SCHOOLS GOING SOLAR

Activities to incorporate installed photovoltaic systems into the classroom learning environment.

GRADE LEVEL
5–12

SUBJECT AREAS
Science
Social Studies
Math
Language Arts
Technology

NEED
Putting Energy into Education

NEED Project PO Box 10101 Manassas, VA 20108 1-800-875-5029 www.NEED.org

Teacher Advisory Board

Teacher Advisory Board Vision Statement
NEED Mission Statement

The mission of the NEED Project is to promote an energy conscious and educated society by creating effective networks of students, educators, business, government and community leaders to design and deliver objective, multi-sided energy education programs.

In support of NEED, the national Teacher Advisory Board (TAB) is dedicated to developing and promoting standards-based energy curriculum and training.

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These suggested activities are for solar schools to use to incorporate the solar arrays into their solar/energy curriculum, in conjunction with the NEED solar curriculum and kits.

NEED Putting Energy into Education

IREC INTERSTATE RENEWABLE ENERGY COUNCIL

Why Introduce PV Projects In Schools?

Schools around the country are being offered opportunities to partner with government agencies, community foundations, utilities, businesses, and corporations to install PV systems. The Solar Electric Power Association states that, "…bringing solar to schools is an important first step to increasing the use of solar energy in the community at large. Schools make an excellent showcase for the benefits of solar photovoltaic electricity, solar thermal energy, and passive solar. Changes and improvements at schools are highly visible and closely followed. As has been the case with recycling programs, which were introduced to many communities by schoolchildren educating their parents, students can carry good ideas from the classroom into the mainstream."

The PV system installed at your school can provide energy savings. Depending on geographical location, a 2kW PV system produces an average of 7kW of electricity per day (enough electricity to power 10 computers) and an average annual output of 3000 kW. The environmental benefits include offsetting carbon dioxide (CO_2) produced by traditional power plants and vehicles.

For most schools, however, the decision to install PV systems is more about education and inspiration for their students than about cost savings. The students get a firsthand view of energy technologies. Integrating the data supplied by the PV systems into the school curriculum helps students learn about how solar electricity works and involves them in the study of the benefits of renewable energy and energy efficiency. The PV system also provides students with an opportunity to learn first-hand about employment opportunities in emerging renewable energy technology fields.

What Do Solar Schools Receive?

Many schools that choose to enter into a PV demonstration partnership receive all of the hardware and software needed for complete integration into the curriculum system. The systems typically range from 500 watts to 10 kilowatts in size and are usually designed to be mounted on peaked or flat roofs. Some systems are designed for ground or wall mounts for increased public visibility.

In order for students to be able to explore the PV system's effects on electricity use, many schools also receive data acquisition systems and interactive educational monitoring software designed to transmit data for educational use from the PV system. The goal of the monitoring software is to provide interaction with students and teachers, while also logging PV system data to a database for simple integration into class curricula. Adding an optional Internet component to the data acquisition hardware will allow data to be sent directly to a centralized database for interactive web explorations.

The data acquisition systems allow schools to monitor the daily and cumulative production of electricity from the system. The Internet-compatible data acquisition systems supplied to many schools allows teachers and students to monitor local atmospheric conditions (i.e. wind speed, temperature, solar radiations, etc.) and compare this data to the electrical production of the system.

In order to make full use of your PV system as a real-world teaching tool, teachers must find ways to integrate its use throughout the school's curricula. This booklet has been designed to provide teachers with ideas for integrating the system into your science, math, language arts, and social studies class curricula. The ideas in this booklet will help your students master the concepts they need to know about solar energy and PV systems.

Correlations to National Science Content Standards

(Bolded standards are emphasized in the unit.)

INTERMEDIATE (5-8) CONTENT STANDARD A: SCIENCE AS INQUIRY

1. Abilities Necessary to do Scientific Inquiry

a. **Identify questions that can be answered through scientific investigations.**

b. **Design and conduct a scientific investigation.**

c. **Use appropriate tools and techniques to gather, analyze, and interpret data.**

d. **Develop descriptions, explanations, predictions, and models using evidence.**

e. **Think critically and logically to make the relationships between evidence and explanations.**

f. **Recognize and analyze alternative explanations and predictions.**

g. **Communicate scientific procedures and explanations.**

h. **Use mathematics in all aspects of scientific inquiry.**

2. Understandings about Scientific Inquiry

c. Mathematics is important in all aspects of scientific inquiry.

d. **Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.**

INTERMEDIATE B: PHYSICAL SCIENCE

3. Transfer of Energy

a. Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

f. The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

INTERMEDIATE E: SCIENCE AND TECHNOLOGY

2. Understandings about Science and Technology

d. Perfectly designed solutions do not exist. All technological solutions have trade-offs, such as safety, cost, efficiency, and appearance. Engineers often build in back-up systems to provide safety. Risk is part of living in a highly technological world. Reducing risk often results in new technology.

e. Technological designs have constraints. Some constraints are unavoidable, for example, properties of materials, or effects of weather and friction; other constraints limit choices in the design, for example, environmental protection, human safety, and aesthetics.

INTERMEDIATE F: SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

3. Natural Hazards

b. Human activities also can induce hazards through resource acquisition, urban growth, land-use decisions, and waste disposal. Such activities can accelerate many natural changes.

SECONDARY (9-12) CONTENT STANDARD A: SCIENCE AS INQUIRY

1. Abilities Necessary to do Scientific Inquiry

a. **Identify questions and concepts that guide scientific investigations.**

b. **Design and conduct scientific investigations.**

c. **Use technology and mathematics to improve investigations and communications.**

d. **Formulate and revise scientific explanations and models using logic and evidence.**

f. **Recognize and analyze alternative explanations and models.**

g. **Communicate and defend a scientific argument.**

2. Understandings about Scientific Inquiry

c. **Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used.**

d. **Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.**

SECONDARY F: SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

3. Natural Resources

a. Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have been and will continue to be used to maintain human populations.

b. The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed.

4. Environmental Quality

a. Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrological cycle, disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.

b. Materials from human societies affect both chemical an physical cycles of the earth.

c. Many factors influence environmental quality. Factors that students might investigate include population growth, resource use, population distribution, over consumption, the capacity of technology to solve problems, poverty, the role of economic, political, and religious views, and different ways humans view the earth.

5. Natural and Human-induced Hazards

b. Human activities can enhance potential for hazards. Acquisition of resources, urban growth, and waste disposal can accelerate rates of natural change.

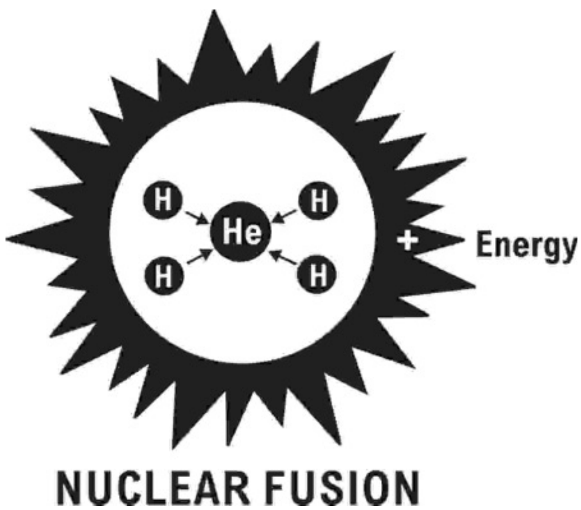
6. Science and Technology in Local, National, and Global Challenges

e. Humans have a major effect on other species. For example, the influence of humans on other organisms occurs through land use—which decreases space available to other species—and pollution—which changes the chemical composition of air, soil, and water.

What Is Solar Energy?

Solar energy is radiant energy from the sun. It is vital to us because it provides the world—directly or indirectly—with almost all of its energy. In addition to providing the energy that sustains the world, solar energy is stored in fossil fuels and biomass, and is responsible for powering the water cycle and producing wind.

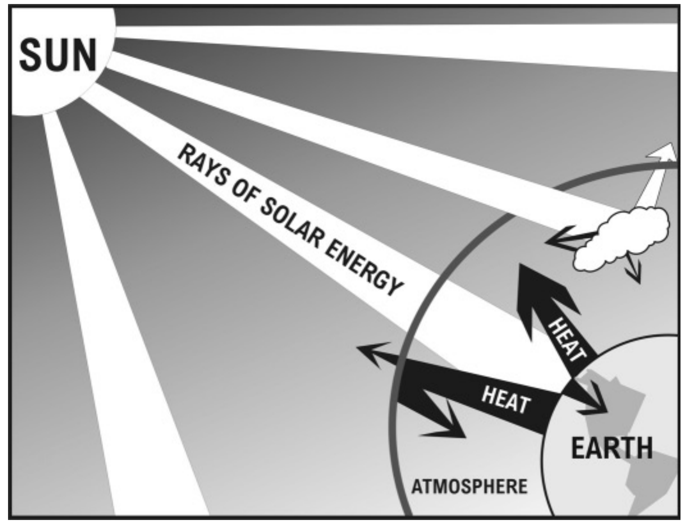
Every day the sun radiates, or sends out, an enormous amount of energy. The sun radiates more energy in one second than people have used since the beginning of time! Solar energy comes from within the sun itself. Like other stars, the sun is a big ball of gases—mostly hydrogen and helium. The hydrogen atoms in the sun's core combine to form helium and radiant energy in a process called **nuclear fusion**.



During nuclear fusion, the sun's extremely high pressure and temperature cause hydrogen atoms to come apart and their nuclei (the central cores of the atoms) to fuse or combine. Four hydrogen nuclei fuse to become one helium atom. But the helium atom contains less mass than the four hydrogen atoms that fused. Some matter is lost during nuclear fusion. The lost matter is emitted into space as **radiant energy**.

It takes millions of years for the energy in the sun's core to make its way to the solar surface, and then just a little over eight minutes to travel the 93 million miles to earth. The solar energy travels to the earth at a speed of 186,000 miles per second (3.0×10^8 meters per second), the speed of light. No heat from the sun travels to the earth; the light turns into heat when it is absorbed by molecules on earth.

Only a small portion of the energy radiated by the sun into space strikes the earth, one part in two billion. Yet this amount of energy is enormous. Every day enough energy strikes the United States to supply the nation's energy needs for one and a half years!



Where does all this energy go? About 15 percent of the sun's energy that hits the earth is reflected back into space. Another 30 percent powers the water cycle: it evaporates water that is then drawn into the atmosphere, turns into clouds, and falls back to earth as precipitation. Plants, the land, and the oceans also absorb solar energy. The rest could be used to supply our energy needs.

Solar energy is considered a **renewable** energy source. Renewable sources of energy are resources that are continually renewed by nature, and hence will never run out. Solar power is considered renewable because the nuclear (fusion) reactions that power the sun are expected to keep generating sunlight for many billions of years to come.

History of Solar Energy

People have harnessed solar energy for centuries. As early as the 7th century B.C., people used simple magnifying glasses to concentrate the light of the sun into beams so hot they would cause wood to catch fire.

More than 100 years ago in France, a scientist used heat from a solar collector to make steam to drive a steam engine. In the United States in the 1860s, John Ericsson developed the first realistic application of solar energy using a solar reflector to drive an engine in a steam boiler.

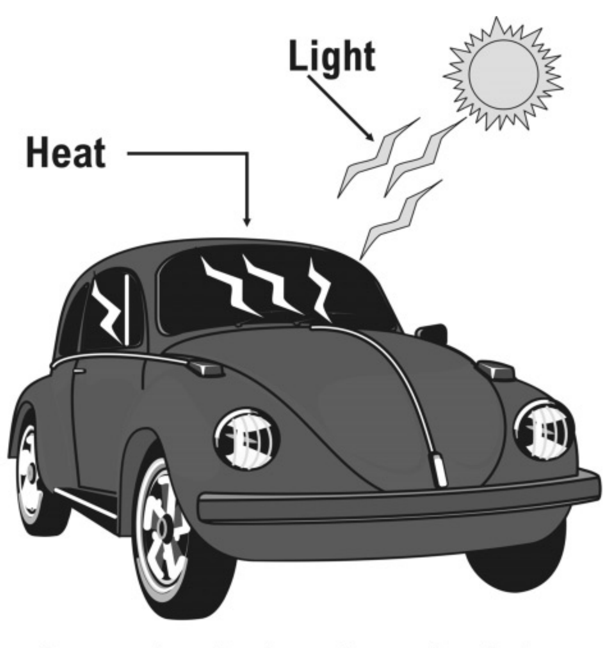
Early in the 1900s, scientists and engineers began seriously researching ways to use solar energy. The solar water heater gained popularity during this time in Florida, California, and the Southwest. The industry was in full swing just before World War II. This growth lasted until the mid-1950s when low-cost natural gas became the primary fuel for heating homes and water, and the use of solar energy lost popularity.

The public and world governments remained largely indifferent to the possibilities of solar energy until the energy crises of the 1970s. Research efforts since that time, in the U.S. and around the world, have resulted in tremendous improvements in solar technologies for heating water and buildings and making electricity.

Solar Collectors

Heating with solar energy is relatively easy—just look at a car parked in the sun with its windows closed. Getting the right amount of heat in a desired location, however, requires more thought and careful design. Capturing sunlight and putting it to work effectively is difficult because the solar energy that reaches the earth is spread out over a large area. The sun does not deliver that much energy to any one place at any one time.

How much solar energy a place receives depends on several conditions. These include the time of day, the season of the year, the latitude of the area, and the clearness or cloudiness of the sky.



On a sunny day, a closed car works as a solar collector. Light passes through the glass, is absorbed and changed into heat. The heat then gets trapped inside.

A solar collector is one way to collect heat from the sun. A closed car on a sunny day is like a solar collector. As the sunlight passes through the car's glass windows, it is absorbed by the seat covers, walls, and floor of the car.

The light that is absorbed changes into heat. The car's glass windows let light in, but don't let all the heat out. This is also why greenhouses work so well and stay warm year-round. A greenhouse or solar collector:

- allows sunlight in through the glass;
- absorbs the light and changes it into heat; and
- traps most of the heat inside.

Solar Space Heating

Space heating means heating the space inside a building. Today many homes use solar energy for space heating. There are two general types of solar space heating systems: passive and active.

Passive Solar Homes

In a passive solar home, the house operates as a solar collector. A passive house does not use any special mechanical equipment such as pipes, ducts, fans, or pumps to transfer the heat that the house collects on sunny days. Instead, a passive solar home relies on properly oriented windows and is designed with added thermal mass to store and release heat. Since the sun shines from the south in North America, passive solar homes are built so that most of the windows face south. They often have few or no windows on the north side.

A passive solar home converts solar energy into heat just as a closed car does. Sunlight passes through a home's windows and is absorbed in the walls and floors. Materials such as tile, stone and concrete are often used, because they can store more heat than wood or sheetrock. To control the amount of heat in a passive solar house, the designer must determine the appropriate balance of mass in the floors and walls and admission of sunlight.

Windows let in the sunlight, which is converted into heat when it is absorbed by the walls and floors. The mass stores the heat from the sun and releases it when the air temperature inside drops below the temperature of the mass. Heating a house by warming the walls or floors is more comfortable than heating the air inside a house.

Additionally, the doors and windows can be closed to keep heated air in or opened to let it out to keep the temperature in a comfortable range. At night, special heavy curtains or shades can be pulled over the windows to keep the daytime heat inside the house. In the summer, awnings or roof overhangs help to shade the windows from the high summer sun to prevent the house from overheating. Passive homes are quiet, peaceful places to live. A well-designed passive solar home can harness 50 to 80 percent of the heat it needs from the sun.

Many passive homeowners install equipment, such as fans to help circulate air, to further increase the comfort and energy efficiency of their homes. When special equipment is added to a passive solar home, it is called a **hybrid** system.

Active Solar Homes

Unlike a passive solar home, an active solar home uses mechanical equipment, such as pumps and blowers, to gain greater control of when, where and how much of the collected heat from the sun gets used. The active solar home is designed to deliver the heat from where it is collected to where it is needed.

Storing Solar Heat

The challenge confronting any solar heating system—whether passive, active, or hybrid—is heat storage. Solar heating systems must have some way to store the heat that is collected on sunny days to keep people warm at night or on cloudy days.

In passive solar homes, heat is stored by using dense interior materials that retain heat well—masonry, adobe, concrete, stone, or water. These materials absorb surplus heat and radiate it back into the room when the air temperature is lower than the surface temperature of the material. Some passive homes have walls a foot thick.

In active solar homes, heat may be stored in one of two ways—a large tank may store a heated liquid, or rock bins beneath the house may store warm mass. Houses with active or passive solar heating systems may also have furnaces, wood-burning stoves, or other heat sources to provide heat during long periods of cold or cloudy weather. These are called **backup** systems.

Solar Water Heating

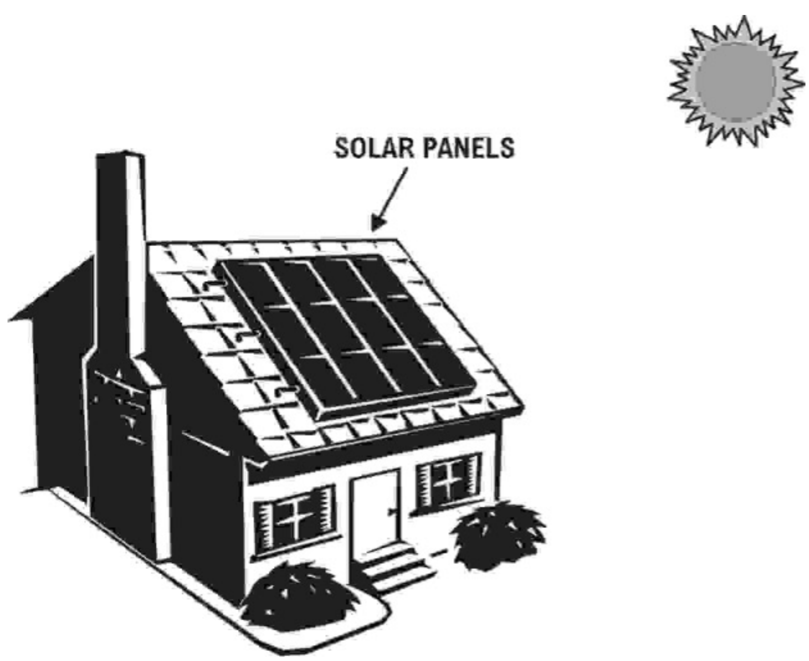
Solar energy is also used to heat water. Water heating is usually the third leading home energy expense, costing the average family over $200 a year.

Depending on where you live, and how much hot water your family uses, a solar water heater can pay for itself in as little as five years. A well-maintained solar water heating system can last 15-20 years, longer than a conventional water heater.

A solar water heater works in the same way as solar space heating. A solar collector is mounted on the roof, or in an area of direct sunlight. It collects sunlight and converts it to heat. When the fluid becomes hot enough, a thermostat starts a pump. The pump circulates the fluid through the collector until it reaches the required temperature, called the set point. Then the heated fluid is pumped to a storage tank where it is used in a heat exchanger to heat water.

The hot water may then be piped to a faucet or showerhead. Most solar water heaters that operate in cold climates use a heat transfer fluid similar to antifreeze that will not freeze and damage the system.

Today, over 1.5 million homes in the U.S. use solar heaters to heat water for their homes or swimming pools. Besides heating homes and water, solar energy also can be used to produce electricity. Two ways to generate electricity from solar energy are photovoltaics and solar thermal systems.



Photovoltaics

Photovoltaic (or PV) systems convert light directly into electricity. The term *photo* comes from the Greek *phos*, which means light. The term *volt* is a measure of electricity named for Alessandro Volta (1745-1827), a pioneer in the development of electricity. Photovoltaics literally means *light–electricity*.

Alessandro Volta

Commonly known as solar cells, PV cells are already an important part of our lives. The simplest PV systems power many of the small calculators and wrist watches we use every day. Larger PV systems provide electricity for pumping water, powering communications equipment, and even lighting homes and running appliances. In certain applications, such as motorist aid call boxes on highways and pumping water for livestock, PV power is the cheapest form of electricity. Some electric utility companies are building PV systems into their power supply networks.

History of Photovoltaics

French physicist Edmond Becquerel first described the photovoltaic (PV) effect in 1839, but it remained a curiosity of science for the next half century. At the age of 19, Becquerel found that certain materials would produce small amounts of electric current when exposed to light. The effect was first studied in solids, such as selenium, by Heinrich Hertz in the 1870s. Soon selenium PV cells were converting light to electricity at one to two percent efficiency.

The **conversion efficiency** of a PV cell is the proportion of sunlight energy that the cell converts into electrical energy relative to the amount of sunlight that is available and striking the PV cell. This is very important when discussing PV devices, because improving this efficiency is vital to making PV energy competitive with more traditional sources of energy, such as fossil fuels.

During the second half of the 20th century, PV science was refined and the process more fully explained. Major steps toward commercializing PV were taken in the 1940s and 1950s, when the Czochralski process was developed for producing highly pure crystalline silicon.

In 1954, scientists at Bell Laboratories depended on the Czochralski process to develop the first crystalline silicon photovoltaic cell, which had a conversion efficiency of four percent.

As a result of technological advances, the cost of PV cells has decreased significantly over the past 25 years, as the efficiency has increased. Today's commercially available PV devices convert seven to 17 percent of the radiant energy that strikes them into electricity.

In the laboratory, combining exotic materials with specialized cell designs has produced PV cells with conversion efficiencies as high as 38 percent.

Solar Systems

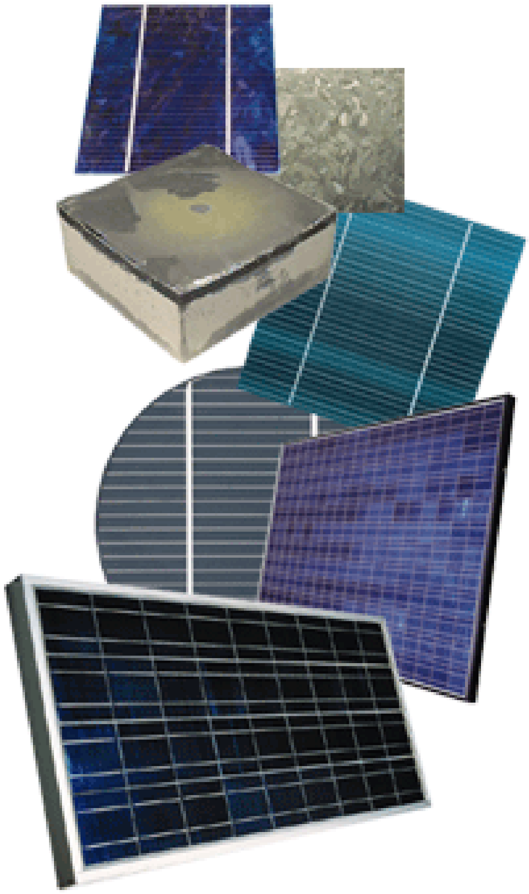
The **photovoltaic effect** is the basic physical process through which a PV cell converts sunlight directly into electricity. PV technology works any time the sun is shining, but more electricity is produced when the light is more intense and when it is striking the PV modules directly—when the rays of sunlight are perpendicular to the PV modules.

Unlike solar systems for heating water, with which you might be more familiar, PV technology does not produce heat to make electricity. Instead, PV cells generate electricity directly from the electrons freed by the interaction of radiant energy with the semiconductor materials in the PV cells.

Sunlight is composed of **photons**, or bundles of radiant energy. When photons strike a PV cell, they may be reflected or absorbed, or transmitted through the cell. Only the absorbed photons generate electricity. When the photons are absorbed, the energy of the photons is transferred to electrons in the atoms of the solar cell, which is actually a semiconductor.

With their newfound energy, the electrons are able to escape from their normal positions associated with their atoms to become part of the current in an electrical circuit. By leaving their positions, the electrons cause holes to form in the atomic structure of the cell into which other electrons can move.

Special electrical properties of the PV cell—a built-in electric field—provide the voltage needed to drive the current through a circuit and power an external load, such as a light bulb.



Photovoltaic Cells

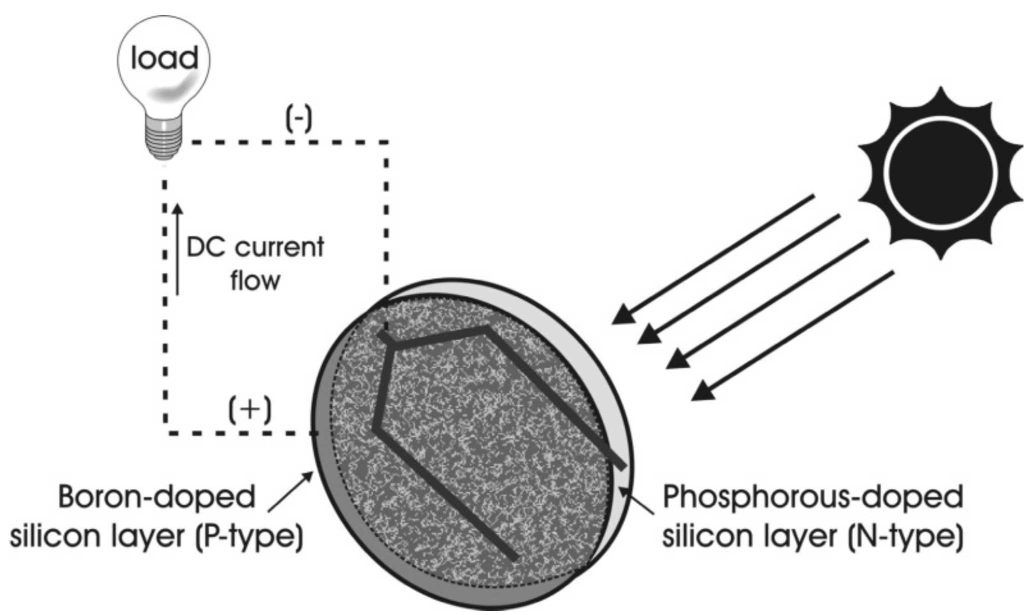
The basic building block of PV technology is the photovoltaic cell. PV cells come in many shapes and sizes. The most common shapes are circles, rectangles and squares. The size and the shape of a PV cell and the number of PV cells required for one PV module depend on the material of which the PV cell is made.

Different materials are used to produce PV cells, but silicon—the main ingredient in sand—is the most common basic material. Silicon is a relatively cheap material because it is widely available and used in other things, such as televisions, radios and computers. PV cells, however, require very pure silicon, which can be expensive to produce.

The amount of electricity a PV cell produces depends on its size, its conversion efficiency, and the intensity of the light source. Efficiency is a measure of the amount of electricity produced from the sunlight that a cell receives. A typical PV cell produces 0.5 volts of electricity. It takes just a few PV cells to produce enough electricity to power a small watch or solar calculator.

The most important parts of a PV cell are the semi-conductor layers, where the electron current is created. There are a number of different materials suitable for making these semi-conducting layers, and each has benefits and drawbacks. Unfortunately, there is no one ideal material for all types of cells and applications.

When sunlight strikes the surface of a PV cell, the electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of electric current, or flow of electrons, when the solar cell is connected in a circuit.



How a PV Cell is Made

Let's look more closely at how a PV cell is made and how it produces electricity.

Step 1

A slab (or wafer) of pure silicon is used to make a PV cell. The top of the slab is very thinly diffused with the dopant phosphorous. On the base of the slab a small amount of the dopant boron is diffused. The boron side of the slab is 1,000 times thicker than the phosphorous side. **Dopants** are similar in atomic structure to the primary material. The phosphorous has one more electron in its outer shell than silicon, and the boron has one less. These dopants help create the magnetic field that makes it easier for the electrons to become dislodged when light strikes the PV cell.

The phosphorous gives the wafer of silicon an excess of free electrons; it has a negative character. This is called the **n-type** silicon. The n-type silicon is not charged – it has an equal number of protons and electrons – but some of the electrons are not held tightly to the atoms. They are free to move to different locations within the layer.

The boron gives the base of the silicon a positive character, because it has a tendency to attract electrons. The base of the silicon is called **p-type** silicon (p = positive). The p-type silicon has an equal number of protons and electrons; it has a positive character but not a positive charge.

Step 2

Where the n-type silicon and p-type silicon meet, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving between the two sides. This point of contact and barrier is called the **p-n junction**.

When both sides of the silicon slab are doped, there is a negative charge in the p-type section of the junction and a positive charge in the n-type section of the junction. This imbalance in electrical charge at the p-n junction produces an electric field between the p-type and n-type.

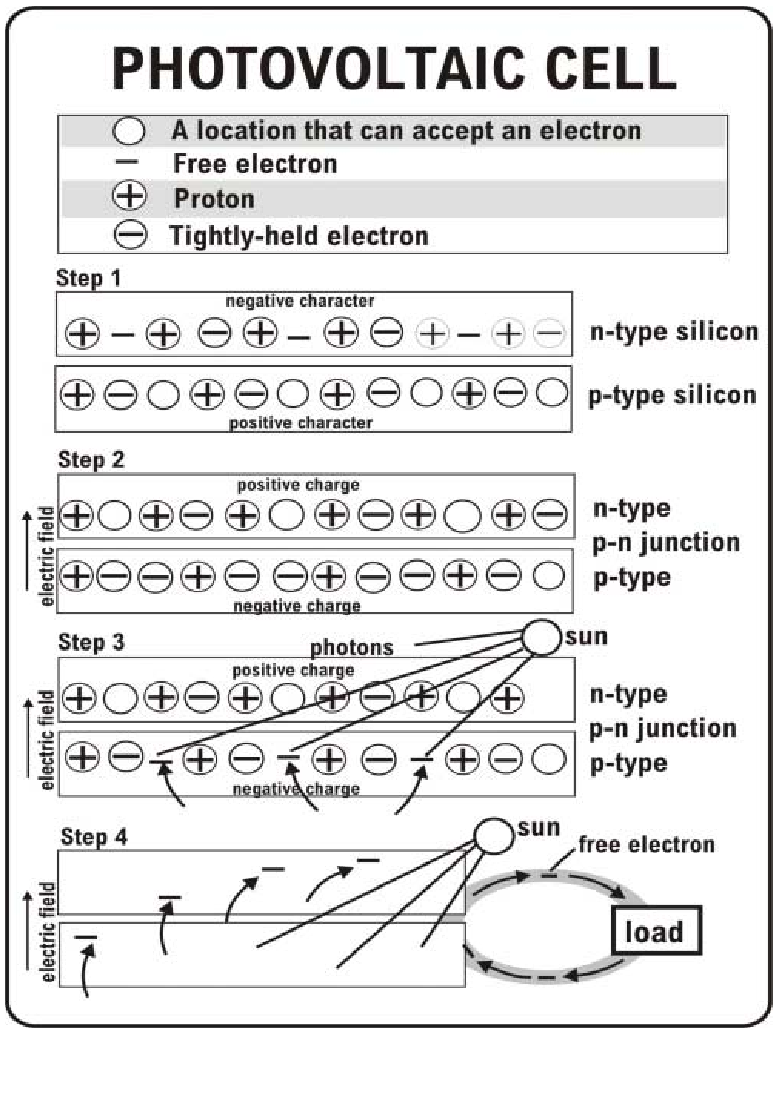
Step 3

If the PV cell is placed in the sun, photons of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-layer and repelled by the negative charge in the p-layer.

Step 4

A conducting wire connects the p-type layer to the n-type layer and forms a circuit. As the free electrons are pushed into the n-type silicon they repel each other because they are of like charge. The wire provides a path for the electrons to move away from each other. This flow of electrons is an electric current that can power a load, such as a calculator or other device, as it travels through the circuit from the n-layer to the p-layer.

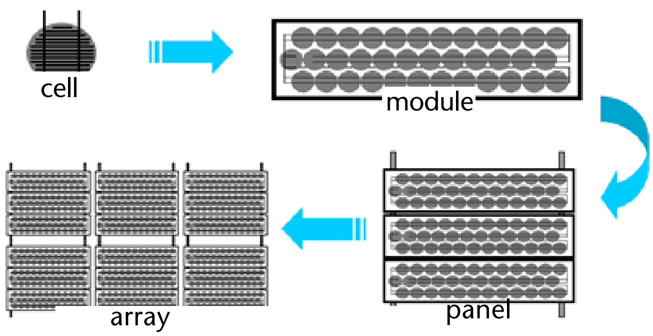
In addition to the semi-conducting materials, solar cells consist of a top metallic grid or other electrical contact to collect electrons from the semi-conductor and transfer them to the external load, and a back contact layer to complete the electrical circuit.



PV Modules, Panels and Arrays

For more power, cells are connected together to form larger units called modules. Photovoltaic cells are connected in series and/or parallel circuits to produce higher voltages, currents and power levels. A PV module is the smallest PV component sold commercially, and can range in power output from about 10 watts to 300 watts.

A typical PV module consists of PV cells sandwiched between a clear front sheet, usually glass, and a backing sheet, usually glass or a type of tough plastic. This protects them from breakage and from the weather. An aluminum frame can be fitted around the PV module to enable easy affixing to a support structure. Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit. A PV array is the complete power-generating unit, consisting of any number of modules and panels.



PV System Components

Although a PV module produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array. Depending on the type of system, these components may include:

Power Inverter: PV modules, because of their electrical properties, produce direct current (DC) rather than alternating current (AC). Direct current is electric current that flows in a single direction. Many simple devices, such as those that run on batteries, use direct current. Alternating current, in contrast, is electric current that reverses its direction of flow at regular intervals (120 times per second). This is the type of electricity provided by utilities and the type required to run most modern appliances and electronic devices.

In the simplest systems, DC current produced by PV modules is used directly. In applications where AC current is necessary, an inverter can be added to the system to convert DC to AC current.

Battery System: PV systems cannot store electricity, so batteries are often added. A PV system with a battery is configured by connecting the PV array to an inverter. The inverter is connected to a battery bank and to any load. During daylight hours, the PV array charges the battery bank. The battery bank supplies power to the load whenever it is needed. A device called a charge controller keeps the battery properly charged and prolongs its life by protecting it from being overcharged and completely discharged.

PV systems with batteries can be designed to power DC or AC equipment. Systems operating only DC equipment do not need an inverter, only a charge controller.

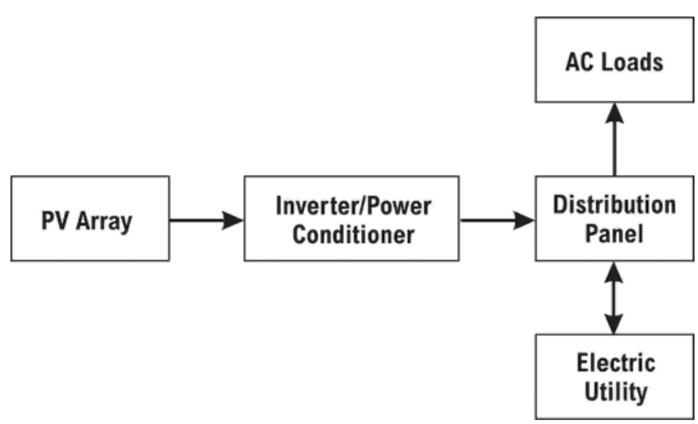
PV Systems

Two types of PV systems are grid-connected systems and stand-alone systems. The main difference between these systems is that one is connected to the utility grid and the other is not.

Grid Connected Systems

Grid-connected PV systems are designed to operate in parallel with and interconnected with the national electric utility grid. What is the **grid**? It is the network of cables through which electricity is transported from power stations to homes, schools and other places. A grid connected PV system is linked to this network of power lines.

The primary component of a grid-connected PV system is the inverter, or power conditioning unit (PCU). The inverter converts the DC power produced by the PV system into AC power consistent with the voltage and power quality requirements of the utility grid. This means that it can deliver the electricity it produces into the electricity network and draw it down when needed; no battery or other storage is needed.



Stand-alone Systems

As its name suggests, this type of PV system is a separate electricity supply system. A stand-alone system is designed to operate independent of the electric utility grid and to supply electricity to a single system. Usually a stand-alone system includes one or more batteries to store the electricity.

Historically, PV systems were used only as stand–alone systems in remote areas where there was no other electricity supply. Today, stand-alone systems are used for water pumping, highway lighting, weather stations, remote homes and other uses away from power lines.

Benefits and Limitations

Benefits

Solar electric systems offer many advantages:

They are safe, clean and quiet to operate.

They are highly reliable.

They require virtually no maintenance.

They are cost-effective in remote areas and for some residential and commercial applications.

They are flexible and can be expanded to meet increasing electrical needs.

They can provide independence from the grid or backup during outages.

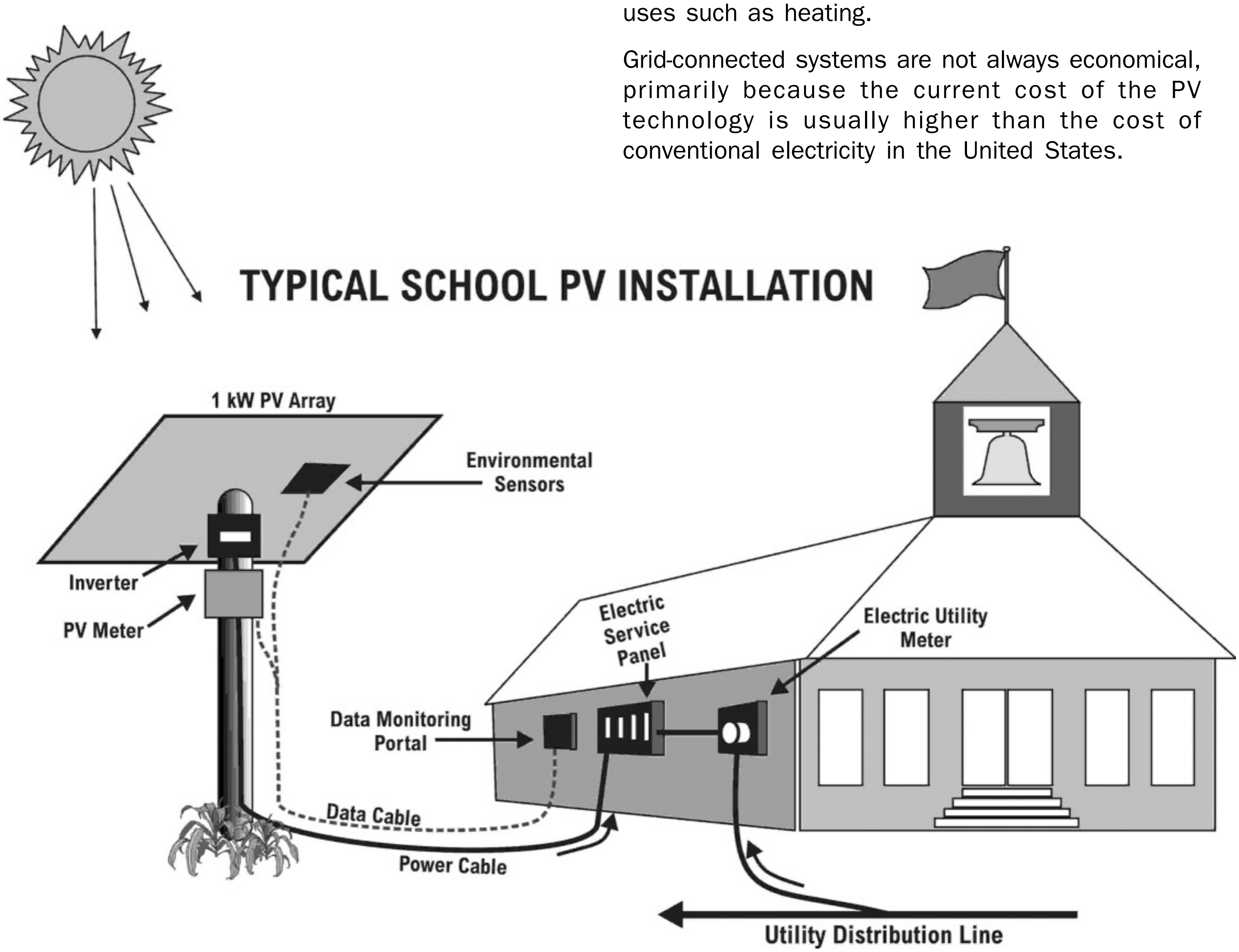
The fuel is renewable and free.

Limitations

There are also several limitations to PV systems:

PV systems are not well suited for energy-intensive uses such as heating.

Grid-connected systems are not always economical, primarily because the current cost of the PV technology is usually higher than the cost of conventional electricity in the United States.



Measuring Electricity

Electricity makes our lives easier, but it can seem like a mysterious force. Measuring electricity is confusing because we cannot see it. We are familiar with terms such as watt, volt, and amp, but we do not have a clear understanding of these terms. We buy a 60-watt lightbulb, a tool that needs 120 volts, or a vacuum cleaner that uses 8.8 amps, and don't think about what those units mean.

Using the flow of water as an analogy can make electricity easier to understand. The flow of electrons in a circuit is similar to water flowing through a hose. If you could look into a hose at a given point, you would see a certain amount of water passing that point each second.

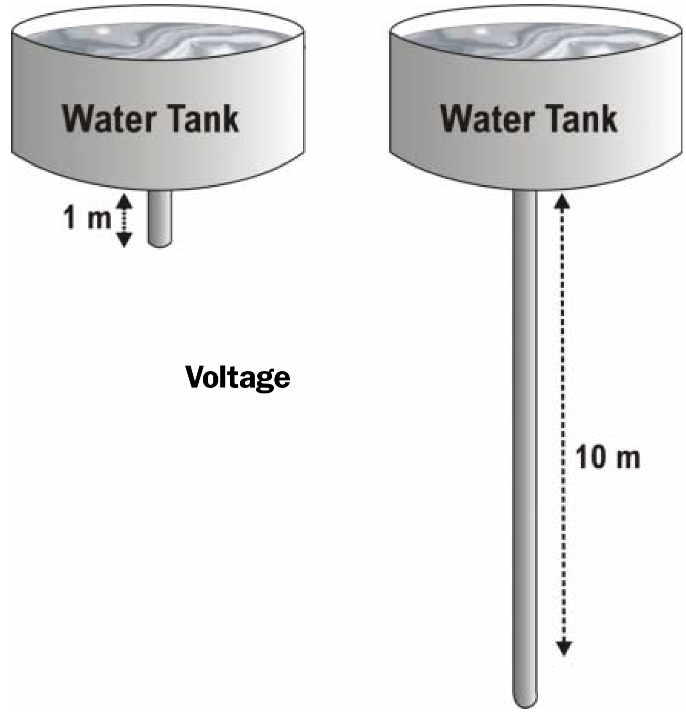
The amount of water depends on how much pressure is being applied––how hard the water is being pushed. It also depends on the diameter of the hose. The harder the pressure and the larger the diameter of the hose, the more water passes each second. The flow of electrons through a wire depends on the electrical pressure pushing the electrons and on the cross-sectional area of the wire.

Voltage

The pressure that pushes electrons in a circuit is called **voltage**. Using the water analogy, if a tank of water were suspended one meter above the ground with a ten-centimeter pipe coming out of the bottom, the water pressure would be similar to the force of a shower. If the same water tank were suspended 10 meters above the ground, the force of the water would be much greater, possibly enough to hurt you.

Voltage (V) is a measure of the pressure applied to electrons to make them move. It is a measure of the strength of the current in a circuit and is measured in **volts (V)**. Just as the 10-meter tank applies greater pressure than the 1-meter tank, a 10-volt power supply (such as a battery) would apply greater pressure than a 1-volt power supply.

AA batteries are 1.5-volt; they apply a small amount of voltage or pressure for lighting small flashlight bulbs. A car usually has a 12-volt battery—it applies more voltage to push current through circuits to operate the radio or defroster. The voltage of typical wall outlets is 120 volts—a dangerous amount of voltage. An electric clothes dryer is usually wired at 240 volts—a very dangerous voltage.

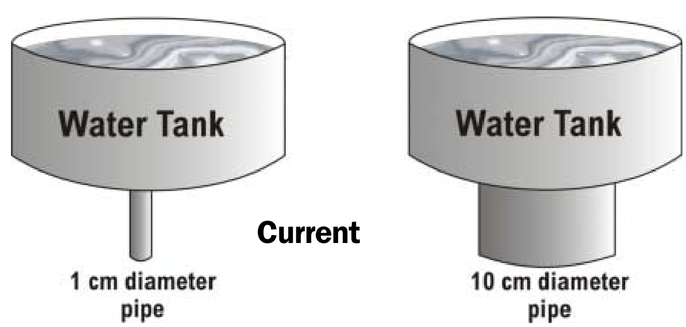


Voltage

Current

The flow of electrons can be compared to the flow of water. The water current is the number of molecules flowing past a fixed point; electrical current is the number of electrons flowing past a fixed point. **Electrical current (I)** is defined as electrons flowing between two points having a difference in voltage. Current is measured in **amperes** or **amps (A)**. One ampere is 6.25 X 10^{18} electrons per second passing through a circuit.

With water, as the diameter of the pipe increases, so does the amount of water that can flow through it. With electricity, conducting wires take the place of the pipe. As the cross-sectional area of the wire increases, so does the amount of electric current (number of electrons) that can flow through it.



Current

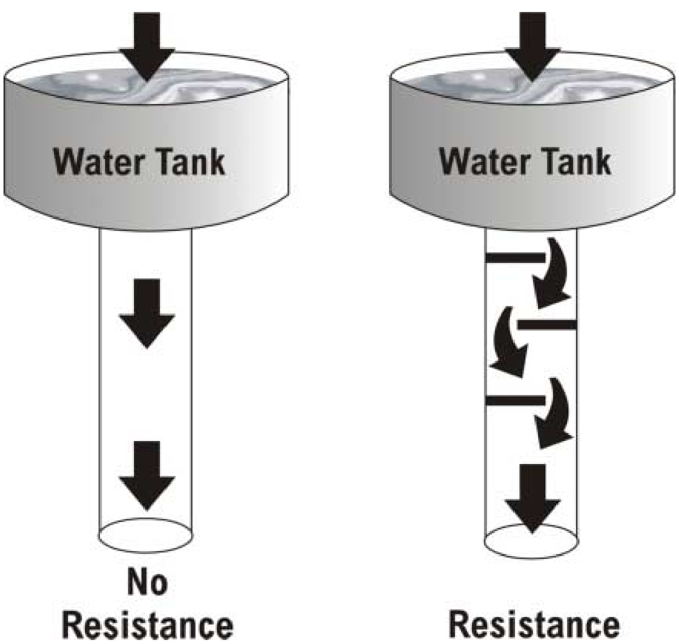
Resistance

Resistance (R) is a property that slows the flow of electrons. Using the water analogy, resistance is anything that slows water flow, a smaller pipe or fins on the inside of a pipe.

In electrical terms, the resistance of a conducting wire depends on the metal the wire is made of and its diameter. Copper, aluminum, and silver—metals used in conducting wires—have different resistance.

Resistance is measured in units called **ohms (Ω)**. There are devices called **resistors**, with set resistances, that can be placed in circuits to reduce or control the current flow.

Any device placed in a circuit to do work is called a **load**. The lightbulb in a flashlight is a load. A television plugged into a wall outlet is also a load. Every load has built-in resistance.



Ohm's Law

George Ohm, a German physicist, discovered that in many materials, especially metals, the current that flows through a material is proportional to the voltage.

In the substances he tested, he found that if he doubled the voltage, the current also doubled. If he reduced the voltage by half, the current dropped by half. The resistance of the material remained the same.

This relationship is called **Ohm's Law**, and can be written in a simple formula. If you know any two of the measurements, you can calculate the third using the following formula:

voltage = current x resistance

$V = I \times R$ or $V = A \times \Omega$

Electrical Power

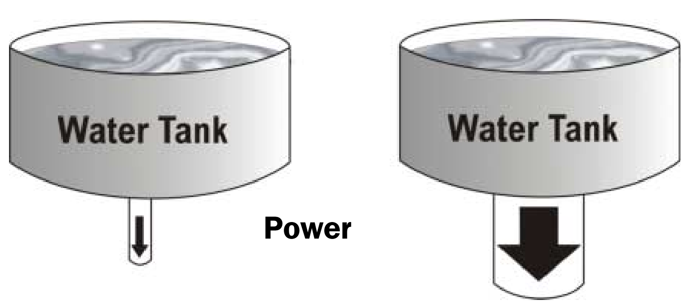
Power (P) is a measure of the rate of doing work or the rate at which energy is converted. Electrical power is the rate at which electricity is produced or consumed. Using the water analogy, electric power is the combination of the water pressure (voltage) and the rate of flow (current) that results in the ability to do work.

A large pipe carries more water (current) than a small pipe. Water at a height of 10 meters has much greater force (voltage) than at a height of one meter. The power of water flowing through a 1-centimeter pipe from a height of one meter is much less than water through a 10-centimeter pipe from 10 meters.

Electrical power is defined as the amount of electric current flowing due to an applied voltage. It is the amount of electricity required to start or operate a load for one second. Electrical power is measured in **watts (W)**. The formula is:

power = voltage x current

$P = V \times I$ or $W = V \times A$



Electrical Energy

Electrical energy introduces the concept of time to electrical power. In the water analogy, it would be the amount of water falling through the pipe over a period of time, such as an hour. When we talk about using power over time, we are talking about using energy. Using our water example, we could look at how much work could be done by the water in the time that it takes for the tank to empty.

The electrical energy that an appliance or device consumes can be determined only if you know how long (time) it consumes electrical power at a specific rate (power).

To find the amount of energy consumed, you multiply the rate of energy consumption (measured in watts) by the amount of time (measured in hours) that it is being consumed. Electrical energy is measured in **watt-hours (Wh)**.

Energy (E) = Power (P) x Time (t)

E = P x t　　or　　E = W x h = Wh

Another way to think about power and energy is with an analogy to traveling. If a person travels in a car at a rate of 40 miles per hour (mph), to find the total distance traveled, you would multiply the rate of travel by the amount of time you traveled at that rate.

If a car travels for 1 hour at 40 miles per hour, it would travel 40 miles.

Distance = 40 mph x 1 hour = 40 miles

If a car travels for 3 hours at 40 miles per hour, it would travel 120 miles.

Distance = 40 mph x 3 hours = 120 miles

When we look at power, we are talking about the rate that electrical energy is being produced or consumed. Energy is analogous to the total distance traveled.

A person wouldn't say he took a 40-mile per hour trip because that is the rate. The person would say he took a 40-mile trip or a 120-mile trip. Just as the total distance is calculated by multiplying miles per hour by time, the amount of energy is calculated by multiplying power (work/time) by time.

The same applies with electrical power. You would not say you used 100 watts of light energy to read your book, because 100 watts represents the rate you used energy, not the total energy used. The amount of energy used would be calculated by multiplying the rate by the amount of time you read.

If you read for 5 hours with a 100-W bulb, for example, you would use the formula as follows:

Energy = Power x Time (E = P x t)

Energy = 100 W x 5 hour = 500 Wh

One watt-hour is a very small amount of electrical energy. Usually, we measure electrical power in larger units called **kilowatt-hours (kWh)** or 1,000 watt-hours. (kilo = thousand). A kilowatt-hour is the unit that utilities use when billing most customers. The average cost of a kilowatt-hour of electricity for residential customers in the U.S. is about $0.11.

To calculate the cost of reading with a 100-W bulb for five (5) hours, you would change the watt-hours into kilowatt-hours, then multiply the kilowatt-hours used by the cost per kilowatt-hour, as shown below:

500 Wh divided by 1,000 = 0.5 kWh

0.5 kWh x $0.11/kWh = $0.055

It would cost about five and a half cents to read for five hours with a 100-W bulb.

PV System Performance

Goal

To introduce students to variables that affect photovoltaic system performance.

Introduction

Students investigate the variables affecting power generation using solar energy. Web-based data acquisition systems (DAS) for installed panels collect downloadable data that allows students to compare and contrast variables for a single installation or to compare various installations. While every DAS is different, the major focus of each is to bring real time and/or historical data to building users.

Concepts

- The sun produces enormous amounts of energy, some in the form of radiant energy that travels through space to the Earth.
- We can use the sun's energy to produce electricity.
- It is difficult to capture the sun's energy because it is spread out—not concentrated in any one area.
- Photovoltaic (PV) cells convert radiant energy directly into electrical energy.

Grade Level

Upper elementary to high school.

Time

Three to four class periods. One to brainstorm and break into groups, one to two to download and explore data, and one to answer additional questions.

Materials

- Computers with internet access.
- Copies of the student worksheet.

Preparation

1. Become familiar with your DAS. Make sure you can easily navigate between pages and that you understand how to download data into a spreadsheet (most DAS programs download into Excel using comma separated values (CSV) format). Some DAS graph data on the Web. If this is the case, you can choose to not have your students create their own graphs, but to use the ones provided by the DAS instead.
2. If you are not already familiar with the terms used to describe photovoltaic installations and the variables surrounding power output, a glossary can be found at the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy website www1.eere.energy.gov/solar/solar_glossary.html#balance.
3. Ensure that your students are familiar with how solar energy is used to generate electricity.
4. Secure computer lab time, if needed.

Procedure

Day One

1. Ask your students to brainstorm ideas that might impact the energy output of the PV system. Be sure students include time of day, time of year, weather, geographic location, amount of available solar energy (solar irradiance), and temperature.

2. Have students develop questions they would like answered about solar power generation. Sample questions may include:

   When is the time of day for peak solar electric output?
   Is solar electric output influenced by the ambient temperature?
   Does geographic location impact solar electric output?
   Is there a direct correlation between solar electric output and time of day?
   Does time of year/season impact solar electric output?

3. Group students according to the questions they would like answered. For older students, allow each to answer his/her own question. However, it may be easier for younger students in the same group to answer the same question. Allow time for students to discuss what data they need to collect to answer their question and how they plan to organize and analyze the data.

4. Allow students to rephrase or adjust their hypothesis based on group discussions.

Days Two and Three

1. Take your students on a "virtual tour" of the DAS website demonstrating how to navigate the site, including how to select particular schools, time frames (day; week; month; etc.) and how to select output modes (CSV or graph).

2. Review the key types of data collected and critical terms: irradiance, cell temperature, and ambient temperature.

3. Make sure students understand how to select more than one school and how to specify which variables to display.

4. Have students log on to your Data Acquisition System (DAS) website and download PV output data for a specific period of time, such as a day, week, month or year.

   Optional: Output CSV data and have students use this data to create graphs. Compare student graphs to DAS graph output for same data.

5. If students are looking at data for more than a week, there will be a large number of data points. How the data is handled is dependent upon the questions the students would like answered. For older students, have each student determine the best way to handle the data. For younger students, consider helping each group or discussing as a class the best methods of data grouping and analysis. Students can also determine if they can eliminate data that does not contribute to the exploration, such as when the solar panels are not producing any power.

6. Have students analyze the data for the time period selected. Make sure students choose appropriate visuals to answer their questions.

Day Four

1. If answering different questions, have students review the analysis of others in their group. Have students ask each other questions about methodology used and conclusions drawn.

2. Allow student groups time to share their conclusions with the class. Discuss conflicting and complementing conclusions.

3. Ask students to determine additional information they can infer from the data, such as approximately what time the sun set and rose each day or what weather conditions existed during the time period studied.

Sample Analyses

On pages 21-23 are sample analyses from a DAS. Your students' analyses may look very similar or very different based upon your PV output, weather, time of year, etc.

Solar Schools Websites

The following websites have data from schools with PV installations.

American Electric Power
www.wattsonschools.com

Bonneville Environmental Foundation - Solar 4R School
www.b-e-f.org/solar4rschools

Honey Electric Solar
http://honeyelectricsolar.com/schools_intro.asp

Illinois Solar Schools
www.illinoissolarschools.org

Madison Gas and Electric
www.mge.com/environment/green/solar/schools.htm

New York State Energy Research and Development Authority
www.powernaturally.org/Programs/SchoolPowerNaturally/AboutSPN/ParticipatingSchools

PG&E–Pacific Gas and Electric
www.need.org/pgesolarschools

Soltrex
www.soltrex.com

TXU Solar Academy
http://txu-solaracademy.need.org

Solar Calculator
http://solar.sharpusa.com/solar/ez_calculator/

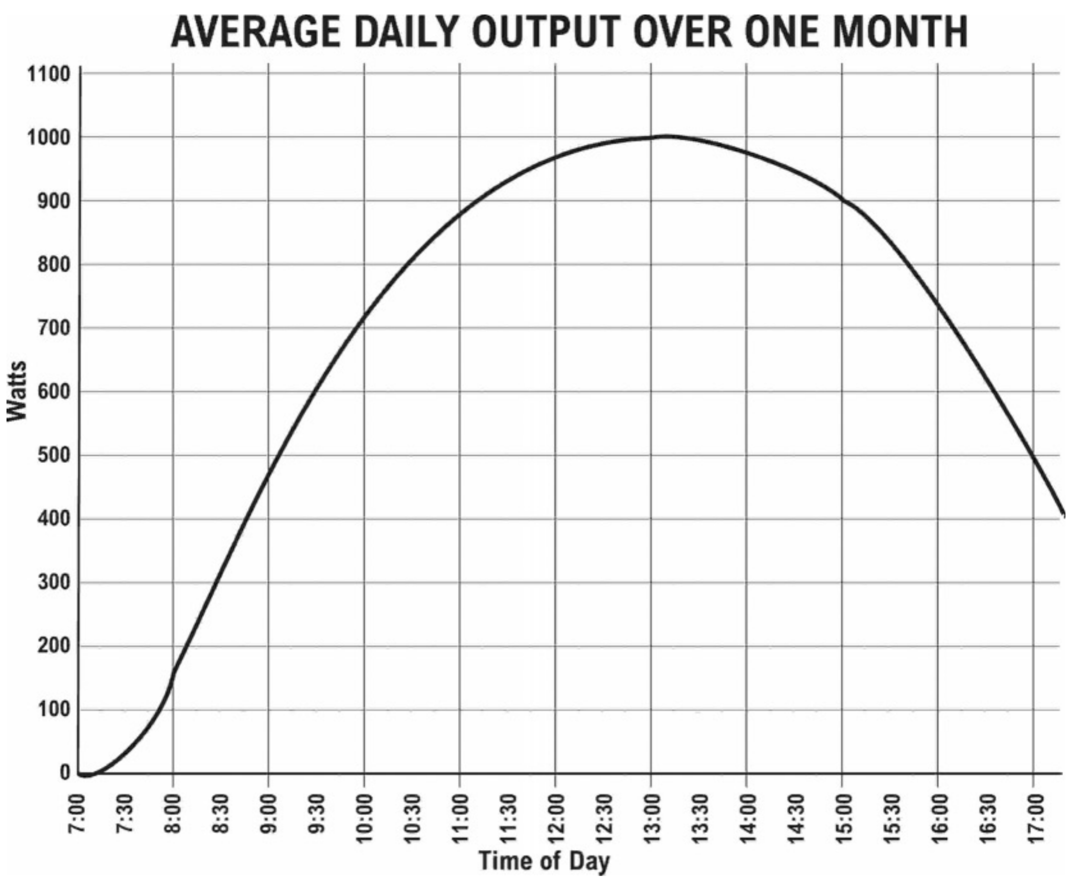
Extension Activities

- Invite a solar installer to lead a tour of the PV system for your students. Have students prepare some questions ahead of time about the system, the work the installer does, and how they got involved in the solar industry.
- Have students predict PV output based on weather forecasts. Use local weather forecasts or the National Oceanic and Atmospheric Administration's National Weather Service website at **www.weather.gov**.
- Have students investigate the impact of more than one variable on PV performance. A lesson plan for comparing solar irradiation, temperature and power can be downloaded from the Watts on Schools website at **www.wattsonschools.com/activities.htm**.
- Have students calculate the efficiency of the PV system in converting sunlight into electricity. A lesson plan can be found on the Watts on Schools website at **www.wattsonschools.com/activities.htm**.
- Have students compare the electrical output of the PV system to other forms of energy. Use the interactive calculator on the Watts on Schools website at **www.wattsonschools.com/calculator.htm**.
- Have students compare PV systems in different areas of the country, or other countries using the PVWATTS website at **http://rredc.nrel.gov/solar/codes_algs/PVWATTS**. Students can change the design aspects of a PV system (or use the preset defaults) and the program calculates monthly and annual energy production plus monthly savings. Students can also look at the program predictions for their PV system and compare it to actual data they download from the data acquisitioning system.
- Have students determine the circuit wiring for a PV system. A complete lesson plan with background information can be found on the Power...Naturally website at **www.powernaturally.org/Programs/SchoolPowerNaturally/InTheClassroom**. The lesson is found in the Level III grouping and is called Series or Parallel.
- Have students determine the equivalent behavioral energy savings to one day's PV production.

Variable: Time

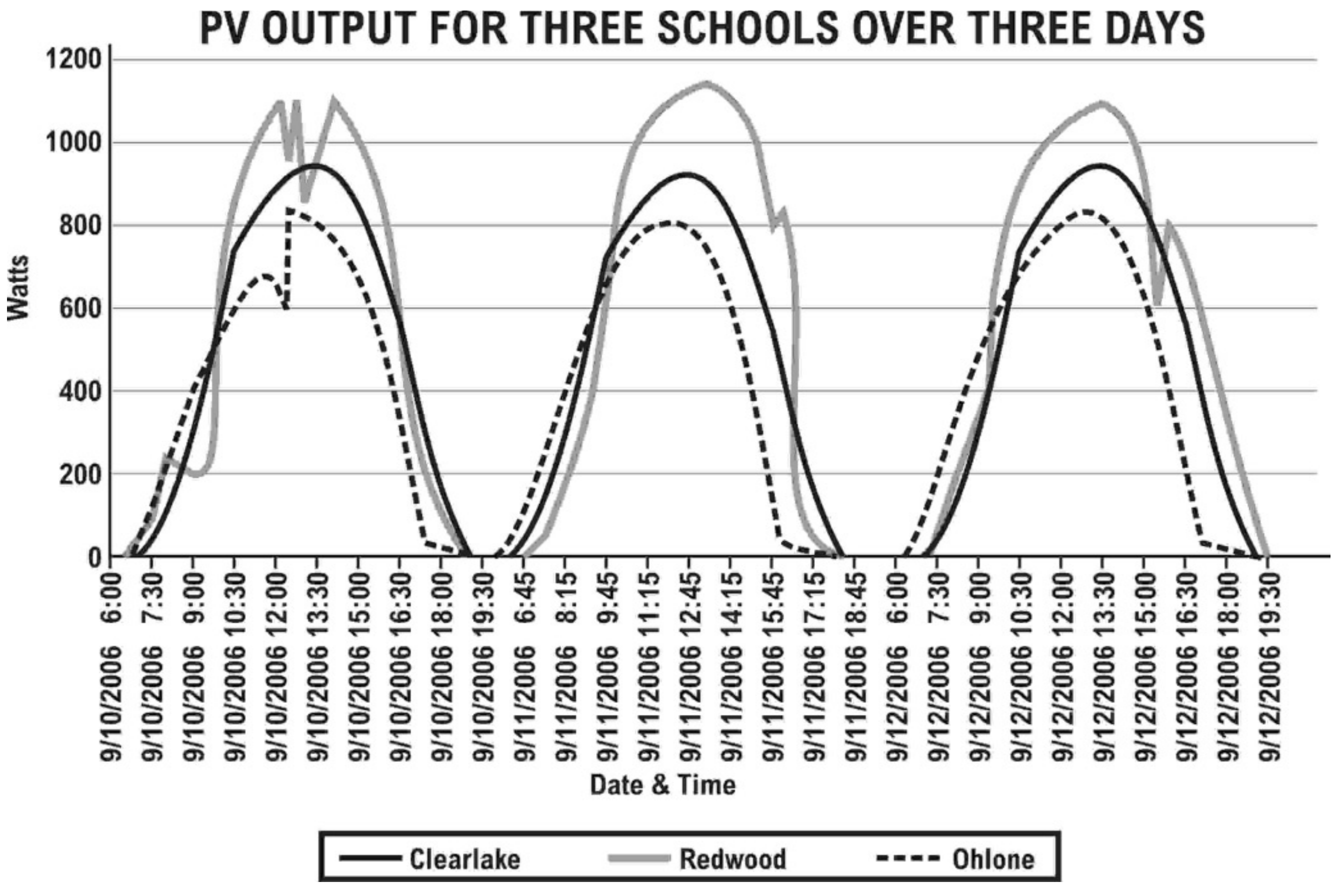
Sample analysis for answering the question, "What is the peak time of day for solar power output?" The first group designed a data table to show peak hours for one month. The second group graphed the same school with one month of data averaged for each 15 minute collection period from 7:00 am to 7:00 pm.

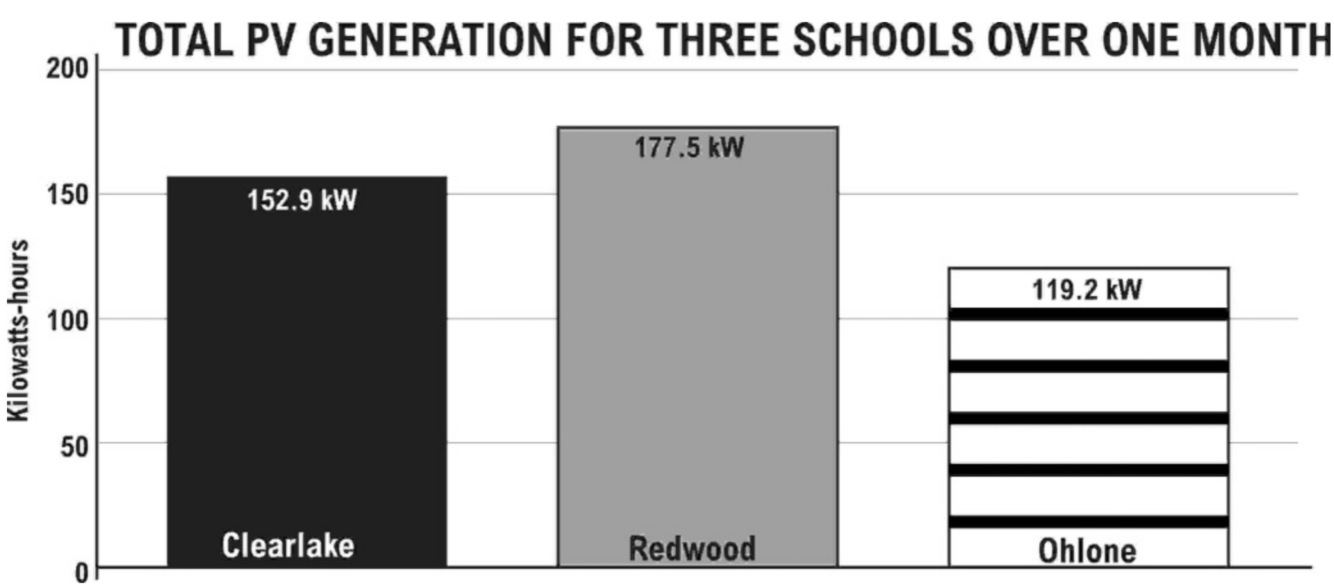
PEAK TIME	NUMBER OF DAYS	AVERAGE PV OUTPUT
12:15 pm	1	973.5 W
12:30 pm	5	1053.8 W
12:45 pm	7	1043.5 W
1:00 pm	10	1021.9 W
1:15 pm	5	1036.6 W
1:30 pm	1	998.1 W
1:45 pm	1	1046.4 W
2:30 pm	1	1063.3 W



Variable: Location

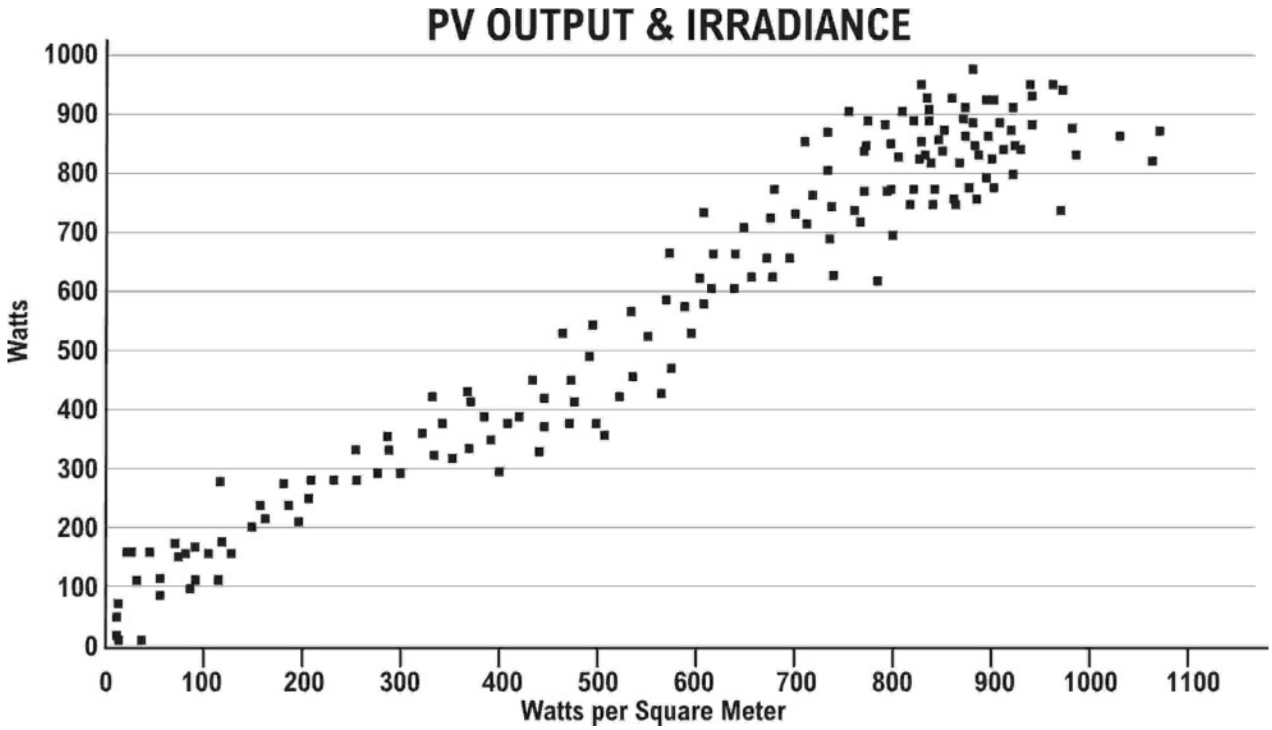
Sample analysis for answering the question, "Does geographic location impact solar power output?" The first group graphed three schools' data for three days, excluding hours with no output. The second group created a bar graph showing the total generation of each system over a month. All three schools have PV systems of 1.1 kilowatts.

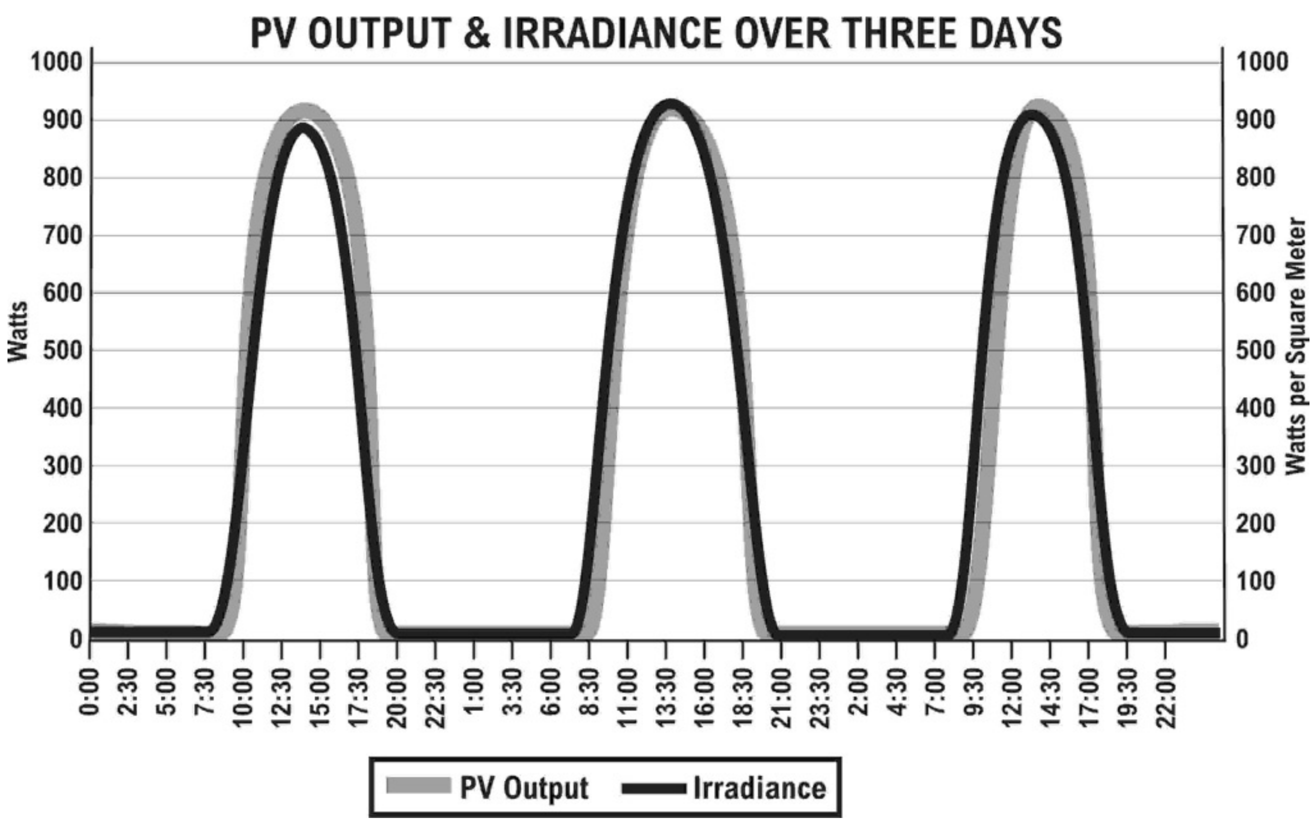




Variable: Irradiance

Sample analysis for answering the question, “How are PV output and irradiance related?” The first group created a scatter plot using data from one school for five days. The second group created a graph comparing PV output and solar irradiance for one school over three days.





Name: ______________________________ Date: ______________

Variables Affecting Photovoltaic System Performance

1. What variables can impact PV electricity generation?

2. What would you like to learn more about?

3. What is your hypothesis about your variable and PV system performance?

4. What data do you need to collect to verify your hypothesis? Be specific, such as time frame and number of PV locations.

5. How do you plan to organize and analyze the data? Again, be specific, such as graphs or tables, comparing averages or percentages, etc.

6. Clarify your hypothesis, if needed, based on group discussions and planned data gathering.

7. Attach your data analysis to this worksheet. What conclusions did you draw from your data? Explain how the data supports or disproves your hypothesis.

8. Did people in your group draw other conclusions? If so, how do they complement or conflict with your conclusions?

9. Did other groups come to conclusions that support or refute your hypothesis? If so, what data would account for the differences in conclusions?

10. If you were to complete this study again, what data would you include or leave out and why?

11. What other conclusions can be inferred from the data gathered?

PV Systems and Schools

Goal

To introduce students to the electric needs of the school and how having a PV system offsets those needs.

Introduction

Students learn the electric load of appliances in their school. They compare electric output of the PV system to the load. Students determine the amount the PV system offsets the school's electric consumption.

Concepts

- The electrical appliances we use consume a lot of energy.
- We use can the sun's energy to produce electricity.
- PV systems offset school electric needs, but do not generate all electricity needed.

Grade Level

Upper elementary to high school.

Time

Three to four class periods.

Materials

- Copies of the student worksheets.

Preparation

1. Obtain a copy of your school electric bill or the total kilowatt-hours used per month, prior to the installation of the PV system. If desired, obtain a year's worth of information and incorporate mathematical averaging into the lesson.
2. Either determine the cost per kilowatt-hour for electricity for your school or incorporate into the lesson for students to determine. If unknown, use $0.10 per kilowatt-hour.
3. Ensure that your students are familiar with how solar energy is used to generate electricity and how electricity is measured.
4. Obtain, or have the students determine, the measurements of the PV system, including square feet of panels and maximum power output.
5. Obtain permission for students to be in offices, other classrooms, labs, etc.
6. Collect, if desired, sample small appliances on which the students may read electric nameplates.

Procedure

Day One

1. Ask the students to think about how much electricity the school uses each day. Have students predict the electric usage of the school for a month.
2. Introduce electric nameplates. Hand out the Electric Nameplate worksheet and explain to students how to read electric nameplates and what information can be learned from them.
3. Divide the students into working groups. If using small appliances for practice nameplate reading, hand them out and have the students fill in one or two rows of the chart. Check to make sure all groups understand the calculations and have correct information.
4. Send the groups to various rooms in the school where they can collect electric nameplate information. Be sure to include the copy room and the office, if possible. Assign completing the worksheet for homework, if needed.

Day Two

1. Review the data collected from the previous day.
2. Provide the students with copies of the school electric bill or tell them how much electricity the school uses each month.
3. Complete the Cost of Using Appliances worksheet in class.
4. Have students complete the Photovoltaic Systems and School Electricity Use worksheet. Assign for homework if needed.

Day Three

1. Discuss with the students their predictions and the school's actual electric use.
2. Discuss with the students the feasibility of using solar generated electricity for all of the school's electric load.
3. Discuss with students the advantages and disadvantages to solar generated electricity.
4. Have students write persuasive pieces to the school board with a for or against stance to adding more solar panels to the school's PV system.

Optional Activity—Calculating PV Array Efficiency

1. Find the area of the solar array in square meters (m^2).
2. Use the DAS website to find the peak output of the system under optimal conditions, or it's highest historic output in (watts).
3. Calculate peak output per m^2, peak output ÷ area = output (watts/m^2).
4. Find the irradiance at the time of peak output (watts/m^2).
5. Calculate PV array efficiency: output/area ÷ irradiance = efficiency.

Extension Activities

- Have students research how a PV system is designed, manufactured and installed. Have students brainstorm the career opportunities available through the solar industry. More information about careers can be found on the Bureau of Labor Statistics website at **www.bls.gov**.
- Have a community solar day where the students lead tours of the PV system. Students could create posters and educational displays with additional information about solar energy. Students could also prepare and present songs or plays as a part of the event.
- Have students research additional solar technologies. Have them consider if any are viable for use on the school in addition to the PV system.
- Have students determine whether installing a PV system is cost-effective for their needs and whether or not there are any financial incentives for installing PV systems in their area. A solar power incentive map and other resources can be found at **www.findsolar.com**.
- Have students participate in a simulation where they determine the feasibility of installing a PV system on the roof of a school in the community. A complete lesson plan (To Go Solar or Not to Go Solar) and with student worksheets can be found on the Power...Naturally website at **www.powernaturally.org/Programs/SchoolPowerNaturally/InTheClassroom** under Level II lessons.
- Participate in the next National Renewable Energy Lab sponsored Junior Solar Sprint. For more information visit, **www.nrel.gov/education/jss_hfc.html**.

Name: ____ Date: ______________

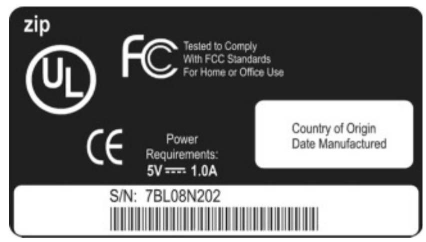
Electric Nameplates

Some appliances use more energy than others to accomplish the same task. Appliances that are very energy efficient are approved by the government's ENERGY STAR® program and have the ENERGY STAR® label on them. This means they have met high standards set by the government for energy efficiency.

Every machine that runs on electricity has an **electric nameplate** on it. The nameplate is usually a silver sticker that looks like the picture below. The nameplate has information about the amount of electricity the machine uses. Sometimes, the current is listed. The current is measured in amperes (A). Sometimes, the voltage the machine needs is listed. The voltage is listed in volts (V). Sometimes, the wattage is listed. The wattage is measured in watts (W). If the wattage isn't listed, then the current and voltage are both listed.

If the wattage isn't listed, you can calculate the wattage using the following formula, like this:

$$\text{wattage} = \text{current} \times \text{voltage}$$
$$W = A \times V$$
$$W = 1.2A \times 110V$$
$$W = 132W$$



Often, the letters UL are on the nameplate. UL stands for Underwriters Laboratories, Inc., which conducts tests on thousands of machines and appliances. The UL mark means that samples of the machines and appliances have been tested to make sure they are safe.

You can find out how much it costs to operate any appliance or machine if you know the wattage. Let's take a look at some of the machines in your school. The nameplate is usually located on the bottom or back. See if you can find the nameplates on the computers, printers, monitors, televisions and other machines in your classroom. Put the information in the chart below and figure out the wattage for each one.

Appliance	Current	Voltage	Wattage	UL tested	Weekly Use
Copier	**11 A**	**115 V**	**1,265 W**	**yes**	**10 h/wk**

Name: ______________________________ Date: ______________

Cost of Using Appliances

Once you know how much wattage an appliance needs and how much time it operates each week, you can determine how much electricity it uses and how much it costs to operate for a year.

1. To estimate yearly costs, use the data you gathered previously and multiply by 40. Since there are not people using the building every week of the year, a 40 week year is a good estimate. Using the copier as an example, you can find the yearly use with the following formula:

   Yearly Use = 10 hours/week x 40 weeks/year = 400 hours/year

2. Electricity is measured in kilowatt-hours. To determine how much an appliance or machine costs to operate each year, you will need to change watts to kilowatts. One kilowatt equals 1,000 watts. If you know the wattage and want to know kilowattage, you need to divide the watts by 1,000. Using the copier as an example, you can find the kilowatts with the following formula:

   $$\text{kW} = \frac{\text{W}}{1000\ \text{W/kW}}$$

   kW = 1265 W/1000 W/kW = 1.265 kW

3. Find out the electric rate for your school and use it to determine how much the appliances and machines cost to use. The copier sample uses the school electric rate national average of $0.10 per kilowatt-hour.

   Yearly Cost = Hours Used x Kilowatts x Cost of Electricity

   Yearly Cost = 400 hours/year x 1.265 kW x $0.10/kWh

   Yearly Cost = $50.60/year

4. Complete the chart for the appliances for which you already gathered data.

Appliance	Watts	Kilowatts	Weekly Use	Yearly Use	Rate	Yearly Cost
Copier	1265 W	1.265 kW	10 h/wk	400 h/yr	$0.10 kWh	$50.60/yr

Name: ______________________________ Date: ______________

Photovoltaic Systems and School Electricity Use

The photovoltaic (PV) system installed on your school provides electricity for the school to operate. But how much of the total school consumption does it provide?

1. Predict how much of the school electric consumption you think the PV system provides.

   I predict the PV system provides ________ percent of the school's total electric needs.

2. Calculate the amount of electricity needed yearly for the appliances for which you already gathered data. Use the following formula:

   Yearly Electric Use = Yearly Use x Kilowatts

   Copier Yearly Electric Use = 400 h/yr x 1.265 kW = 506 kWh/yr

Appliance	Yearly Use	Kilowatts	Yearly Electricity Use
Copier	400 h/yr	1265 kW	506 kWh/yr
		TOTAL	

3. Add together the totals from other groups' charts to get an estimate of your school's yearly electric use. Be sure to only include rooms once.

   School's estimated annual electric consumption = ______________ kilowatt-hours/year

4. Determine how much electricity the PV system provides your school each year. You can gather the yearly production data directly from your data acquisition system (DAS) or you can add the monthly totals for one year.

   PV system's annual electric production = ______________ kilowatt-hours/year

5. Next, determine what percentage was provided by the PV system for the electric needs of the appliances. Use the following formula:

$$\textbf{PV System Percentage} = \frac{\textbf{PV System Yearly Production}}{\textbf{Total Appliance Yearly Electric Use}} \times 100$$

$$\textbf{PV System Percentage} = \frac{\text{\_\_\_ kWh/yr} \times 100}{\text{\_\_\_ kWh/yr}} = \text{\_\_\_\_\_\_\_\_\_\_\_\_ \%}$$

6. This gives you an estimate of the electric needs of your school and the electric production of your PV system. But are the appliances and machines you looked at the only thing that uses electricity? List other electricity using devices.

7. Find out how much electricity your school used each year before the PV system was installed. Determine how much the PV system offsets the total electric needs of your school.

8. How much money is your school saving each year due to the PV system?

9. Bonus: Determine the size of your PV system in square feet. How many more square feet of PV panels would you need to produce half the electric consumption of your school?

PV Systems and the Environment

Goal

To introduce students to the concept that using electricity impacts the environment and to explore how using solar energy can offset carbon dioxide production.

Introduction

Students learn that using electricity generated from fossil fuels emits carbon dioxide (CO_2) into the air. Students learn that using electricity generated from solar power can decrease the amount of CO_2 emitted. Students determine how much CO_2 their PV system prevents from being emitted.

Concepts

- Using electricity impacts the environment.
- We can use the sun's energy to produce electricity.
- Using PV systems to generate electricity for schools decreases the amount of CO_2 emitted.

Background

Carbon dioxide (CO_2) is a greenhouse gas. Human activities have dramatically increased its concentration in the atmosphere. Since 1800, the level of CO_2 in the atmosphere has increased about 30 percent. Generating electricity accounts for a large portion of CO_2 emissions in the U.S. Some electricity generation, such as hydropower, solar, wind, geothermal and nuclear, does not produce CO_2 because no fuel is burned.

About half of the nation's electricity comes from burning coal. Another 23 percent comes from burning natural gas, petroleum and biomass. There is a direct correlation between the amount of electricity we use and the amount of CO_2 emitted into the atmosphere. The rule of thumb is that generating a kilowatt-hour of electricity emits 1.6 pounds of CO_2 into the atmosphere.

Grade Level

Upper elementary to high school.

Time

One class period.

Materials

- Completed copies of the student worksheets from PV Systems and Schools lesson.
- Copies of the student worksheet.

Preparation

1. The PV Systems and Schools lesson needs to be completed prior to this one. Data collected during that lesson will be used for this activity.
2. Ensure that your students are familiar with how solar energy is used to generate electricity and how electricity is measured.

Procedure

Complete the student worksheet in class.

Extension Activities

- Have students calculate their own carbon footprint and determine ways to offset their contributions to atmospheric pollution. Carbon footprint calculators can be found on the BP website at **www.bp.com** under Environment and Society and on the Texas State Conservation Office website at **www.infinitepower.org/calculators.htm**.
- Have students determine trade-offs involved with installing PV systems using the interactive calculators on the Texas State Conservation Office website at **www.infinitepower.org/calculators.htm**.
- Conduct an energy audit of the school to help lessen the carbon footprint of the school. Use materials and lesson plans from NEED's Energy Management curriculum (Primary: *Saving Energy at Home and School*, Elementary: *Building Buddies*, Intermediate: *Monitoring and Mentoring*, and Secondary: *Learning and Conserving*).

Name: ______________________________ Date: ______________

Photovoltaic Systems and the Environment

Carbon dioxide (CO_2) is a greenhouse gas. Greenhouse gases hold heat in the atmosphere. They keep our planet warm enough for us to live. But in the last 200 years, we have been producing more carbon dioxide than ever before.

Research shows that greenhouse gases are trapping more heat in the atmosphere. Scientists believe this is causing the average temperature of the earth's atmosphere to rise. They call this global climate change or global warming. Global warming refers to an average increase in the temperature of the atmosphere, which in turn causes changes in climate. A warmer atmosphere may lead to changes in rainfall patterns, a rise in sea level, and a wide range of impacts on plants, wildlife and humans. When scientists talk about the issue of climate change, their concern is about global warming caused by human activities.

When we breathe, we produce carbon dioxide. When we burn fuels, we also produce carbon dioxide. Driving cars and trucks produces carbon dioxide. Heating homes with natural gas, wood, heating oil or propane produces carbon dioxide, too.

Making electricity can also produce carbon dioxide. Some energy sources, such as hydropower, solar, wind, geothermal and nuclear, do not produce carbon dioxide because no fuel is burned. However, about half of our electricity comes from burning coal. Another 23 percent comes from burning natural gas, petroleum and biomass.

The general rule is that generating one kilowatt-hour of electricity produces, on average, 1.6 pounds of carbon dioxide that is emitted into the atmosphere.

1. You can use this standard to determine how much carbon dioxide is produced by the machines and appliances used in your school. The figures for the sample copier are:

   Yearly CO_2 Emissions = yearly electric use x rate of CO_2/kWh

   Yearly CO_2 Emissions = 506 kWh/yr x 1.6 lbs CO_2/kWh = 810 lbs CO_2

2. Use the figures from earlier worksheets to complete the chart below.

Appliance	Yearly Electricity Use	Yearly CO_2 Emissions
Copier	**506 kWh/yr**	**810 lbs**

3. Gather data from other groups and calculate your school's carbon dioxide emissions from the machines and appliances used. Be sure to include a room's data only once.

School's estimated CO_2 emissions = _______________ lbs/yr

4. Use the school building electric consumption figure from before the PV system was installed to calculate your school's total carbon dioxide emissions due to using electricity.

School's CO_2 emissions = _______________ lbs/yr

5. When using an energy source that does not emit carbon dioxide to generate electricity, scientist discuss the amount of carbon dioxide emissions that were avoided. This means that instead of using a conventional fuel, which produces 1.6 pounds of carbon dioxide for each kilowatt-hour of electricity, solar energy produces zero pounds of carbon dioxide for each kilowatt-hour of electricity generated on the system. In one year, how much carbon dioxide emissions are avoided due to your school's PV system?

6. What other steps can your school take to reduce the amount of carbon dioxide emissions?

7. **Bonus 1:** How many more square feet of PV panels would you need to reduce the carbon dioxide emissions of your school by half?

   Bonus 2: The DAS website indicates how many pounds of carbon dioxide production are avoided by use of the PV system. Calculate the volume of one ton of carbon dioxide in cubic meters. Calculate the volume of one ton of carbon dioxide in cubic feet (The density of CO_2 is 1.98 kg/m^3, 1 kilogram = 2.2 pounds, 1 ton = 2000 pounds or 907.18 kilograms, and 1 foot = 0.3048 meter).

Additional Resources

Solar Energy Websites

American Solar Energy Society
www.ases.org

Energy For Educators
www.energyforeducators.org

Energy Information Administration Energy Kids
www.eia.doe.gov/kids

Florida Solar Energy Center
www.fsec.ucf.edu/en/consumer/solar_electricity/basics/index.htm

How Stuff Works
www.howstuffworks.com/solar-cell.htm

National Energy Education Development Project
www.need.org

National Renewable Energy Laboratory
www.nrel.gov/learning/re_solar.html

Sandia National Laboratories
http://photovoltaics.sandia.gov

Solar Electric Power Association
www.solarelectricpower.org

Solar Energy Industries Association
www.seia.org

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
Solar Energy Technologies Program
www1.eere.energy.gov/solar

Glossaries of Energy Terms

Energy Information Administration Energy Kids
www.eia.doe.gov/kids

Sandia National Laboratories
www.sandia.gov/pv/docs/glossary.htm

U.S. Department of Energy
www.energy.gov/energyglossaries.htm

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
www1.eere.energy.gov/solar/solar_glossary.html#balance

PV Glossary

For more solar terms, visit www1.eere.energy.gov/solar/solar_glossary.html#balance.

alternating current (ac)—a type of electrical current, the direction of which is reversed at regular intervals or cycles

ambient temperature—the temperature of the surrounding area

ampere (amp or A)—a unit of electrical current or rate of flow of electrons

converter—a device that converts direct current (dc) voltage to another dc voltage

data acquisition system (DAS)—a computer program and its related hardware components designed to collect data about a photovoltaic system

diffuse insolation—sunlight received indirectly as a result of scattering due to clouds, fog, haze, dust or other obstructions in the atmosphere

direct current (dc)—a type of electrical current in which electricity flows in one direction, usually with relatively low voltage and high current

direct insolation—sunlight falling directly upon a collector

electric circuit—the path followed by electrons from a power source (generator, battery, PV array), through an electrical system, and returning to the source

electric current—the flow of electrical energy (electricity) in a conductor, measured in amperes

electricity—energy resulting from the flow of charge particles, such as electrons or ions

electron—part of an atom with a negative electrical charge

energy—the capability of doing work

incident light—light that shines onto the face of a solar cell

input voltage—determined by the total power required by both the alternating current loads and the voltage of any direct current loads

insolation ($W/m^2/h$)—the solar power density incident on a surface of stated area and orientation, usually expressed as Watts per square meter per hour

inverter—a device that converts direct current (dc) to alternating current (ac)

irradiance (kW/m^2)—the direct, diffuse, and reflected solar radiation that strikes a surface, usually expressed as kilowatts per square meter

kilowatt (kW)—a standard unit of electrical power equal to 1,000 watts, or to the energy consumption at a rate of 1,000 joules per second

kilowatt-hour (kWh)—a unit of energy equaling 1,000 watts acting over a period of one hour

load—the demand on an energy production system; the energy consumption or requirement of a piece or group of equipment, usually expressed as amperes or watts

photon—a particle of light that acts as an individual unit of energy

photovoltaic (PV)—direct conversion of light to electricity

photovoltaic (PV) array—an interconnected system of PV modules that function as a single electricity-producing unit

photovoltaic (PV) cell—the smallest semiconductor element within a PV module that performs the conversion of light to electricity (also called a solar cell)

photovoltaic (PV) conversion efficiency—the ratio of the electric power produced by a PV device to the power of the sunlight incident on the device

photovoltaic (PV) effect—the phenomenon that occurs when photons strike electrons in the atoms of a semiconductor, knocking them loose and causing a flow of electrons in one direction

photovoltaic (PV) module—an environmentally protected collection of solar (PV) cells, the interconnections, and other parts (terminals, diodes) needed to provide a direct current

photovoltaic (PV) panel—a connected collection of PV modules

photovoltaic (PV) system—a complete set of components for converting sunlight into electricity, including the array and additional system components

semiconductor—any material that has a limited capacity for conducting an electric current

silicon (Si)—a semi-metallic element with semiconductor properties used to make photovoltaic (PV) devices

solar energy—electromagnetic energy transmitted from the sun (solar radiation)

transformer—a device that changes the voltage of alternating current electricity

volt (V)—a unit of electrical force equal to that amount of electromotive force that will cause a steady current of one ampere to flow through a resistance of one ohm

voltage—the amount of electromotive force that exists between two points, measured in volts (V)

watt (W)—the rate of energy transfer equal to one ampere under the electrical pressure of one volt

SCHOOLS GOING SOLAR
Evaluation Form

State: ___________ **Grade Level:** ___________ **Number of Students:** __________

1. Did you conduct the entire activity?	Yes	No
2. Were the instructions clear and easy to follow?	Yes	No
3. Did the activity meet your academic objectives?	Yes	No
4. Was the activity age appropriate?	Yes	No
5. Were the allotted times sufficient to conduct the activity?	Yes	No
6. Was the activity easy to use?	Yes	No
7. Was the preparation required acceptable for the activity?	Yes	No
8. Were the students interested and motivated?	Yes	No
9. Was the energy knowledge content age appropriate?	Yes	No
10. Would you use the activity again?	Yes	No

How would you rate the activity overall (excellent, good, fair, poor)?

How would your students rate the activity overall (excellent, good, fair, poor)?

What would make the activity more useful to you?

Other Comments:

Please fax or mail to:
NEED Project
PO Box 10101
Manassas, VA 20108
FAX: 1-800-847-1820

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Indiana Office of Energy and Defense Development
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Iowa Energy Center
Kentucky Clean Fuels Coalition
Kentucky Department of Energy Development and Independence
Kentucky Oil and Gas Association
Kentucky Propane Education and Research Council
Kentucky River Properties LLC
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Louisville Gas and Electric Company
Maine Energy Education Project
Maine Public Service Company
Marianas Islands Energy Office
Maryland Energy Administration
Massachusetts Division of Energy Resources
Michigan Energy Office
Michigan Oil and Gas Producers Education Foundation
Minerals Management Service – U.S. Department of the Interior
Mississippi Development Authority–Energy Division
Montana Energy Education Council
Narragansett Electric – A National Grid Company
NASA Educator Resource Center–WV
National Alternative Fuels Training Center–West Virginia University
National Association of State Energy Officials
National Association of State Universities and Land Grant Colleges
National Hydropower Association
National Ocean Industries Association
National Renewable Energy Laboratory
Nebraska Public Power District
New Jersey Department of Environmental Protection
New York Power Authority
New Mexico Oil Corporation
New Mexico Landman's Association
North Carolina Department of Administration–State Energy Office
Offshore Energy Center/Ocean Star/ OEC Society
Offshore Technology Conference
Ohio Energy Project
Pacific Gas and Electric Company
PECO
Petroleum Equipment Suppliers Association
Poudre School District–CO
Puerto Rico Energy Affairs Administration
Puget Sound Energy
Roswell Climate Change Committee
Roswell Geological Society
Rhode Island State Energy Office
Sacramento Municipal Utility District
Saudi Aramco
Sentech, Inc.
Shell
Snohomish County Public Utility District–WA
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U.S. Department of Energy – Wind for Schools
Virgin Islands Energy Office
Virginia Department of Mines, Minerals and Energy
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