# The Power of Solar Energy

A curriculum unit for Grades 7-10


*Graphic courtesy of CON.WEB*

National Center for Appropriate Technology

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# Introduction

The Power of Solar Energy is an intermediate-level thematic unit appropriate for grades 7-10. The unit is intended to engage your students in learning about solar energy through a "hands-on, minds-on" approach. This unit is designed to be flexible. It can be implemented as a stand-alone unit, or its pieces may be used individually as appropriate. The unit has cross-curricular applications, i.e. some lessons might be used in science classes, where others might be used in math, economics, or other classes.

### Alignment with Science Education Standards

This unit is intended to meet the goals of Science Content Standard 2: Students demonstrate knowledge of properties, forms, changes, and interactions of chemical and physical systems.

## Expected Outcomes

By the end of this unit, your students will have a more solid understanding of energy production and use, renewable energy sources and applications, and solar energy system components. They, as the next generation of energy users, will be able to better predict the consequences of their energy choices.

## Learning Objectives/Benchmarks

After completing this unit, students will:

1. Define and classify renewable and nonrenewable energy sources
2. Describe the impacts of energy use on society
3. Describe the benefits of solar and other renewable energy sources
4. Identify and describe photovoltaic systems and components
5. Conduct experiments that demonstrate the principles of solar energy

## Acknowledgements

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# Background

## Learning About Renewable Energy

*(Source: Energy Efficiency and Renewable Energy Network)*

Can you imagine life without television, cars, or computers? What if you had to cook your dinner over a fire or fetch water from a river? It might be fun for a camping trip, but you probably would not want to do it every day. But that's how life was before scientists and inventors discovered ways to use energy to make our lives easier.

Today, most of the energy we use comes from fossil fuels. Coal, oil, and natural gas are all fossil fuels. Over millions of years, the decay of plants, dinosaurs, and other animals was formed into fossil fuels. These fuels lie buried between layers of earth and rock. The only way to get them out is to drill or mine for them. While fossil fuels are still being created today by underground heat and pressure, they are being consumed more rapidly than they are created. For that reason, fossil fuels are considered nonrenewable; that is, they are not replaced as soon as we use them. So, we could run out of them sometime in the future. Or, we might someday use so much fossil fuel that we won't be able to drill or mine fast enough to keep up with the demand.

Because our world depends so much on energy, we need to find sources of energy that will last a long time. What if there was a type of energy that never ran out? There is. It is called renewable energy.

In addition, because there are so many people on the earth using fossil fuels, we create a lot of pollution. So, we should also use energy sources that produce as little pollution as possible. While all energy sources cause some pollution in their creation or their consumption, renewable energy systems generally are less polluting than fossil fuel systems.

### What is renewable energy?

Renewable energy systems use resources that are constantly replaced and are usually less polluting. Examples of renewable energy systems include solar, wind, and geothermal energy (getting energy from the heat in the earth). We also get renewable energy from trees and plants, rivers, and even garbage.

### Solar energy

We can use the energy in sunshine to warm and light our homes, heat our water, and provide electricity to power our lights, stoves, refrigerators, and other appliances. This energy comes from processes called solar heating, solar water heating, photovoltaic energy (converting sunlight directly into electricity), and solar thermal electric power (when the sun's energy is concentrated to heat water and produce steam, which is used to produce electricity).

### Solar heating

Have you ever sat in a car that was closed up on a sunny day? Did you notice how hot it was in the car? This warmth is just one example of solar heating. We can use the sun to heat other things, including our homes. Today, more than 200,000 houses in the United States have been designed to use features that take advantage of the sun's energy. These homes often use passive solar designs, which do not normally require pumps, fans, or other mechanical equipment to store and distribute the sun's energy. In contrast, active solar designs need additional mechanical components.

A passive solar home or building naturally collects the sun's heat through large, south-facing windows, which are just one aspect of passive design. Once the heat is inside, we need to capture and absorb it. Think about a sunny spot on the floor of your house on a cold day. That "sun spot" is nice and warm, right? It is warm because it holds the sun's heat, and we call such things absorbers.

In solar buildings, sunspaces are built onto the south side of the structure and act as large absorbers. The floors of sunspaces are usually made of tiles or bricks that absorb heat throughout the day, then release heat. When the air is colder than the floor, the tiles or bricks release the heat to the air.

A challenge with solar heating is keeping the heat inside the house. One way to do this is to use special windows that reflect the heat back into the house. Another aspect of solar heating is that the house absorbs heat even during hot weather, when the last thing you need is more heat! So, passive solar homes need to be designed to let the heat in during cold months and block the sun in the hot months. How can you do this?

You can use deciduous trees or bushes in front of the south-facing windows. These plants lose their leaves in the winter and allow most of the sun in, while in the summer, the leaves will block out a lot of the sunshine and heat. Or, you can design your house to have overhangs above the south-facing windows. This will block out the summer sunshine when the sun is high in the sky but let it in when the sun is lower in the winter.

### Solar water heating

The sun also can heat water for bathing and laundry. Most solar water-heating systems have two main parts: the solar collector and the storage tank. The collector heats the water, which then flows to the storage tank. The storage tank can be just a modified water heater, but ideally it should be a larger, well-insulated tank. The water stays in the storage tank until it is needed for something, say a shower or to run the dishwasher.

A common collector is called a flat-plate collector, and is usually mounted on the roof. This collector is a rectangular box with a transparent cover that faces the sun. Small tubes run through the box, carrying the water or other fluid such as antifreeze to be heated. The tubes are mounted on a metal absorber plate, which is painted black to absorb the sun's heat. The back and sides of the box are insulated to hold in the heat. Heat builds up in the collector, and as the fluid passes through the tubes, it heats up.

Like solar-designed buildings, solar water-heating systems can be either active or passive. The most common systems are active, which means they use pumps to move the heated fluid from the collector and into the storage tank.

While a solar water-heating system can work well, it can't heat water when the sun isn't shining—and we all know it can be cloudy for days at a time! For that reason, homes also have a conventional backup system that uses fossil fuels.

### Photovoltaic energy

The sun's energy can also be made directly into electricity using photovoltaic (PV) cells, sometimes called solar cells. PV cells make electricity without moving, making noise, or polluting. They are used in calculators and watches. They also provide power to satellites, electric lights, and small electrical appliances such as radios. PV cells are even being used to provide electricity for homes, villages, and businesses. Some electric utility companies are building PV systems into their power supply networks.

Although the PV cells used in calculators and watches are tiny—less than a half inch (1.2 centimeters) in diameter—PV cells for larger power systems are about 4 inches (10 centimeters) in diameter. When more power is needed, PV cells can be wired together to form a module. A module of about 40 cells is often enough to power a small light bulb. For more power, PV modules are wired together into an array. PV arrays can produce enough power to meet the electrical needs of your house—or for even larger uses.

Today, PV systems are mostly used for water pumping, highway lighting, weather stations, and other electrical systems located away from power lines. For example, if you had a cabin on a mountain top, a PV system would allow you to read some of your favorite books before you went to sleep!

Because PV systems can be expensive, they are not used in areas that have electricity nearby. But if someone needs electricity in a remote place, PV can be quite economical. Another aspect of PV power is "intermittency," which means that if the sun isn't shining, the system can't make electricity. Because PV systems only produce electricity when the sun is shining, these remote systems need batteries to store the electricity.

### Solar thermal electric power

Solar thermal systems can also change sunlight into electricity, but not in the same way as PV cells. In most cases, solar thermal systems concentrate (focus) sunlight to produce heat. This heat boils water to make steam. The steam rotates a turbine, which is made of several rows of blades mounted on a large shaft. The steam's pressure flows through the turbine, pushes against the blades, and causes the shaft to turn, much like you can make a pinwheel spin by blowing on it. The turbine is attached to a generator that makes electricity.

Like electricity from PV systems, solar thermal power can be intermittent. To avoid this problem, many systems use a backup system that relies on natural gas to heat the water. Because solar thermal systems concentrate the sun's energy, they need to be located in areas of the world that receive a lot of intense sunshine.

### Wind power

Did you know that wind is considered an indirect form of solar energy? This is because the wind is driven mainly by temperature differences on the surface of the earth that are caused by sunshine.

For centuries, the wind has been used to sail ships, grind grain, and pump water. Now, people use the wind to generate electricity. The windmills built long ago had many blades, but today's wind turbines usually have just two or three blades that turn when the wind blows. But the blades on wind turbines are much longer than those you might see on a windmill. In fact, wind turbine blades can be up to 82 feet (25 meters) long!

The blades drive a generator that produces electricity, much like steam turbines. The longer the blades and the faster the wind speed, the more electricity the turbine generates. Wind turbines are placed on towers because the wind blows harder and more steadily above the ground.

To produce the most electricity, wind turbines need to be located in areas where the wind blows at a constant speed, which it does not do in all parts of the world. Wind speed is described by seven "classes." For example, Class 7 winds are extremely strong, while Class 2 winds are mild breezes. Generally, Class 4 winds and above are considered adequate for a wind turbine to produce electricity.

Large groups of wind turbines, called wind farms or wind plants, are connected to electric utility power lines and provide electricity to many people. New turbine designs now take advantage of less windy areas by using better blades, more electronic controls, and other improvements. Some new turbines can also operate efficiently over a wide range of wind speeds.

An advantage of wind turbines over some forms of renewable energy is that they can produce electricity whenever the wind blows (at night and also during the day). In theory, wind systems can produce electricity 24 hours every day, unlike PV systems that can't make power at night. However, even in the windiest places, the wind does not blow all the time. So, while wind farms don't need batteries for backup storage of electricity, small wind systems do need backup batteries. And, we're still learning about local wind patterns and how they affect wind turbines and blades.

## Geothermal energy

We can also get energy directly from the heat in the earth. This is known as geothermal energy, from "geo" for earth and "thermal" for heat. Geothermal energy starts with hot, molten rock (called magma) miles below the earth's surface that heats a section of the earth's crust. The heat rising from the magma warms underground pools of water known as geothermal reservoirs. Sometimes the water can even boil to produce steam. If there is an opening through the rock to the surface, the hot underground water may seep out to form hot springs, or it may boil to form geysers. One such geyser that you may have seen is Old Faithful in Yellowstone National Park.

For thousands of years, people have been using hot springs for bathing and for cooking food. With today's technology, we do not have to wait for the hot water to come to the earth's surface. Instead, we can drill wells deep below the surface of the earth to tap into geothermal reservoirs. This is called direct use of geothermal energy, and it provides a steady stream of hot water that is pumped to the earth's surface so its heat can be used.

Geothermal energy also is used to produce electricity. Similar to solar thermal electricity, steam—either pulled directly from the geothermal reservoir or from water heated to make steam—is piped to the power plant. There, it rotates a turbine that generates electricity.

One source of geothermal power is The Geysers geothermal field located in northern California. This power plant is the largest source of geothermal energy in the world and produces as much power as two large coal or nuclear power plants.

While geothermal energy is a good source of power, we could run out of it by drawing so much energy out of the reservoir that it is not able to replenish itself at the rate we're using it. In addition, water from geothermal reservoirs often contains minerals that are corrosive and polluting.

### Biomass energy

When you burn a log in your fireplace or in a campfire, you are using biomass energy. Because plants and trees depend on sunlight to grow, biomass energy is a form of stored solar energy. Although wood is the largest source of biomass energy, we also use corn, sugarcane wastes, and other farming byproducts.

There are three ways to use biomass. It can be burned to produce heat and electricity, changed to a gas-like fuel such as methane, or changed to a liquid fuel. Liquid fuels, also called biofuels, include two forms of alcohol: ethanol and methanol. Because biomass can be changed directly into a liquid fuel, it could someday supply much of our transportation fuel needs for cars, trucks, buses, airplanes, and trains. This is very important because nearly one-third of our nation's energy is now used for transportation.

Diesel fuel can also be replaced by biodiesel made from vegetable oils! In the United States, this fuel is now being produced from soybean oil. However, any vegetable oil—corn, cottonseed, peanut, sunflower, or canola—could be used to produce biodiesel. Researchers are also developing algae that produce oils, which can be converted to biodiesel.

The most commonly used biofuel in the United States is ethanol, which is produced from corn and other grains. A blend of gasoline and ethanol is already used in cities with high air pollution. However, ethanol made from corn is currently more expensive than gasoline on a gallon-for-gallon basis. And even if we took all the corn that could possibly be grown in the United States and used it to produce ethanol, it would not make enough ethanol to power all our cars. So, it is very important for scientists to find less expensive ways to produce ethanol from other biomass crops.

Today, we have found new ways to produce ethanol from grasses, trees, bark, sawdust, paper, and farming wastes. These processes could greatly increase the use of biomass energy in the United States. Imagine a new type of farm where energy crops, such as fast-growing trees or grasses, might be grown and harvested for their energy content!

Of course, like many resources, we need to manage our use of biomass or we might consume it faster than we produce it. Also, like any fuel, biomass creates some pollutants when it is burned or converted into energy.

### Hydropower

The water in rivers and streams can be captured and turned into hydropower, also called hydroelectric power. The most common form of hydropower uses dams on rivers to create large reservoirs of water. Water released from the reservoirs flows through turbines, causing them to spin. The turbines are connected to generators that produce electricity.

Hydroelectric power plants in the United States generate enough electricity to power whole towns, cities, and even entire regions of the country. Hydropower currently is one of the largest sources of renewable power, generating about 10 percent of the United States' electricity.

Hydropower is also inexpensive, and like many other renewable energy sources, it does not produce air pollution. However, the drawback to hydropower is that damming rivers can change the ecology of the region. For example, the water below the dam is often colder than what would normally flow down the river, so fish sometimes die. The water level of the river below the dam can be higher or lower than its natural state, which affects the plants that grow along the riverbanks.

### Energy from trash

What you may throw out in your garbage today just might become fuel for someone else. That's right, whether you call it trash or garbage, this municipal solid waste has the potential to be a large energy source.

In 1993, the Environmental Protection Agency estimated that the United States generated 207 million tons (188 million metric tons) of trash. Out of all that trash, however, only 32 million tons (29 million metric tons) were converted to energy.

Garbage is also an inexpensive energy resource. Unlike most other energy resources, someone will collect garbage, deliver it to the power plant, and pay to get rid of it. This helps cover the cost of turning the garbage into energy. Garbage is also a unique resource because we all contribute to it.

Municipal solid waste can be burned in large power plants to generate electric power. Municipal waste-to-energy plants currently generate about 2500 megawatts of electricity—the equivalent of several large coal plants.

There is also a way to use the energy trapped in landfill garbage. When food scraps and other wastes decay, a gas called methane is produced. Methane is the main ingredient in natural gas. We can drill wells into landfills to release this gas. Pipes from each well carry the methane gas to a central point where it is cleaned. The gas can then be burned to produce steam in a boiler, or it can be used to power generators to produce electricity.

However, as with burning any type of fuel, municipal solid wastes can produce air pollution when they are burned and turned into energy.

### Renewable energy in your future

One day, all your home's energy may come from the sun or the wind. You may not think twice about filling your car's gas tank with biofuel. And your garbage might contribute to your city's energy supply. As scientists push the limits of renewable energy technologies and improve the efficiencies and costs of today's systems, we will soon be to the point when we may no longer rely mostly on fossil fuel energy.

# More Information About Photovoltaics

## Systems that Convert Sunlight to Electricity Can Meet Many Different Needs

*(Source: Federal Energy Management Program)*

Photovoltaics is a technology that converts radiant light energy (photo) to electricity (voltaics). Photovoltaic (PV) cells are the basic building blocks of this energy technology.

PV cells (also called solar cells) are made of semiconductor materials, most typically silicon. The amount of electricity a PV cell produces depends on its size, its conversion efficiency (see box below), and the intensity of the light source. Sunlight is the most common source of the energy used by PV cells to produce an electric current.

It takes just a few PV cells to produce enough electricity to power a small watch or solar calculator. For more power, cells are connected together to form larger units called modules. Modules, in turn, are connected to form arrays, and arrays can be interconnected to generate electricity for a large load, such as a group of buildings.

Single-crystal silicon is the most common semiconductor material used in making PV cells. Polycrystalline silicon, in the form of a thin film or coating on an inexpensive base of glass or plastic, is also used, and PV modules can also be made of thin films of amorphous (noncrystalline) silicon. Thin films are usually less expensive to manufacture because they require less silicon and the process is less labor-intensive. PV devices are also being developed using combinations of other materials, such as cadmium, copper, indium, gallium, selenium, and tellurium.

PV modules are typically installed on or near a building or other structure. They can also be specially designed as an integral part of a building's roof, wall, skylight, or other element. This is called building-integrated PV or BIPV.

### What are the important terms?

Balance of system (BOS)—every element (and its associated costs) of a PV system except the modules themselves; this includes the design; land and site preparation; installation; support structures; and power conditioning, operation and maintenance, and storage equipment.

Break-even cost—the cost of a PV system at which the value of the electricity it produces equals the cost of electricity from an alternative source plus the delivery of this electricity to the site; a break-even distance is the distance a power line needs to be extended to match the installation cost of a PV system.

Peak watt—the "rated" output of a cell, module, or system; the amount of power a PV device produces when operating at 25°C during tests; the peak rating is usually determined during indoor tests rather than outdoors.

PV conversion efficiency—the percentage of available sunlight converted to electricity by a PV module or cell; technically, the ratio of electric power produced by a cell to the power of the sunlight striking the cell.

## What are PV energy systems?

A PV energy system usually includes a module or array and the structural hardware needed to install it. The simplest PV systems generate DC electricity, usually for a small load, when the sun is shining or they are exposed to artificial light. More complex systems include a power inverter that converts the direct current (DC) generated by PV to alternating current (AC), and batteries that store energy for use at night or when the sun isn't shining.

Today, PV is used primarily for cathodic (corrosion) protection, traffic warning lights, water pumping for irrigation and livestock, telecommunications, security and lighting systems, resource monitoring, and electric load management. Many of these uses are remote (or off-grid) power generation applications, not connected to utility power lines. PV systems are already used in many off-grid applications in the Federal government, such as for emergency call boxes near interstate highways.

When the electricity required for an application exceeds the amount a PV system can supply, a conventional electric generator can be added to create a hybrid PV/generator system. Wind systems can also be added.

PV systems actually have many benefits:

- Portability—many kinds of PV systems can be moved about easily.
- Reliability—they operate for long periods with little maintenance.
- Low operating costs—the fuel is free and there are no (or few) moving parts.
- Low environmental impact—they are quiet and nonpolluting (no greenhouse gas emissions).
- Stand-alone capability—they operate in remote areas far from power lines.
- Modularity—power output can be increased by adding more modules.
- Safety—they are not flammable and meet National Electric Code requirements.
- Versatility—they operate well in almost any climate.
- Short lead time—prepackaged PV systems are available, and utility easements aren't needed.
- Ease of installation—no heavy construction equipment is required.

## What are some opportunities for using PV?

Photovoltaics is a good choice for remote applications in which the daily electric load falls somewhere between a few watt-hours and about 100 kilowatt-hours. Because it is nonpolluting, PV should definitely be considered for remote areas that rely on fossil-fueled generators for electric power.

On a first-cost basis, the installed cost of a PV system can be less than the cost of utility service. But PV may also be a good choice in areas where the reliability of a power plant is questionable, or where an agency is being charged high rates during peak hours.

The National Park Service has installed more than 450 PV systems, chiefly to provide power for resource-monitoring equipment. These are some additional, widely demonstrated, off-grid applications for PV:

- Lights for walkways, streets, highways, and common areas
- Residential uses (fans, lights, refrigerators) in remote areas
- Elctricity for campgrounds, marinas, and offshore drilling platforms
- Equipment for weather stations and fire observation towers
- Communications equipment and facilities (e.g., emergency roadside phones, microwave repeater stations)
- Cathodic (corrosion) protection for metal pipes and similar objects
- Highway and warning signs, security systems, transmission tower beacons
- Livestock watering pumps, irrigation systems, and disinfection equipment
- Emergency power during times of crisis.

## What is required?

A potential user should evaluate different PV systems on the basis of cost, system performance, system reliability, and maintenance needs. These are some additional requirements:

- Modules must face south and be unshaded; they can be mounted on the
- application (e.g., a highway sign), on a roof, or on the ground.

- Batteries are often needed to meet peak loads or for nighttime use; they require
- periodic maintenance.

- Power inverters will be needed if the load requires AC electricity.

## What does a PV system cost?

To determine the economic feasibility of using a PV system, consider these three main factors:

- The size and nature of the load
- The availability of the solar resource
- The cost of alternative sources of power.

On a 20-year, life-cycle-cost basis, a remote PV system typically costs from 25¢–50¢ per kilowatt-hour. In off-grid applications, PV can be more cost-effective than many alternatives.

# Solar Power for Montana

*(Source: MontanaGreenPower.com)*

Montana has an abundant solar resource that can be used to save energy in residential and commercial construction, and farming, ranching, recreation and other industries.

## How Solar Energy Benefits Montana

Solar energy can play a key role in creating a clean, reliable energy future in Montana. The benefits are many and varied. Consumers who use these technologies will benefit directly and immediately. Using solar energy produces immediate environmental benefits. Electricity is often produced by burning fossil fuels such as oil, coal, and natural gas. The combustion of these fuels releases a variety of pollutants into the atmosphere, such as carbon dioxide ($CO_2$), sulfur dioxide ($SO_2$), and nitrogen oxide ($NO_x$), which create acid rain and smog. Carbon dioxide from burning fossil fuels is a significant component of greenhouse gas emissions. These emissions could significantly alter the world's environment and lead to the global warming predicted by most atmospheric scientists.

The combustion of fossil fuels releases more than 6 billion tons of carbon into the atmosphere each year. The United States alone is responsible for 23 percent of these emissions. Clean energy sources, such as solar energy, can help meet rising energy demands while reducing pollution and preventing damage to the environment and public health at the same time.

Solar energy is an excellent alternative to fossil fuels for many reasons:

Solar energy is clean energy. Even when the emissions related to solar cell manufacturing are counted, photovoltaic generation produces less than 15 percent of the carbon dioxide from a conventional coal-fired power plant. Using solar energy to replace the use of traditional fossil fuel energy sources can prevent the release of pollutants into the atmosphere. Using solar energy to supply a million homes with energy would reduce $CO_2$ emissions by 4.3 million tons per year, the equivalent of removing 850,000 cars from the road.

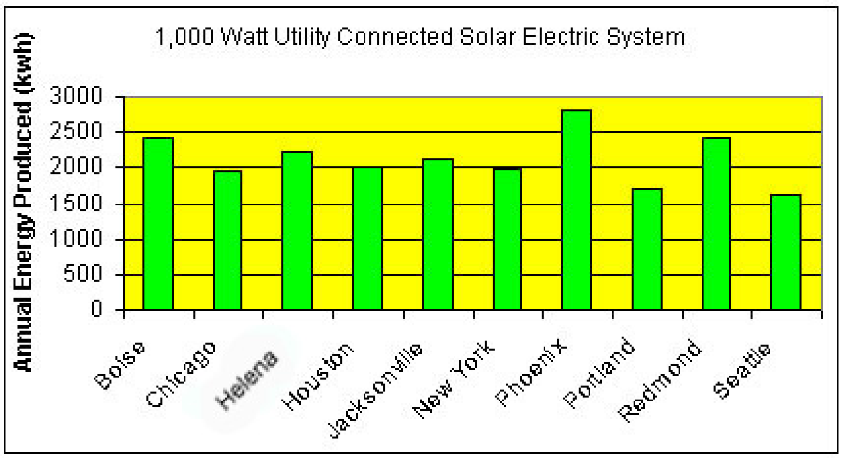
Solar energy uses fewer natural resources than conventional energy sources. Using energy from sunlight can replace the use of stored energy in natural resources such as petroleum, natural gas, and coal. Energy industry researchers estimate that the amount of land required for photovoltaic (PV) cells to produce enough electricity to meet all U.S. power needs is less than 60,000 square kilometers, or roughly 20 percent of the area of Arizona.

Solar energy is a renewable resource. Some scientists and industry experts estimate that renewable energy sources, such as solar, can supply up to half of the world's energy demand in the next 50 years, even as energy needs continue to grow.

## The Montana Solar Resource

Montana's abundant solar resource can be used to save energy in residential and commercial construction, and farming, ranching, recreation and other industries. The amount of sunshine available at a given location is called the "solar resource" or insolation. The amount of electrical energy produced by a PV array depends on the insolation at a given location and the collector bank orientation, tilt angle, and module efficiency.

Solar energy technologies work well in the Northwest. The graph shows that many Northwest cities, including Helena, rank above Jacksonville, Florida, and are nearly as good as Phoenix. Longer summer days and cooler temperatures add up to higher performance.




Montana can be divided for insolation roughly the way it is divided geographically—Eastern Montana and Western Montana. Eastern Montana receives an annual average of 5 hours of full sun; Western Montana receives an annual average of 4.2 hours.

# Solar Energy Timeline

*(Source: Florida Solar Energy Center)*

4.5 billion years ago
Solar energy reaches the earth

7th Century B.C.E.
Magnifying glass used to concentrate sun's rays to make fire

3rd Century B.C.E.
Greeks and Romans use "burning mirrors" to focus sunlight as weapons of war to ignite fires and burn sails of enemy war ships

20 A.D.
Chinese document use of burning mirrors to light torches for religious purposes

100
Italian historian Pliny the Younger builds passive solar home using glass for the first time to keep heat in and cold out

1-500
Roman baths built with large windows facing south to let sunlight for heat

6th Century
Justinian Code enacted to protect sunrooms on houses and public buildings so that shadows will not interfere with the sun used for heat and light

1300s
Ancestors of Pueblo people called Anasazi, in North America live in south-facing cliff dwellings that capture the winter sun

1600s
Educated people accept the idea that the sun and stars are the same

1643-1715
Reign of French King Louis XIV, ("Sun King"), is an era of solar experiments

1695
French Georges Buffon concentrates sunlight using mirrors to ignite wood and melt lead

1700s
European aristocracy use walls to store solar heat for ripening fruit (fruit walls)
England and Holland lead development of greenhouses with sloping glass walls facing south;

Frenchman Antoine Lavoisier builds solar furnace to melt platinum

1767
Swiss scientist Horace de Saussure invents first solar collector (solar hot box)

1800s
Wealthy Europeans build and use solar-heated greenhouses and conservatories;
French scientist uses heat from solar collector to make steam to power a steam engine

1830s
Astronomer Sir John Herschel uses solar cooker to cook food for his expedition to South Africa

1839
French scientist Edmund Becquerel observes photovoltaic effect

1860s
Post Civil War U.S. development of solar energy; pioneers find that water left in black pans in the sunlight gets hot

1861
French scientist Augustin Mouchot patents solar engine

1870s
Augustin Mouchot uses solar cookers, solar water pumps for irrigation, and solar stills for wine and water distillation (most widespread use of solar energy)

1880s
Engineer John Ericsson, "first American Solar Scientist," develops solar-driven engines for ships;
Solar-powered printing press working in France

1891
Baltimore inventor Clarence Kemp ("real father of solar energy in the U.S.") patents first commercial Climax Solar Water Heater

1892
Inventor Aubrey Eneas founds Solar Motor Company of Boston to build solar-powered motors to replace steam engines powered by coal or wood

1897
Kemp's water heaters used in 30% of homes in Pasadena, CA

1908
Los Angeles: Carnegie Steel Company invents modern type of roof solar collector

1920s
Solar Industry focus moves from California to Florida

1936
American astrophysicist Charles Greeley Abbott invents solar boiler

1940s
Great demand for solar homes, both active and passive, creates Your Solar House, a book of house plans by 49 great solar architects

1941
Approximately 60,000 solar water heaters in use in Florida

1950s
Architect Frank Bridgers designs world's first solar-heated office building;
Low-cost natural gas becomes primary heating fuel

1954
Birth of solar cells (photovoltaics)

Late 1950s
Extensive use of solar cells in space industry for satellites

1960s
Some U.S. solar companies manufacturing solar cells or solar hot water heaters;
U.S. oil imports surpass 50 percent

1970s
U.S. Department of Energy established; national solar research labs established

1973
Energy shortages/oil embargo;
Indifference about solar energy begins to decline

1974
Florida Solar Energy Center (FSEC), largest state solar center, is established

1977
President Jimmy Carter installs solar panels on the White House and promotes incentives for solar energy systems

1979
Second U.S. oil embargo;
Solar trade association (Solar Energy Industries Association) established in Washington, DC

1980
Energy Security Act virtually shuts down national solar research programs;
States begin establishing solar research facilities

1980s
U.S. government and private industry assist several thousand Navaho and Hopi Indians in Arizona and New Mexico supplement their passive solar homes with photovoltaic power

1983

Wisconsin enacts solar access law to protect the "right to light" for urban gardens, soon enacted in Arizona and Michigan

1990s

Tokyo has approximately 1.5 million buildings with solar water heaters (more than in the entire U.S.);

Israel uses solar water heating for approximately 30 percent of their buildings and all new homes are required to install solar water heating systems;

Greece, Australia and several additional countries are ahead of the U.S. in solar energy usage

# What Your Students Should Know About Solar Energy

According to the National Energy Education Development Project (NEED), your students should know the following upon high school graduation:

All students show know:

1. Solar energy provides the world—directly and indirectly—with almost all of its energy. As well as providing the light and heat energy that sustain the world, solar energy is stored in fossil fuels and biomass, and is responsible for hydropower and wind energy.

2. Radiant energy is produced as a result of nuclear fusion in the sun's core.

3. Solar energy is a renewable energy source. Its potential as an energy source is vast.

4. Using solar energy produces no air pollution.

5. Solar energy is abundant, but it is diffuse and not available at all hours. It is not yet economical to harness on a large scale to produce electricity.

6. Most of the solar energy we use for heat and light cannot be measured. Harnessed solar energy provides a small amount (0.1%) of the nation's total energy consumption.

7. Photovoltaic cells convert sunlight directly into electrical energy. Today, they are mainly used in remote areas and for special applications.

8. Solar energy is used directly to light and heat buildings and heat water.

9. Back-up energy systems are usually needed when using solar energy.

Advanced students also should know:

1. Photovoltaic–produced electricity costs more than conventionally produced power; however, PV manufacturing costs are decreasing and cell efficiencies are increasing.

2. Concentrating solar energy and directing it toward a receiver can produce high temperatures capable of producing electricity.

3. Using proven construction techniques, solar heated and lighted buildings decrease the need for conventional energy sources.

4. Solar resources are affected by time of day, season, and location. Using solar energy for heating and lighting is a feasible choice in many areas of the country with current technologies.

5. The environmental and economic advantages and disadvantages of using solar energy.

6. How photovoltaic cells and concentrated solar power systems transform sunlight into electricity.

7. How passive and active solar systems operate.

# Lesson 1: What is Renewable Energy?

## Objectives:

- Students will define/explain renewable energy resources
- Students will demonstrate how two types of renewable energy systems work.

## Background:

**Renewable energy** comes from resources that are easily and continually replenished, such as the sun, wind, and water. In comparison, the **fossil fuels** (such as oil, coal, and natural gas) that we commonly use for energy, are nonrenewable. Fossil fuels are formed within the earth from ancient decayed plants and animals. These limited resources will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve.

A renewable energy system converts the energy in sunlight, wind, falling water, and other resources into a form we can use, such as heat or electricity. Historically, renewable energy was used exclusively as man's energy source until coal was first used in the 13th century, oil at the end of the 19th century and uranium in the middle of the 20th century.

The most common renewable energy resources are:

- **Solar energy**—energy from the sun. Solar energy, can be used directly for heating and lighting homes and other buildings, for generating electricity, and for water heating, solar cooling, and a variety of commercial and industrial uses.

- **Wind energy**—energy from wind. The sun's heat drives the wind, whose energy is captured with wind turbines.

- **Geothermal energy**—heat energy extracted from reservoirs in the earth's interior. Old Faithful geyser in Yellowstone National Park is an example of geothermal energy. Heat pumps, another geothermal application, provide heating and cooling for homes by utilizing the earth's heat.

- **Biomass energy**—stored energy in plants and trees. Burning a log in your fireplace is an example of biomass energy.

- **Hydropower energy**—electricity produced from falling water. Most often, hydropower energy is captured through the use of dams on rivers to create large reservoirs of water. Utilities commonly use hydropower to produce electricity for their customers, accounting for about 10 percent of U.S. electric generating capacity. Dams provide electricity by guiding water down inside a pipe, called a **penstock**, and through a turbine at high speed. Although hydropower does not produce any air emissions, dams—especially large ones—cause serious environmental problems. Hydropower facilities have characteristically high initial investment costs and associated environmental impacts, but also enjoy the benefits of low operating costs, no pollutant emissions, and use of an existing renewable energy resource.

### Activity 1: How Does Heat Affect a Turbine? (Source: Laura Haug, Energy Day)

Heat from the sun is a renewable source of energy. Illustrate how solar energy can move a turbine.

Materials:

- Three light bulbs of varying wattage
- Waxed paper
- Lamp
- Ruler
- Heavy thread
- Needle
- Scissors
- Watch with second hand

Method:

1. Cut a circle approximately 6 inches in diameter from the waxed paper.
2. Cut the waxed paper into a spiral with three or four loops.
3. Thread the needle with the thread. Run the needle through the middle of the spiral to make a turbine.
4. Light up the lowest wattage bulb. Hold the turbine about 8 inches over the bulb for about 20 seconds. Count and record the number of rotations.
5. Repeat step 4 for the other two bulbs.

### Activity 2: Demonstrating a Water Wheel (Source: Laura Haug, Energy Day)

Moving or falling water is a natural, and renewable, source of energy. Make this small water wheel to illustrate how water can make things move.

Materials:

- Empty spool of thread
- Index card
- Thin straw or long nail that will fit inside the spool
- Tape
- Scissors

Method:

1. Cut the index card into strips measuring one inch by one and a half inches.
2. Fold the strips in half and tape to the spool to make paddles.
3. Put the straw or nail through the spool.
4. Hold the wheel under gently running water to see how moving water will turn the wheel.

### Wrap-up:

Ask your students to investigate how concepts would be applied to designing larger renewable energy systems. How would these basic designs be used to provide electricity? What other design components are needed?

# Lesson 2: What are the Benefits of Renewable Energy?

## Objectives:

- Students will explain the benefits of renewable energy systems compared to conventional fossil fuel energy sources.

## Background:

Renewable energy has many benefits, including:

- **Environmental benefits:** Because renewable energy technologies are clean, or non-polluting, sources of energy, they have a much lower environmental impact than conventional energy technologies.

- **Reliable supplies:** Renewable energy will never run out. Other sources of energy are finite and will some day be depleted.

- **Economic benefits:** Most renewable energy investments are spent on materials and workmanship to build and maintain the facilities, rather than on costly energy imports. Renewable energy investments are usually spent within the United States, frequently in the same state, and often in the same town. This means your energy dollars stay home to create jobs and boost local economies, rather than going overseas. Meanwhile, renewable energy technologies developed and built in the United States are being sold overseas, helping to reduce the U.S. trade deficit.

- **Energy security:** After the oil supply disruptions of the early 1970s, our nation has increased its dependence on foreign oil supplies instead of decreasing it. Relying more on renewable energy systems allows us to reduce our dependence on foreign sources.

In comparison, fossil fuels are available only in limited supplies, costly to extract, and contribute to **greenhouse gas** emissions. Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Certain human activities, however, add to the levels of most of these naturally occurring gases:

- **Carbon dioxide** is released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned.

- **Methane** is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from the decomposition of organic wastes in municipal solid waste landfills, and the raising of livestock.

- **Nitrous oxides** are emitted during agricultural and industrial activities, as well as during combustion of solid waste and fossil fuels.

## Activity 1: How Much Can Solar Energy Reduce Pollution?

Renewable energy systems are non-polluting. Find out how much solar energy can reduce harmful greenhouse gas emissions in the atmosphere.
Materials:

- Computer with Internet access.
- Calculator
- Colored markers or pens
- Paper or poster board to chart results

Method:

1. Break class into several teams.
2. E
   ach team will determine how much pollution they contribute to the atmosphere through energy and water use at home.
3. (Hint: for help, each team should complete the online calculators at websites such as Atmospheric Carbon: What's Your Share? http://www.infinitepower.com/carboncalc.html or
4. The Personal Environmental Impact Calculator http://fatman.neep.wisc.edu/~eic/personal.impact.html) Because every household is different, ask each team to enter determine an average value for their group.
5. Plot this information on a chart.
6. Determine how much pollution emissions will be avoided by using solar energy to provide a portion of this energy use. Assign a different solar energy percentage to each team for comparison purposes. *(Hint: students can calculate pollution savings for solar water heating, photovoltaics (solar electricity), and solar pool heating at EPA's Environmental Benefits of Solar Energy website http://199.223.18.230/epa/rew/rew.nsf/solar/index.html).*
7. Chart this information on the same graph as step 2 but in a different color for comparison.
8. Have each team share their results with the class.

### Wrap-up:

Lead a class discussion on what this reduced pollution might mean for your town. Your students might conclude that the air would be cleaner, the school would spend less money on its energy bills, or similar things. How can your family, school, and community reduce pollution by using less energy?

# Lesson 3: What is Solar Energy?

## Objectives:

- Students will explain what solar energy is
- Students will demonstrate how different variables increase or decrease solar energy potential

## Background:

The sun is a giant energy source. For many years, people have been using the sun's energy, called **solar energy**, to make buildings brighter and warmer. Today, we use special equipment and specially designed buildings to capture solar energy for lighting, to heat our living spaces and our water, and even to produce electricity.

Capturing and using solar energy has become more important than ever. Traditional fuels like natural gas and oil are limited, and as these fuels become more scarce, their cost increases. Solar energy also is non-polluting and thus helps us achieve a cleaner environment.

If you collect enough solar heat, you can use it instead of heat from a furnace. One way to collect heat is to trap solar energy with **solar collectors**. Solar collectors allow sunlight in through plastic or glass, absorbing that sunlight and convert it to heat. Because the heat is unable to pass easily through the plastic or glass, it is trapped inside the collector. An example of how a solar collector works is a car that has all its windows closed tightly. When sunlight passes through the windows of the car, it is either absorbed by the seats and other surfaces inside the car, or it is reflected back out through the window. Light that is absorbed changes into heat. Darker colored surfaces absorb more sunlight than lighter colors. Similarly, different materials hold heat more efficiently than others and are thus better suited to store solar energy.

Solar collectors come in many shapes and sizes. **Passive** solar collectors move heat from the collectors to other spaces naturally, without the use of fans or pumps. An attached sunroom or a south-facing room with a large window area and a tile floor (which serves to collect, retain, and then release heat) are examples of passive solar heating systems. **Active** solar systems use fans (for systems that heat the air) or pumps (for systems that heat water) to move the heat from the collector to another part of the building.

**Activity 1: Which Material Best Stores Solar Energy?** (Source: Solar Energy Research and Education Foundation—SEREF)

Materials:

- Cardboard box
- Black paint
- Four small metal cans
- Four thermometers
- Sand
- Salt
- Water
- Torn-up paper
- Scale

Method:

1. Paint the entire surface of the box (inside and outside) with the black paint.
2. Place the box in the sun.
3. Pick the can to hold the torn paper, place a thermometer in the can and using the scale, record the combined weight (grams).
4. Position the thermometer in the middle of the can and pack torn paper into the can; filling the bottom of the can, around the thermometer, and up to the top of the can.
5. Record the weight of the torn-paper filled can. Subtract the initial weight from the filled weight to determine how much torn paper you added to the can.
6. sand equal to the weight of the torn paper.
7. In each can, attach the thermometer such that the thermometer is positioned in the middle of the material inside.
8. Place the cans in the box.
9. Close the box and leave it for half an hour.
10. Remove the cans
11. Watch the temperatures in each can fall and record the temperatures for each on the chart below.
12. Using this information, determine which material best stores heat.

| | **Starting Temp.** | **2 min.** | **4 min.** | **6 min.** | **8 min.** | **10 min.** |
|---|---|---|---|---|---|---|
| Salt | | | | | | |
| Sand | | | | | | |
| Water | | | | | | |
| Paper | | | | | | |

**Activity 2: In Collecting Solar Energy, Is Bigger Better?** (Source: Solar Energy Research and Education Foundation—SEREF)

Materials:

- Large disposable pie plate
- Small disposable pie plate
- Black paint (non-water-soluble spray paint is easiest)
- Thermometer
- Metric measuring cup
- Clear plastic food wrap
- Newspapers
- Styrofoam cups
- Masking tape
- Water

Method:

1. Paint both pie plates black.
2. When the paint dries, add 100ml of water to each pie plate
3. Record the temperature of the water in each plate.
4. Wrap plastic tightly over them.
5. Tape the plastic securely.
6. Place each on a stack of newspapers in the sun for 10 minutes.
7. Pour the water into styrofoam cups and measure the temperatures, recording the temperatures below.
8. Using this information, determine which plate had hotter water.

| **Temperature (in degrees Celsius)** | | | |
|---|---|---|---|
| Before | | After | |
| Large | Small | Large | Small |
| | | | |

### Wrap-up:

Lead a class discussion about how these concepts would be applied to designing a solar energy system. Your students should demonstrate an understanding of why surface area of the solar collector and the choice of storage material will affect the system's performance.

# Lesson 4: How Is Solar Energy Used to Heat Water?

### Objective:

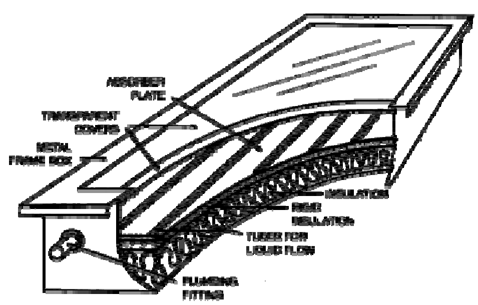
- Students will understand and demonstrate how solar water-heating systems work

### Background:

Just as solar energy can be used to heat air in buildings, it also can be used to heat water for bathing and laundry. Most solar water-heating systems have two main parts: the **solar collector** and the **storage tank**. The solar collector heats the water, which then flows to the storage tank. The storage tank can be simply a modified water heater, but ideally it should be a larger, well-insulated tank. The water stays in the storage tank until it is needed for something, such as a shower or to run the dishwasher.

A common collector—called a **flat-plate collector**—is usually mounted on the roof. This collector is a rectangular box with a transparent cover that faces the sun. Small tubes run through the box, carrying the water or other fluid, such as antifreeze, to be heated. The tubes are mounted on a metal absorber plate, which is painted black to absorb the sun's heat. The back and sides of the box are insulated to hold in the heat. Heat builds up in the collector, and as the fluid passes through the tubes, it heats up.

Like solar-designed buildings, solar water-heating systems can be either **active** or **passive**. The most common systems are active, which means they use pumps to move the heated fluid from the collector and into the storage tank. While a solar water-heating system can work well, it can't heat water when the sun isn't shining. For that reason, homes also have a conventional backup system that uses fossil fuels.



Source: North Carolina Solar Center

### Activity 1: Showing the Movement of Water as it Heats (Source: Australian Academy of Science)

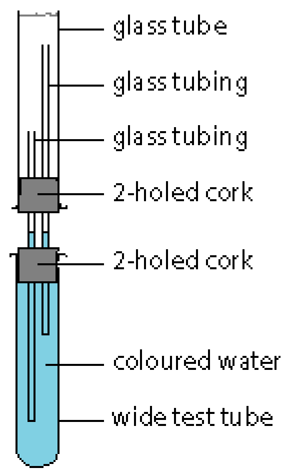
Hot water weighs less than cold water. This is because a substance occupies more volume, and is therefore less dense, when it is heated. In gases and liquids, a light substance will rise to the top, since hot water rises above cold water. Observe how this principle is used in solar water heaters.

Materials:

- Wide test tube (about 4 inches in diameter)\
- Glass tube about the same width as the test tube, or a second test tube with the bottom cut off
- Two lengths of glass tubing, long enough to fit inside your glass test tubes, as shown in the graphic below
- Two corks with two holes cut the size of the glass tubing in each
- Cold water
- Food coloring
- Thermometer

Method:

1. Set up the apparatus as shown in the diagram below.




2. Fill the bottom tube with colored water, and the upper tube with clear water. Note: don't fill the tubes quite full to allow for expansion as the water heats.
3. Place the apparatus in direct sunlight.
4. Record the temperature of the water in the lower tube every two minutes until there is no further evidence of the movement of water through the system.
5. Ask your students to try to describe what happened to bring about the changes in the appearance of the water. These changes occur because as water heats, it will expand, forcing the colored water in the lower tube up through the pieces of glass tubing in the upper tube.

**Activity 2: Making a Simple Solar Water Heater** (Source: Australian Academy of Science)
Illustrate how solar water heaters take advantage of the fact that hot water rises.

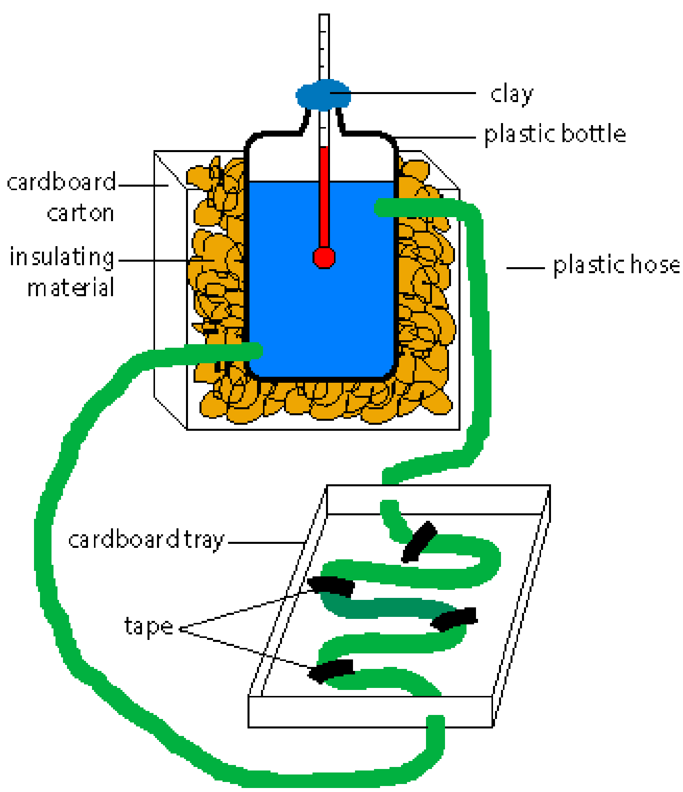
Teacher's Notes: Ideally, this experiment is conducted by breaking your class into two groups, having each group build two model solar water heaters (four total). The experiment will take three class periods to complete. You can reduce the time to two days by eliminating the third-day experiment.

Materials:

- Four large card board tray, approximately 2 feet x 1 foot x 6 inches (made by cutting down a cardboard carton)
- Four sections of plastic tubing or garden hose, approximately 20 feet long
- Four 2-liter plastic bottles
- Four cardboard cartons (large enough to hold the plastic bottle)
- Four thermometer
- Scissors with pointed ends
- Clay or similar product to hold thermometer in place while sealing bottle opening
- Sticky tape
- Water
- Black and white poster paints
- Two sheets of clear plastic, larger than 2 feet x 1 foot
- Insulating material such as sawdust, plastic foam, crumpled newspapers

Method:

1. **Day 1:** Each group constructs two model solar water heaters as shown in the diagram below.



2. One group paints the bottom of both cardboard trays white. The other group paints the bottom of each tray black.
3. **Day 2:** Fill each 2-liter bottle and the plastic tubing with water. Note: don't fill the bottle quite full; the water will need a few inches at the top for expansion as it heats.
4. Each group records the initial temperature of the water in each bottle.
5. Place each unit in a sunny location for 20 minutes and then record the water temperature of each.
6. Each group then changes the tilt angle of one of their units by tilting the cardboard tray to a different angle than the other tray.
7. Leave the units in the sun for 20 minutes. Record the tilt angle (in degrees) and water temperature of each.
8. **Day 3**: Each group records the initial water temperature of both units. Then place the units in a sunny location for 20 minutes and record temperature again.
9. Each group then covers one of its trays with the plastic. Record the temperatures after 20 minutes.

## Wrap-up:

Lead a class discussion on how different factors affect water temperature. Your students might observe that darker surfaces collect more heat, that different tilt angles capture more energy, or similar things.

# Lesson 5: What is Montana's Solar Energy Potential?

## Objectives:

- Students will analyze and understand Montana's solar resource potential
- Students will compare the solar potential of major Montana cities
- Students will compare Montana's solar potential with other states

## Background:

More solar energy falls on the earth each minute than the world consumes in one year! However, not all of this energy is available to us for direct use. **Solar insolation**—the amount of sunshine available at a given location—varies according to such things as weather patterns and season, latitude, and elevation. Solar insolation data, expressed in kilowatt-hours per square meter per day (kWh/m^2/day), is used to determine how much energy a solar system will produce.

Montana has an abundant solar resource compared to many locations, and this valuable resource can be used to save energy in residential and commercial construction, as well as farming, ranching, recreation, and other industries.

### Activity 1: How Does Solar Insolation Differ by Location?

Materials:

- Computer with Internet access
- Colored pens or markers
- Paper or poster board for charting results

Method:

1. Separate class into three groups.
2. Assign one group to find solar insolation data for several Montana cities (select cities in both the western and eastern part of the state), and the other groups to find solar insolation data for the same number of cities in various states in the U.S. To make an effective comparison, instruct the groups to select cities as follows:

    - Group 1 will choose Montana cities with the same latitudes but different elevations.
    - Group 2 will choose U.S. cities with the same basic climate but different latitudes.
    - Group 3 will choose U.S. cities with the same elevation but different climates. *(Hint: this information can be found on websites such as http://solstice.crest.org/renewables/solrad/data/index.html)*
3. Instruct each group to graph insolation data by month and by city or state, and to note latitude, average monthly climate information, and elevation for each site.
4. Each group will present findings to class.

## Wrap-up:

Lead a class discussion on why there is more solar insolation available at different locations. Your students should be able to correlate the impact of latitude, climate, season, and elevation on solar insolation.

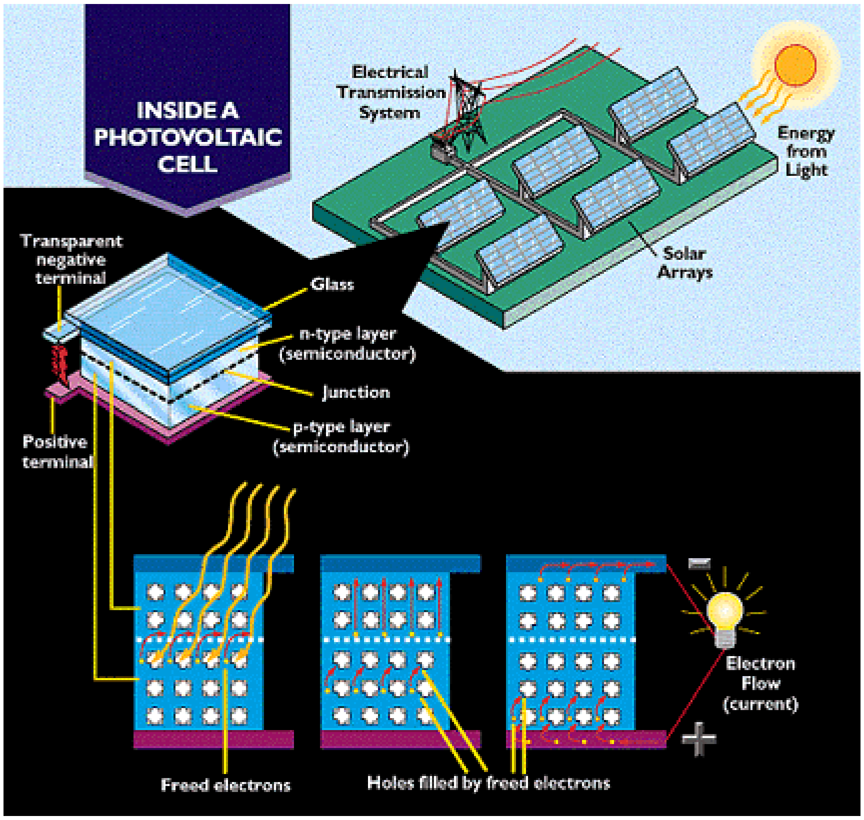
# Lesson 6: What is Photovoltaics?

## Objectives:

- Students will describe how photovoltaic (PV) systems convert sunlight to electricity
- Students will identify PV system components
- Students will understand the factors that contribute to the efficiency of a PV system
- Students will demonstrate the effect of solar energy on electrical output

## Background:

Photovoltaic (PV) systems convert sunlight into electricity. The **photovoltaic effect** is the basic physical process through which this happens. Sunlight is composed of **photons**, or particles of solar energy. These photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons strike a PV cell, they may be reflected or absorbed, or they may pass right through. Only the absorbed photons generate electricity. When this happens, the energy of the photon is transferred to an electron in an atom of the cell (which is actually a semiconductor). With its newfound energy, the electron is able to escape from its normal position associated with that atom to become part of the current in an electrical circuit. By leaving this position, the electron causes a "hole" to form. Special electrical properties of the PV cell—a built-in electric field—provide the voltage needed to drive the current through an external load (such as a light bulb).




Source: Utility Photovoltaic Group

In order for the photovoltaic effect to occur efficiently, a potential installation site must meet certain requirements, including:

- **Orientation**: the building must have a southern exposure. For maximum daily power output, the installed PV modules must face due south (180 degrees), plus or minus 30 degrees (i.e., 150-210 degrees) and be exposed to the sun for as much of the day as possible, especially during the peak hours of 9 a.m. to 3 p.m.

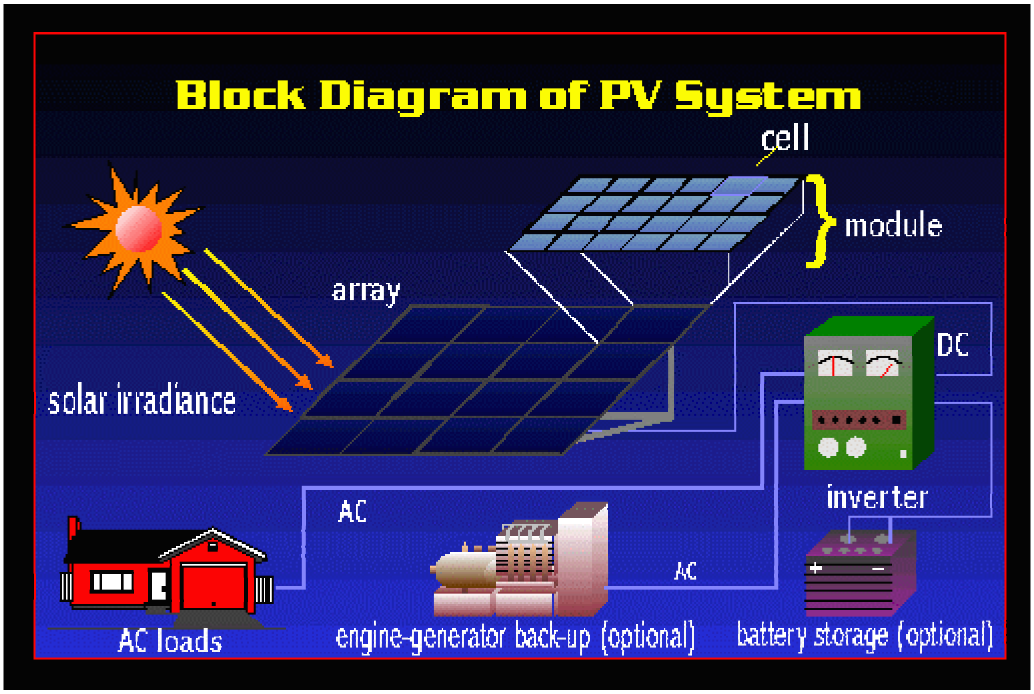
- **Shading**: Significant shading from trees, buildings, mountains, and other obstructions on the roof between 3 hours before and after solar noon will reduce solar energy collection. Solar noon is the midpoint between sunrise and sunset times.

A PV system comprises several components. The basic building block of a PV panel is the PV **cell**, which is a solid state, or non-mechanical, device. A solar system uses a number of PV panels, each made of silicon, plus boron and phosphorous. The output of a single cell under direct sunlight is about one watt. To increase their effectiveness, dozens of individual cells are interconnected together in a sealed, weatherproof glass package called a **module**. Modules come in a range of wattages, and their nature allows for great flexibility in designing systems that meet a variety of electrical needs.

Since PV modules are only capable of producing direct current (DC) electricity, an **inverter** is required to convert the **direct current (DC)** output produced by the PV array into **alternating current (AC)** power. AC electricity is needed to run computers, refrigerators and other appliances, and lighting.

A utility-intertied—sometimes called grid-connected—PV system, such as those installed under the Sun4Schools project, generate electricity which is supplemented by the energy provided by the existing utility grid. A utility-intertied PV system requires neither battery storage nor an emergency back-up system since it is connected directly to the utility grid, which is used as the storage medium. Systems that are not connected to the utility grid use batteries to store energy for use when the sun is not shining. While a utility-intertied PV system can be designed to provide all of a building's electrical needs, most systems provide only a portion of the total electricity requirements.

A well-designed and properly installed PV system with a consistent maintenance schedule will operate for more than 20 years. The PV module, which has no moving parts, has an expected lifetime of more than 30 years.




Source: Utility Photovoltaic Group

## Activity 1: The Effect of Solar Energy on Light or Electrical Output

*(Source: Utah State Science)*

Solar energy can be measured directly (if connected to a voltmeter) or indirectly (by noting light output when cells are wired to a small light bulb). Demonstrate how reducing solar input reduces current voltage and, in turn, reduces light output.

Teacher's Notes: Caution students to perform this experiment carefully by ensuring that all connections are secure. Students should handle all materials carefully to prevent breakage. Materials:

- Three or more solar cells* (Note: Students will need three 0.5-volt solar cells to make a 1.5-volt light work correctly)
- Short lengths of 22-gauge wire
- Four to six small alligator clips
- One small LED flashlight bulb OR one voltmeter capable of measuring voltages below 1.5 volts*
- Several pieces of cellophane of various colors, large enough to cover all solar cells when they are wired to form a simple circuit
- Screening of different mesh sizes and materials, large enough to cover all solar cells **
- Wax paper or other transparent material, large enough to cover all solar cells Glass plate, clear plastic wrap, or other clear material, large enough to cover all solar cells
- Sunny room or area in which to place circuit

*available from electronic components stores, solar equipment dealers, or catalogs (a list of Montana solar equipment dealers is located at http://www.montanagreenpower.com/dealers.html)
**available from craft stores or floral shops

Method:

1. Have students wire a simple circuit **in series**—connected end to end so that the current through each is the same. To wire the circuit in series, use the alligator clips to connect the three solar cells as follows:
   - Connect the negative (black) lead from cell #1 to the positive (red) lead of cell #2.
   - Connect the negative (black) lead from cell #2 to the positive (red) lead of cell #3.
   - Connect the negative (black) lead from cell #3 to the negative (black) lead of the light or voltmeter.
   - Connect the positive (red) lead from the voltmeter or light to the negative (black) lead of cell #1.
2. When the light or voltmeter is working correctly, experiment with each cover material (colored cellophane, screening, wax paper, glass or clear plastic) and record the effects of each material on the light or voltage output.

## Wrap-up:

Lead a class discussion on why different materials might affect output. Student might observe, for example, that darker colors reduce available sunlight reaching the solar cells and thus reduce output. Screening with larger mesh allows more sunlight to pass through to the solar cells than smaller mesh. How might this concept be applied to the effect of clouds or shading on PV system output?

# Lesson 7: How is PV Used?

## Objectives:

- Students will demonstrate an understanding of the different applications in which PV systems are used.
- Students will analyze and calculate how much energy typical household appliances and devices use and calculate the size of a basic PV system.

## Background:

Photovoltaics—commonly referred to as PV—is used in a variety of applications. Some smaller applications are quite common, such as PV-powered calculators and watches. There also are numerous large-scale PV applications, including:

- **Water pumping** for small-scale remote irrigation, stock watering, residential uses, remote villages, and marine sump pumps;
- **Lighting** for homes, billboards, security, highway signs, streets and parking lots, pathways, recreational vehicles, remote villages and schools, and marine navigational buoys;
- **Communications** by remote relay stations, emergency radios, orbiting satellites, and cellular telephones;
- **Refrigeration** for medical and recreational uses;
- **Corrosion protection** for pipelines and docks, petroleum and water wells, and underground tanks;
- **Utility grids** that produce utility- or commercial-scale electricity; and
- **Household appliances** such as ventilation fans, swamp coolers, televisions, blenders, and stereos.

Virtually any power need can be met with photovoltaics, but some situations are more cost-effective than others. (Cost-effectiveness is discussed further in Lesson 8.) PV systems are well-suited to locations where accessing an **electrical grid** (the system through which your utility company supplies electricity to its customers) is either not feasible or expensive.

Many small household appliances can be cost-effectively powered with PV. In general, though, PV is not used to generate electricity for hot water, space heating, electric cook stoves or ovens, refrigerators, or other applications with high power needs. Propane is a more cost-effective fuel for these applications. In the case of refrigerators, super-efficient models that use considerably less electricity than conventional models are available and are often used instead of propane models.

## Activity 1: Sizing A PV System

Sizing a PV system requires analysis of many factors. Perform a simple sizing calculation to determine how many PV modules a system will need.

*Teacher's Notes: Set the stage for this activity as follows: You are designing a PV system to meet the electrical needs of a **remote** home in Montana (one that is located a great distance from the utility grid). In this activity, you will determine how many PV modules your system will require. This activity is for illustrative purposes only. Sizing and designing a complete PV system requires analyses of many more issues than are addressed here. Remind your students that PV will be the only source of electricity for this house. If they fail to account for any electrical use when sizing a system, they may not have enough electricity to meet their demands. While, in a* *real situation, a single PV system would be designed to meet the needs of the entire house, for purposes of this activity, you will treat each area in the house as though it is a separate, stand-alone building.*

Materials:

- Computer with Internet access
- Calculator for each group

Method:

1. Separate the class into four groups. Assign one group to each of the following areas of the house.
   - Kitchen
   - Living Room
   - Garage (including any power tools that might be used)
   - Bedroom/Study

2. Instruct each group to determine their daily energy use using the following steps:
   - Identify all electrical devices that will rely on the system for power.
   - Determine each device's power usage in watts *(Hint: you can find wattage charts for common appliances and devices at http://thermomax.com/load.htm or http://www.atlantasolar.com/wattage.html).*
   - Estimate the average daily use of each device in hours per day.
   - Multiply each device's wattage by the hours of daily use to get watt-hours per day.
   - Add together the watt-hours for all devices to get the total energy requirement.

   *(Note: if the energy requirement varies from season to season, it must be calculated for each season to determine the largest requirement. Residences tend to use more energy in winter when the days are shorter, since lights and other appliances are on longer.*

3. Adjust the load for system losses, module output and average winter sunlight by multiplying your estimated daily load by 1.4.
4. Assuming you will use 50-watt modules (12-volt), calculate how many watt-hours of electricity each module will provide. To do this, multiply the module rating (50 watts) by 3 (Montana's solar multiplier). Divide the result of Step 3 by the result of Step 4. This is how many modules you will need to meet your electricity needs. If your result is not an even number, round up to the next number.
5. Combine the number of modules from the four groups.

## Extension:

Instruct your students to expand this activity by sizing the system's battery storage and inverter. They can find help at websites such as http://aaasolar.com/design/pvsizing/PVSIZING.htm

## Wrap-up:

Lead a class discussion about how one might reduce the size of a PV system to make it more cost-effective. How would energy efficiency and energy conservation affect a PV installation? Your students might note such things as more energy-efficient appliances and lighting will use less energy and thus allow a smaller PV system; that eliminating unnecessary electrical items (such as stereos, color televisions, or electric garage door openers) will reduce electrical load; or that switching to other fuels (propane-fired stove, for example) would reduce electricity needs.

# Lesson 8: Are PV Systems Cost-Effective?

## Objectives:

- Students will analyze costs related to PV
- Students will calculate the environmental cost savings of PV compared to fossil fuels
- Students will investigate tax incentives or rebates that would help make PV systems more affordable

## Background:

PV systems are more **cost-effective** in some situations than in others, depending on the size and nature of the load, the availability of the solar resource, and the cost of alternative sources of power. In many situations, PV can be more cost-effective than many alternatives.

For example, PV is often the cheapest source of electricity for a remote home that is located far from the existing utility grid. In these instances, extending the utility grid is often not feasible or very expensive, making PV a good choice. However, in situations where utility-supplied electricity is readily available and inexpensive, PV systems become less cost-effective.

When we think about whether a PV system is cost-effective, we must consider both financial costs and environmental costs. **Financial costs** can include system and component costs, design costs, installation, structural support for the modules, site preparation, and more. Today in Montana, a 2- to 4- kilowatt (kW) grid-intertied PV system will have an installed cost between $9 and $16 per watt, with the electricity produced over the life of the system costing 25 to 30 cents per kilowatt-hour. In comparison, residential electricity purchased from the utility grid costs about 7 cents per kilowatt-hour.

We must also consider hidden environmental costs, called **external costs**. While the above information suggests that fossil fuels are much cheaper than renewable energy, consider these facts:

- **Extracting fossil fuels causes environmental damage** from the extraction equipment and from the pollution that is a by-product of burning those fossil fuels.
- **Fossil fuels are not free**. They cost money to bring out of the ground. This means that as fossil fuels run out, their price will increase.
- **Fossil fuels give off gases when they are burned**. Most of these gases—sulfur oxides, nitrous oxides, and carbon dioxide, for example—can cause environmental problems, such as acid rain. Others, particularly carbon dioxide, may be causing a change in the global climate, sometimes called the **greenhouse effect**, **climate change**, or **global warming**.

If these external costs were included in the price we pay for fuels, the price of those fuels would increase considerably.

### Activity 1: What is the "Real" Value of your PV System?

Calculating the value of a PV system requires an analysis of both economic and environmental factors. Analyze your PV system's value.

Method:

1. First calculate the "economic value" of your PV system. Go to the PV Watts calculator at http://rredc.nrel.gov/solar/codes_algs/PVWATTS/
2. Click on Montana and then choose a city nearest to your location that has similar topography.
3. To get an accurate assessment of the system installed on your school, use these values:
   - AC Rating (kW): 2.0
   - Array Type: Fixed Tilt
   - Array Tilt (degrees): 45
   - Array Azimuth (degrees): 180
   - Cost of Electricity (cents/kWh): State Average
4. Click on Calculate to see how much your school will save in energy costs.
5. Assuming that your system cost $25,000 and the cost of electricity stays the same, calculate the **simple payback**, or how long it would take for this energy savings to pay for the system.
6. Next, determine the "environmental value" of your PV system by calculating how much pollution is prevented at http://www.ase.org/greenschools/spirit/calculator.htm. Take the total number of kilowatt-hours produced by your PV system (determined in step 4) and calculate how much your system will reduce carbon dioxide, sulfur dioxide, and nitrous oxide emissions.

Extension for Sun4Schools Participants: Your students can gather exact electricity production data on your school through a link at http://www.montanagreenpower.com. Ask students to collect this data over a certain period of time, say one or two months, and then determine the corresponding reduction in pollution. This process is basically the same as the activity above, but is based on school-specific information, rather than nearest location and average electricity production.

### Activity 2: Are Financial Incentives for Solar Energy in Your Area?

Many states offer financial incentives to encourage the use of renewable energy systems. Investigate whether there are any such incentives in your area.

Method:

1. Have students investigate whether there are any rebates or tax incentives for solar systems in Montana.
   *(Hint: see the website http://www.homepower.com/stateincentives.htm for a full list of incentives in your state.)*

### Wrap-up:

Lead a class discussion about whether your students would be willing to pay more for a PV system versus utility electricity. Students should demonstrate an understanding of the financial and environmental factors that go into this.

# Lesson 9: How Do Other Solar Schools Compare to Ours?

*Teacher's Notes: This lesson is appropriate only for schools that have a PV system installed as part of Sun4Schools.*

## Objectives:

- Students will compare performance of their school's PV system to another solar school by monitoring electricity output on the Internet and graphing information for both schools.

## Background:

More than 20 states in the U.S. have solar schools programs. These schools are using solar energy both as an education tool and as a way to reduce energy costs and protect the environment. Some schools are using the sun to light their schools, others are generating electricity from the sun to power their classrooms, and others are heating water with solar energy.

## Activity 1: Comparing Performance

Learn how your school's PV system compares with other solar schools in the nation.

Method:

1. Divide the class into groups of four students.
2. Ask each group to find a "partner" school with a PV of the same size (2kW), aiming for a wide geographic spread of partner schools. *(Hint: you can find partner schools at such websites as http://aepes.com/datapult/school.htm http://www.wattsonschools.com/schools.htm http://www.upvg.org/upvg/schools/index.htm*
3. Each day for a specific block of time (two weeks or a month, for example) have each team find performance data (how much electricity, or kilowatt-hours, the system is producing), as well as weather conditions, for their partner school and record the information on a line graph. Using a second line on the graph, have each team plot the same information for their own school.
4. At the end of the evaluation period, have each team present their findings to the class, indicating how their partner school compared with their own school.

## Wrap-up:

Lead a class discussion about the possible reasons for the differences in performance. Your students may be able to explain the impact of latitude, solar insolation, weather, and other variables on system performance.

# Glossary of Renewable Energy Terms and Phrases

*(Source: U.S. Department of Energy Solar Now Project)*

**AC**
Electrical energy which alternates cyclically between positive and negative in polarity. In many countries, including the U.S., the polarity reversal is made to occur 60 times per second (60 hertz).

**Acid Rain**
Rain mixed with sulphuric, nitric and other acids which arise from emissions released during the burning of fossil fuels.

**Ampere (amp)**
The measure of the number of electrons flowing past a given point in an electrical conductor in a given amount of time; this is the electrical current.

**Ballast**
A charging device in fluorescent lights which give a "jump start" to the gas inside the tube to make it start glowing steadily.

**Biomass**
Living materials (wood, vegetation, etc.) grown or produced expressly for use as fuel.

**Biomass fuels**
Wood and forest residues, animal manure and waste, grains, crops and aquatic plants are some common biomass fuels.

**BTU**
British Thermal Unit—A measure of heat energy; the amount needed to raise the temperature of one pound of water by one degree Fahrenheit.

**Calorie**
Metric thermal unit: a measure of heat energy; the amount needed to raise the temperature of one kilogram of water by one degree Centigrade. This is the large Calorie (used relating to food energy content) definition. The "small" calorie of fuel research is the amount of energy needed to raise the temperature of one gram of water by one degree Centigrade.

**Concentrator**
A tool that uses lenses and/or mirrors to focus and enhance the sun's rays onto the photovoltaic surface.

**Conservation**
Achieving the use of less energy, either by using more efficient technologies or by changing wasteful habits.

**DC**
Electrical energy that does not cyclically alternate in polarity: e.g. electrical energy from a battery or solar cell.

**Efficiency**
The ration of desired work-type output to the necessary energy input, in any given energy transformation device. An efficient LIGHT bulb for example uses most of the input electrical energy to produce light, not heat. An efficient HEAT bulb uses most of its input to produce heat, not light.

**Energy**
The capacity to do work.

**Energy-efficient**
Electrical lighting devices which produce the same amount of light (lumens) using less electrical energy than incandescent electric light bulbs. Such devices are usually of the fluorescent type, which produce little heat, and may have reflectors to concentrate or direct the light ouput.

**Energy sources**
Energy sources are: 1. fossil fuels (coal, oil, gas); 2. nuclear (fission and fusion); 3. renewables (solar, wind, geothermal, biomass, hydro).

**Flat Plate**
A photovoltaic surface installed to face south at a tilt angle equal to the latitude.

**Flat-plat tracker**
A device mounted under a photovoltaic panel that moves the panel to follow the path of the sun.

**Fluorescent light**
A device that uses the glow discharge of an electrified gas for the illuminating element rather than an electrically heated glowing conductive filament.

**Fossil fuels**
Fuels formed eons ago from decayed plants and animals. Oil, coal and natural gas are such fuels.

**Fuel**
A material that is consumed, giving up its molecularly stored energy which is then used for other purposes, e.g., to do work (run a machine).

**Fuel cell**
A device that produces electricity with high efficiency (little heat) by using a fuel and a chemical which reacts with it (an oxidizer) at two seperate electrical terminals. An electric current is thereby produced.

**Fuel efficiency**
The amount of work obtianed for the amount of fuel consumed. In cars, an efficient fuels allows more miles per gallon of gas than an inefficient fuel.

**Gaia Hypothesis**
The idea that Earth is a living system. Life helps create the environment it needs in order to live. Gaia is the avient Greek word for "Mother Earth."

**Geothermal**
Pertaining to heat energy extracted from reservoirs in the earth's interior, as is the use of geysers, molten rock and steam spouts.

**Geothermal energy**
Heat generated by natural processes within the earth. Chief energy resources are hot dry rock, magma (molten rock), hydrothermal (water/steam from geysers and fissures) and geopressure (water satured with methane under tremendous pressure at great depths).

**Global warming**
The gradual warming of the earth due to the "greenhouse effect."

**Greenhouse effect**
The trapping of the sun's radiant energy, so that it cannot be reradiated. In cars and buildings the radiant energy is trapped by glass: in the earth's atmosphere the radiant energy is trapped by gasses such as chlorofluorocarbons (CFCs) and carbon dioxide.

**Hydro**
A prefix meaning produced by or derived from water or the movement of water, as in hydroelectricity.

**Hydro power**
Power obtained from the natural movement of masses of water.

**Incandescent light**
A bulb that uses the ohmic resistance in a conductor to produce light upon the passage of an electrical current through it. The conductor is usually in the form of a wire or filament.

**Insolation**
The solar radiant energy impinging on the earth.

**Inverter**
A device that changes direct current (DC) into alternating current (AC). Direct current is created by photovoltaic modules or batteries and converted to AC through the use of an inverter.

**Nuclear fission**
Atomic nuclear processes which involve the splitting of nuclei with the accompanying release of energy.

**Nuclear fuel**
Energy derived from atomic nuclear processes during fission or fusion.

**Nuclear fusion**
Atomic nuclear processes which involve the fusing of nuclei with an accompanying release of energy.

**OTEC**
Ocean thermal energy conversion technology, which uses the temperature differential between warm surface water and cold deep water to run heat engines to produce electrical power.

**Ocean energy**
The vast amount of potential energy within the oceans.

**PV**
Photovoltaic; pertaining to the production of electricity from light.
**Photovoltaic cell**
(see Solar cell)

**Renewable energy**
Energy from sources that cannot be used up: sunshine, water flow, wind and vegetation.

**Renewable energy devices**
Solar collectors, woodburning stoves, wind machines, hydroelectric turbines, etc. are typical examples.

**Solar cell**
Device made of semiconductor materials that produces a voltage when exposed to light.

**Solar cooling**
The use of devices that absorb sunlight to operate systems similar to gas-fired refrigerators.

**Solar electricity**
Electricity produced directly by action of sunlight; photovoltaics

**Solar greenhouse**
A conventional greenhouse in which mass is added for heat storage, double glazing is used, and the north side is attached to a house or berm.

**Solar heating**
Processes, active or passive, that derive and control heat directly from the sun.

**Solar process heat**
The use of sunlight to drive industrial processes directly.

**Solar thermal energy systems**
Systems using concentrating collectors to focus the sun's radiant energy onto or into receiver to produce heat.

**Stand-Alone system**
A PV installation not connected to a utility power line. A 'direct system' uses the PV-produced electricity as it is produced, e.g., a solar-powered water-pumping station. A 'battery storage system' stores the PV-produced electricity for use a later time, e.g. at night or on cloudy days.

**Utility-Intertied system**
A PV installation connected to a utility power line.

**Weather**
The result of unequal heating of the earth's atmosphere, as a function of terrain, latitude, time-of-year and other secondary factors.

**Wind machines**
Devices powered by the wind that produce mechanical or electrical power.

# Other Resources

If you're interested in investigating solar energy topics in more detail, check out the following resources!

**Links**

American Green Network Renewable Energy Information
http://www.americangreen.org/renewable_links.html

Arizona Solar Center Solar Education Links and Resources
http://www.azsolarcenter.com/education/edlinks.html

Connections + Science: Solar Energy
http://www.mcrel.org/resources/plus/solar.asp

CREST On-Line Renewable Energy Education Module
http://solstice.crest.org/renewables/re-kiosk/index.shtml

Energy Ed Online
http://www.energyed.ecw.org/curricula.html#Classroom

Energy Quest
http://www.energy.ca.gov/education/index.html

Florida Solar Energy Center
http://www.fsec.ucf.edu/

Florida Solar Energy Center Teacher's Internet Links
http://www.fsec.ufc.edu/solar-unit/resources/teacher-links.htm

GoingSOLAR Model Education Kit
http://irecusa.org/goingsolar/

How Stuff Works: How Solar Cells Work
http://www.howstuffworks.com/solar-cell.htm

Interstate Renewable Energy Council
http://www.irecusa.org/

Montana Green Power: Solar Power Links
http://www.montanagreenpower.com/solar/solarlinks.html

Montana Green Power: PhotovoltaicsResources
http://www.montanagreenpower.com/solar/photovoltaic.html

National Energy Education Development (NEED)
http://www.need.org/need

North Carolina Solar Center: Solar Activities for Students
http://www.ncsc.ncsu.edu/fact/25body.htm

Renewable Energy Factsheets
http://www.infinitepower.com/fsindex.html

Secondary Energy InfoBook
http://www.aep.com/environment/solar/power/index.html

Solar Energy Research and Education Foundation (SEREF)
http://www.seref.org/index2.html

Solar Energy Industries Association
http://www.seia.org/SolarEnergy/default.htm

Solstice
http://solstice.crest.org/index.shtml

StudyWeb: Science: Solar Photovoltaic Energy
http://www.studyweb.com/links/84.html

Teacher's Energy Resources
http://www.montanagreenpower.com/solar/schools/teachers.html

The Sun's Joules
http://solstice.crest.org/renewables/SJ/

Utility PhotoVoltaic Group
http://www.ttcorp.com/upvg/index.htm

**Federal Government Resources**

DOE Office of Power Technologies
http://www.eren.doe.gov/power/

Energy Efficiency and Renewable Energy Network
http://www.eren.doe.gov/RE/solar.html

Energy Smart Schools Teaching Resources
http://www.eren.doe.gov/energysmartschools/teach_stuff.html

Million Solar Roofs
http://www.eren.doe.gov/millionroofs/

National Renewable Energy Laboratory (NREL) Center for Education Programs
http://www.nrel.gov/education/links.html

Sandia National Laboratory Photovoltaics Program
http://www.sandia.gov/pv/lib.htm

The Solar Now Project
http://www.eren.doe.gov/solarnow/

**Solar in Schools**

Learning from Light! School Projects
http://www.aep.com/MainNav/Default.htm

Maryland Solar Schools Program
http://www.energy.state.md.us/MEA/ENGPROG/SOLSKOOL.HTM

Schools Going Solar
http://www.ttcorp.com/upvg/schools/index.htm

Watts On Schools
http://www.wattsonschools.com/

**Other Solar Curriculums**

Solar Exchange Unit
http://www.solarpartners.org/download.html

Solar Matters: A Solar Energy Science Unit for Intermediate Students in Grades 4 Through 8
http://www.fsec.ucf.edu/ed/sm/Index.htm

Solar Wonders: A Solar Energy Science Unit for Secondary Students
http://www.fsec.ucf.edu/ed/sw/