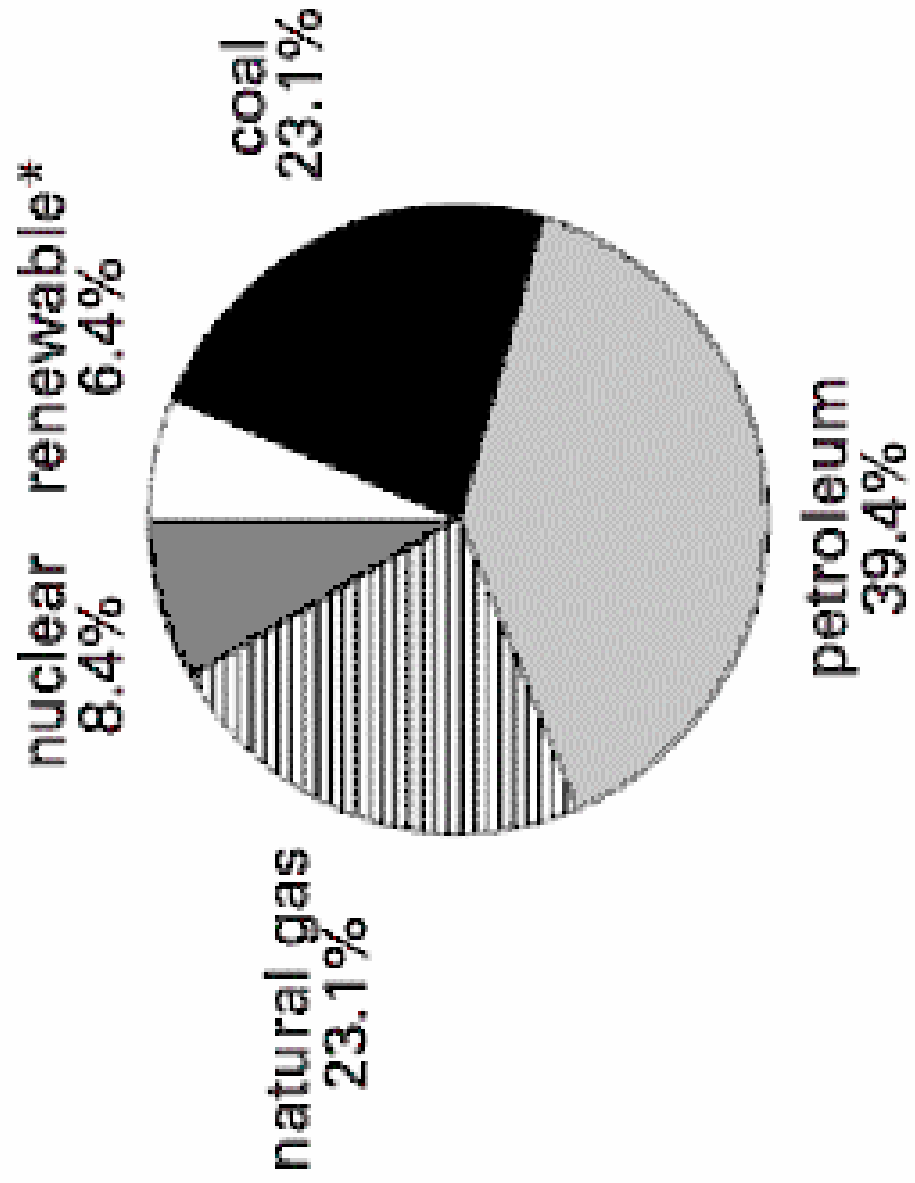
4. Tell the class that their list of energy sources can be placed into two categories: renewable and nonrenewable. Have them brainstorm what they think these terms mean. If they are unsure, you can use the following definitions:

- 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.

U.S. Energy Consumption 2001



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

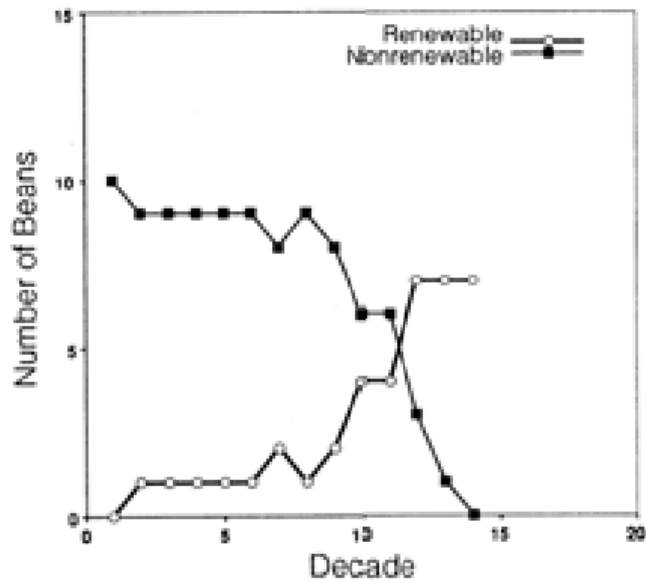
This activity will also give students an opportunity to work with percentages.

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 the 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.

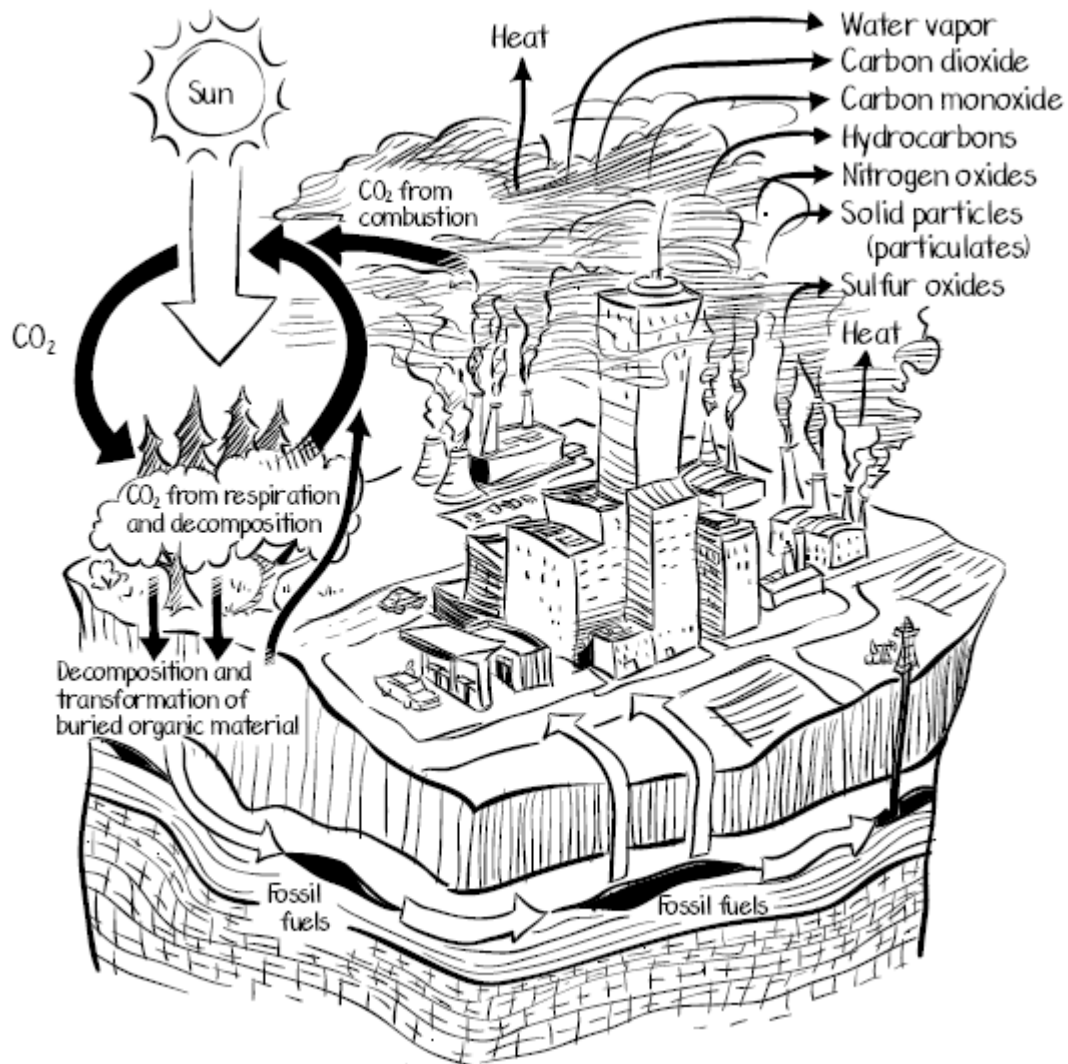
In contrast to fossil fuels, renewable sources of energy produce little or no pollution or hazardous waste and pose few risks to public safety. Furthermore, they are an entirely domestic resource.

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 (CO₂)	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 (CH₄) (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 (O₃)	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 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.

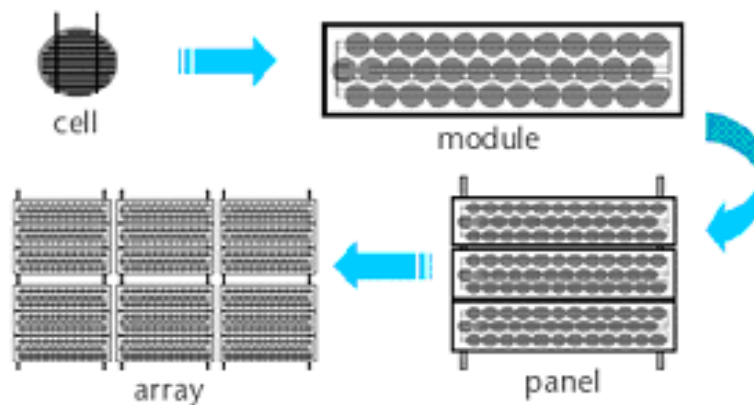
Note: The total amount of solar radiation received by the earth is 1.73×10^{17} watts at any one time. This is enough to warm our entire globe, fuel all of the earth's photosynthesizing plants, and create global climatic systems that drive the winds, the waves, and the water cycle.

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 *voltaiic* 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 PV roofs) 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/>

STUDENT HANDOUT

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

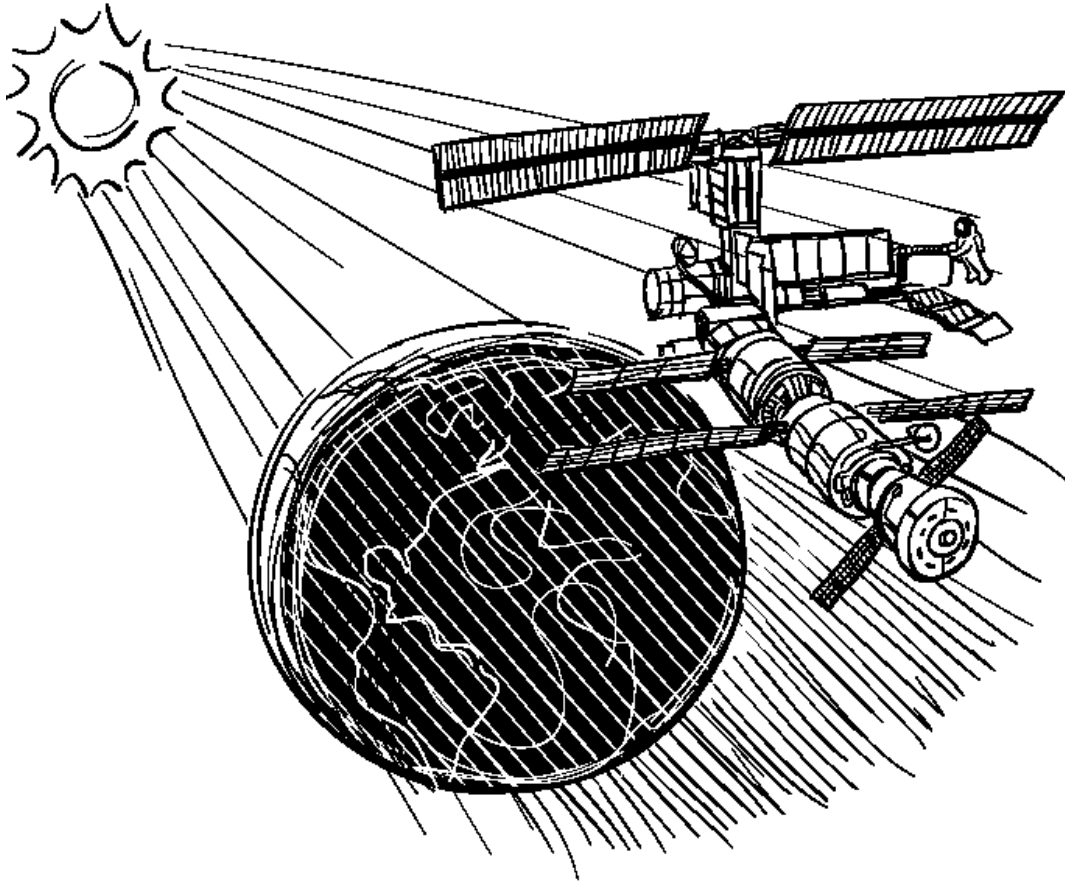


Fossil Fuels: Coal, oil (petroleum), and natural gas

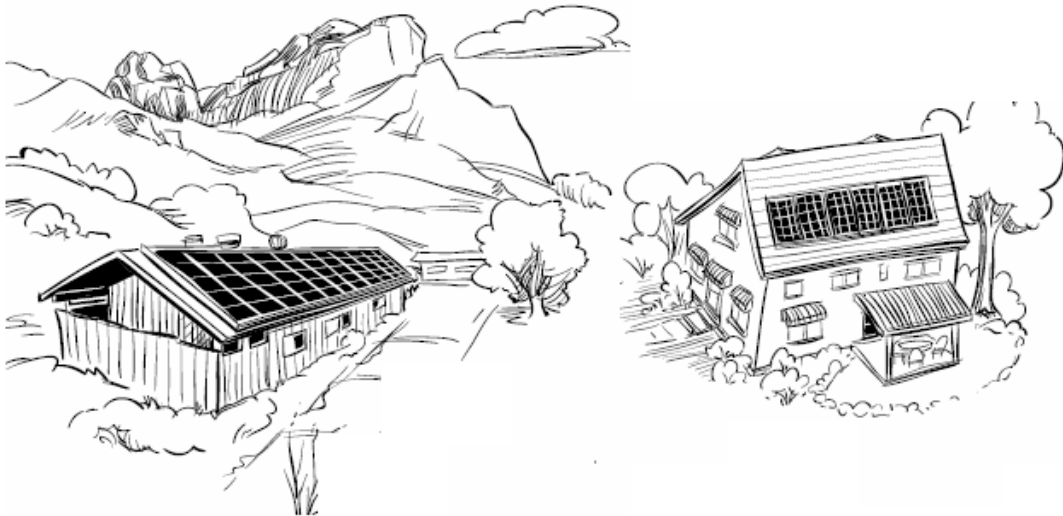
Nuclear Fuels: Elements with unstable nuclei, such as uranium



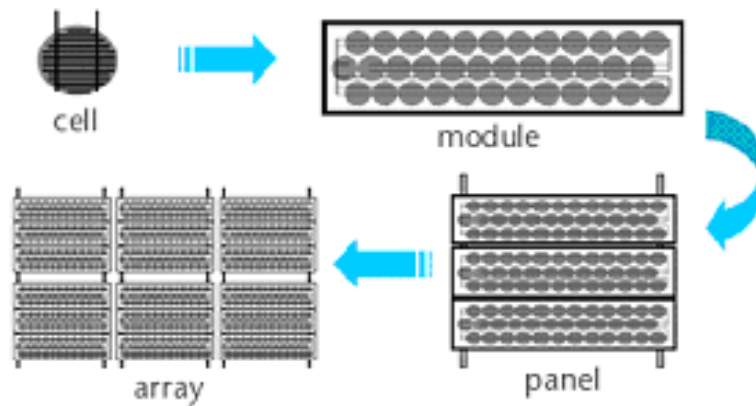
THE SOLAR RESOURCE



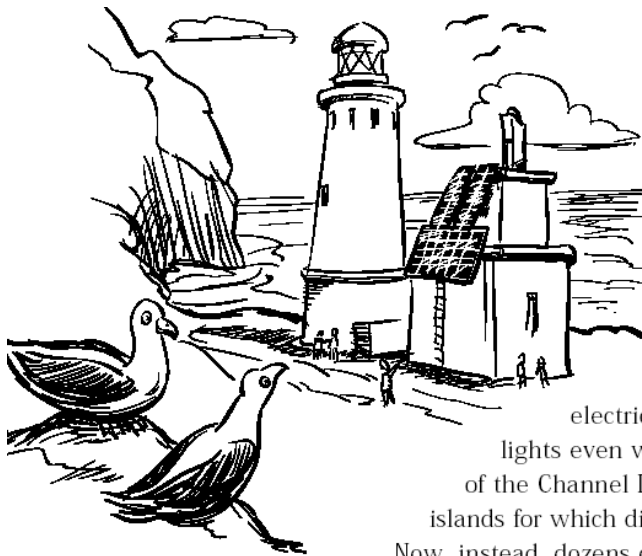
The first use of PV generated electricity was to power satellites ¹



PV systems in use on the roofs of houses ¹



PV Components²



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 systems¹

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?

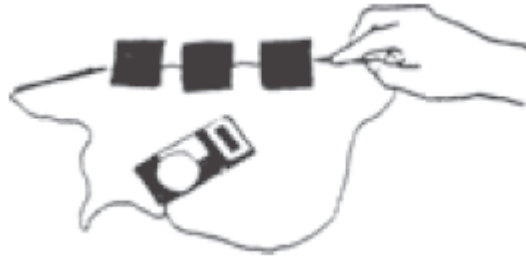
Procedure: Have students measure the current of a PV cell under a light source (a lamp or the sun). Then, have them concentrate the light source on the cell with a magnifying glass (move the magnifying glass around until a bright area appears on the cell). Measure the new current. Alternatively, students 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 measurements. 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:

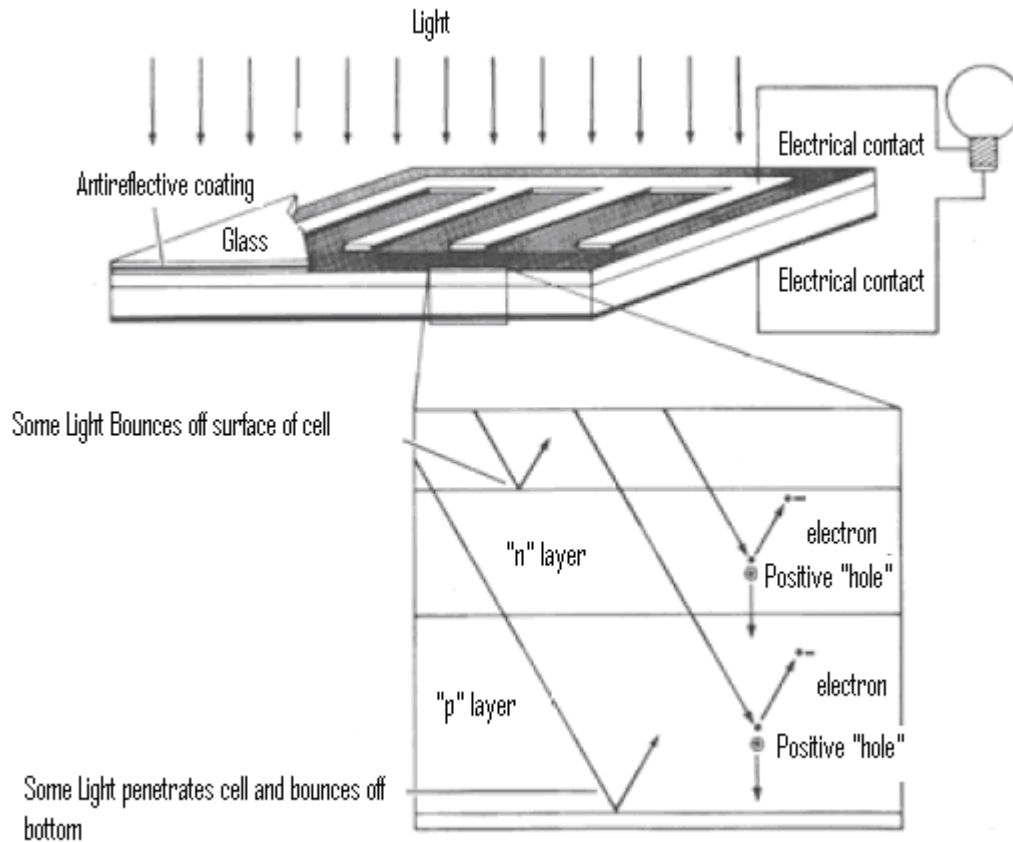
Information on Photovoltaics can be found from a host of sources. A convenient and reliable source is the US Department of Energy – National Center for Photovoltaics. Their website is <http://www.nrel.gov/ncpv/>

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 building's needs, but it does reduce the amount of electricity the school needs to purchase from the electric company.

“

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.

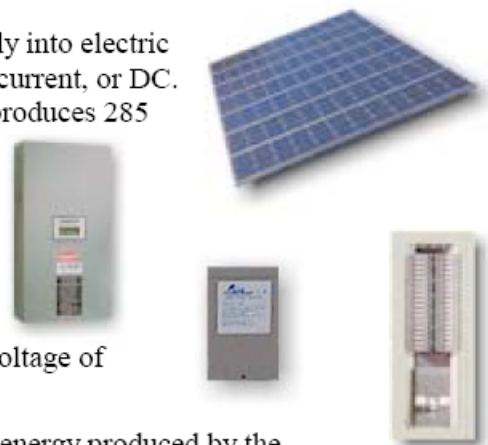
Inverter — The inverter changes the DC electricity produced by the modules into alternating current, or AC, electricity for use in the school building.

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.

» 1

ADDITIONAL INFORMATION FOR TEACHERS

SOURCES FOR THIS ADAPTED ACTIVITY:

1. Watts On Schools. *Introduction To Your School's Solar Electric System*. Available at <http://wattsonschoools.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 | a. Device that measures how much energy is being generated |
| _____ Photovoltaic Module | b. Device that measures sunlight |
| _____ Electric Meter | c. A group of photovoltaic modules |
| _____ PV Cells | d. Converts DC electricity into AC electricity |
| _____ Disconnects/Switches | e. Device that measures temperature |
| _____ Photovoltaic Array | f. Device that measures the wind speed |
| _____ Anemometer | g. Increases (steps up) or decreases (steps down) the voltage |
| _____ Datalogger | h. Made of semiconductor material that produces electricity when light hits it |
| _____ Thermometer | i. Safety devices that immediately stop the flow of electricity |
| _____ Transformer | j. A group of photovoltaic cells |
| _____ Pyranometer | 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

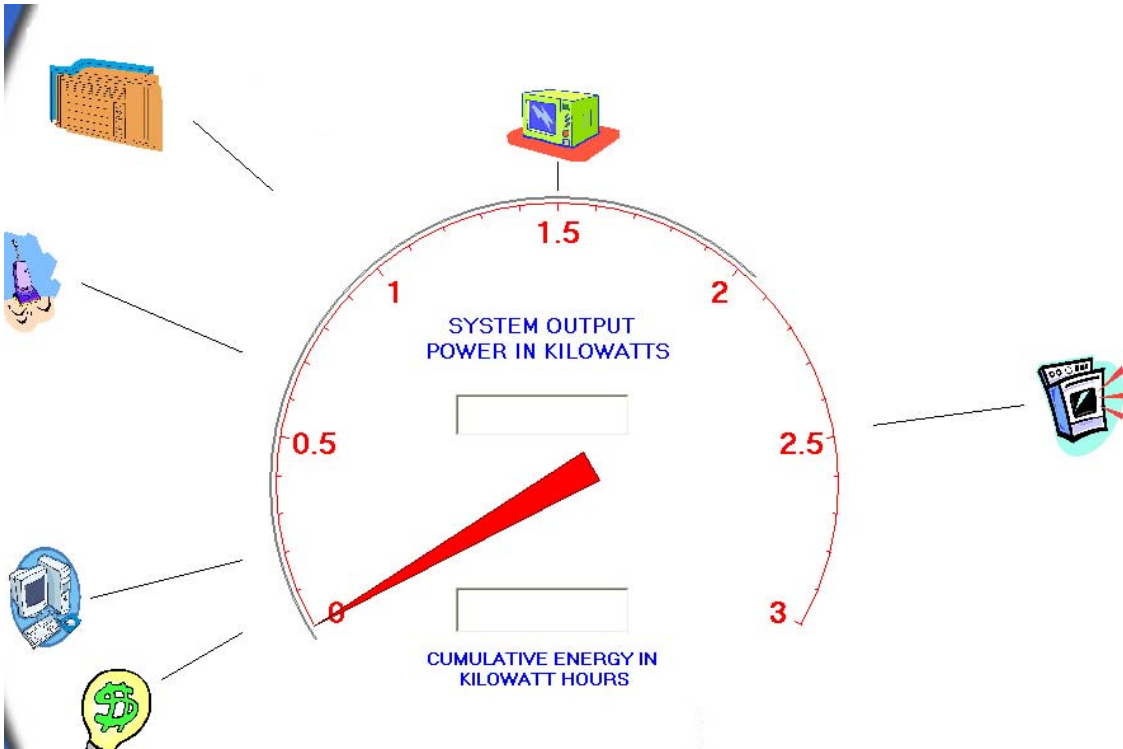
MATERIALS:

- 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?

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

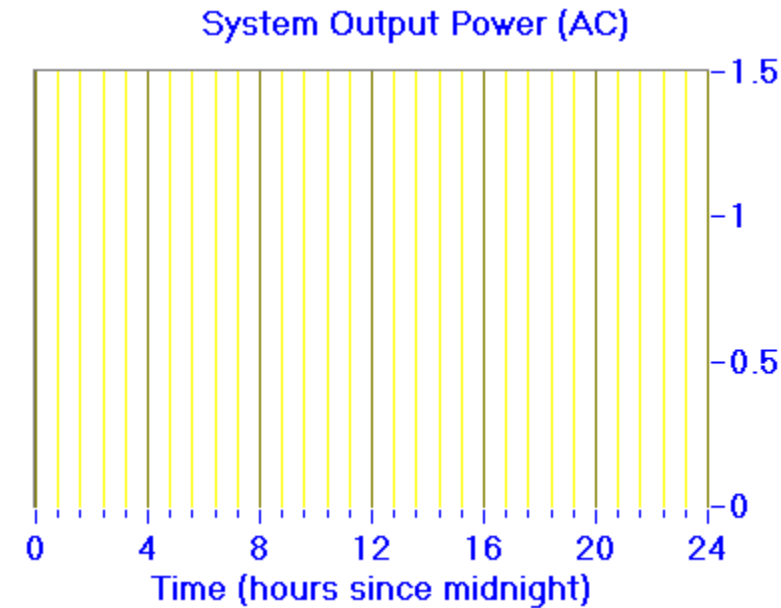
Nitrogen Oxides (NOX)
in kilograms

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).



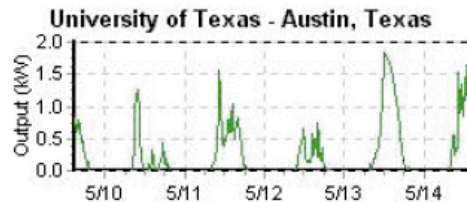
Plot of System Output Power over time

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.wattsonschoools.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.

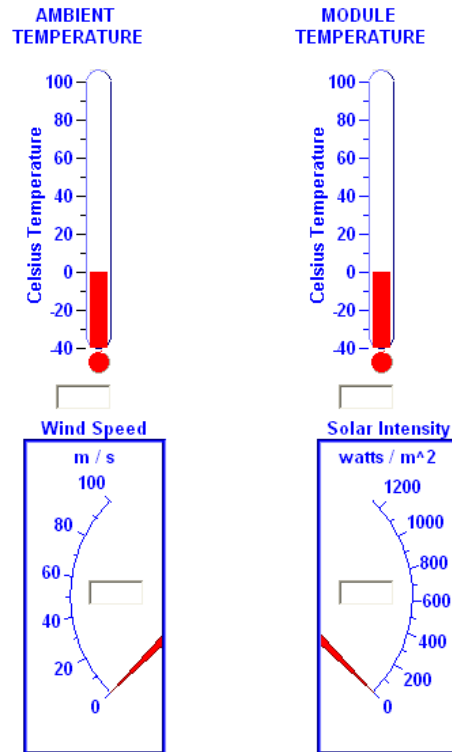
Students should be encouraged to discuss or write about each day on the plot in small groups. Students should be reminded that the graph is not a graph of weather or sunlight, but of the power production of the solar energy system. Although a plot of sunlight would look very much the same, an important 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://wattsonschoools.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:

$$\begin{aligned} &= (\text{Amount of water left} / \text{Amount of water collected}) \times 100 \\ &= (0.5 / 1) \times 100 \\ &= 50\% \end{aligned}$$

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

$$\begin{aligned} & (1 \text{ hamburger actually eaten} / 2 \text{ hamburgers that you could have eaten}) \times 100 \\ & = (1/2) \times 100 \\ & = 0.5 \times 100 \\ & = 50\% \end{aligned}$$

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:

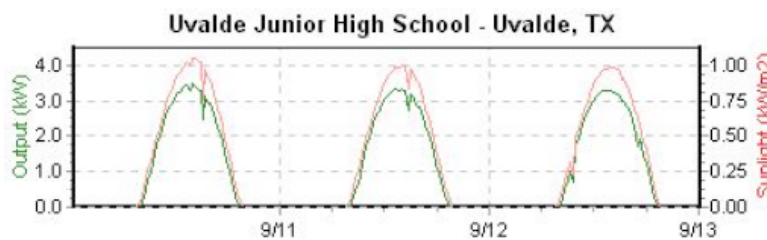
- How much energy the system actually produced at a certain time, and
- How much energy the system could have produced during that time.

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/m ²)
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,

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

For Fayetteville,

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

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:

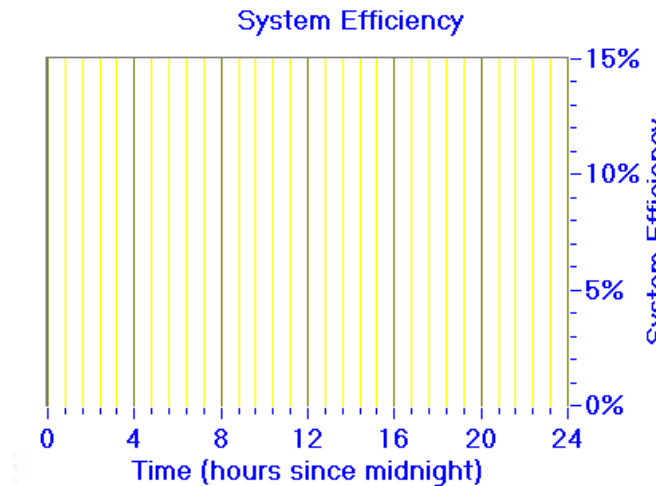
$$\begin{aligned} & (3.25 \text{ kW} / 38.808 \text{ kW}) \times 100 \\ & = 0.0837 \times 100 \\ & = 8.37\% \text{ Efficiency} \end{aligned}$$

For Fayetteville, we have:

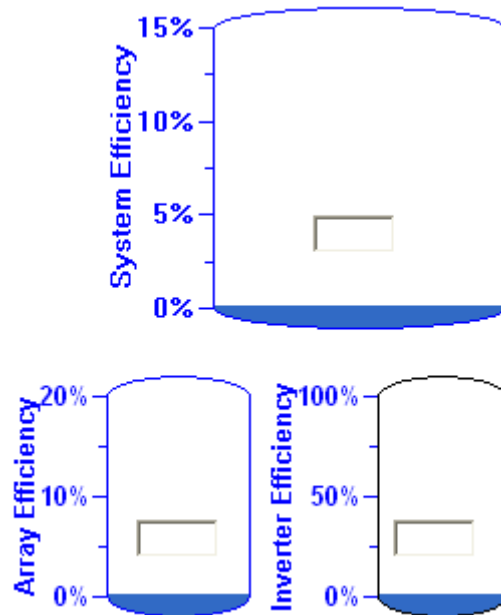
$$\begin{aligned} & (3.279 \text{ kW} / 33.414 \text{ kW}) \times 100 \\ & = 0.0981 \times 100 \\ & = 9.81\% \text{ Efficiency} \end{aligned}$$

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



	REAL TIME	DATA CAPTURE	
Solar Array Efficiency (percent)	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>
Inverter Efficiency (percent)	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>



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://wattsonschoools.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 photovoltaics 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 efficiently 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 data 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.wattsonschoools.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 NYSEDA's New York Energy SmartSM 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 NYSEDA'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* - NYSEDA 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 NYSEDA'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 by 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.