

# The Miracle of Solar Cells

Through a whole-body demonstration, students illustrate how solar cells produce electricity.

**Grade Level:** (5-8) 9–12

**Subject Areas:** English  
Language Arts, Science

**Setting:** Classroom, outdoor  
area near school

**Time:**

**Preparation:** 45 minutes to  
one hour

**Activity:** Two 50-minute periods

**Vocabulary:** Electron,  
N-layer, Photovoltaic cell, P-layer,  
P-N junction

**Major Concept Areas:**

- Development of energy resources
- Future outlooks for the development and use of energy resources

## Objectives

Students will be able to:

- explain how a solar cell produces electricity; and
- describe the basic electrical characteristics of a solar cell.

## Rationale

By understanding the science behind solar electricity, students discover an alternative means of generating electricity that does not use fossil or nuclear fuels.

## Materials

- A solar cell demonstration apparatus (plus extras for student group work, optional). See **Solar Cell Demonstration Apparatus** for materials and instructions
- Copies of the following pages:
  - [How a Solar Cell Produces Electricity](#) (1 per student)
  - [Demonstrating How a Solar Cell Produces Electricity](#)
- Find additional resources related to this activity on [keepprogram.org](http://keepprogram.org) > Curriculum & Resources

## Background

For background information, see [How a Solar Cell Produces Electricity](#) and [Facts about Solar Energy: Solar Electricity](#). Also see the discussion in [Demonstrating How a Solar Cell Produces Electricity](#).

## Procedure

### Orientation

Ask students if they know what a solar cell is. To help them understand, tell students that solar cells are also called photovoltaic (PV) cells. Point out that the word photovoltaic comes from photo, meaning light, and voltaic, meaning voltage. A solar cell uses light to produce electricity. If necessary, review basic electrical concepts such as current and voltage with students.

### Steps

1. Show students the solar cell demonstration apparatus or have students experiment with their own sets. Put cell under a bright, directional light source or in sunlight to run the motor or light the bulb. Have the class suggest how the cell generates electricity.

2. Have each pair of students read *How a Solar Cell Produces Electricity* (see **Read and Explain Pairs** for a suggested reading comprehension strategy). Discuss the reading with the class and encourage students to ask questions about sections they did not understand. In addition, students can show how a solar cell works by taking part in the performance discussed in *Demonstrating How a Solar Cell Produces Electricity*.

### Closure

Demonstrate the solar cell demonstration apparatus once again and have students summarize how the cell works.

### Assessment

#### Formative

- Can students explain how a solar cell works?
- Can students accurately describe the electrical characteristics of a solar cell?

#### Summative

Challenge students to suggest experiments or investigations they could do to learn more about the properties and capabilities of solar cells.

### Extension

Challenge students to build a motorized object, such as a fan, a blender, or a model race car, using the motor powered by the solar cell. Students can organize a contest or exhibition to show their inventions. For example, if they build cars they may want to race them in a competition. There is a national organization called Junior Solar Sprint (JSS) that helps teams of students from middle schools build and race model race cars powered by the sun. The students are provided with kits that include a motor and a photovoltaic panel. The body of the

car, wheels, and transmission are made from any other materials. The race is run on a 20-meter runway equipped with guide wires to direct the movement of the cars.

For more information contact: Education Office, NREL. 1617 Cole Boulevard, MS 1741. Golden, CO 80401.

### Related KEEP Activities

You may want to adapt some of the K-5 Energy Sparks for Theme II: “Sunvestigations” to have students learn more about solar energy. Electricity, basic electrical circuits, and batteries are also addressed in “Circuit Circus.” An investigation of how electric motors work is covered in “Electric Motors and Generators.” “The Miracle of Solar Cells” complements the concepts in “Why Use Renewable Energy?” See Doable Renewables for more lessons about solar energy and photovoltaics.



This solar electric panel provides lights for a restroom at Cave Point County Park in Door County, WI. The building has very energy-efficient lights to conserve energy, thus reducing the amount of solar panel needed.

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The Wisconsin K-12 Energy Education Program is supported through funding from



Wisconsin K-12 Energy Education Program (KEEP)  
College of Natural Resources  
University of Wisconsin - Stevens Point



# Solar Cell Demonstration Apparatus

## Materials

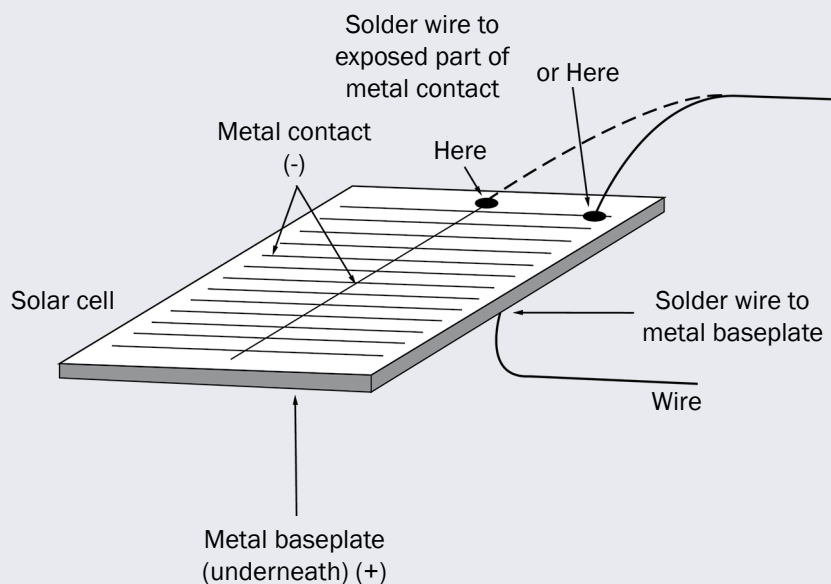
- A small solar photovoltaic cell with at least a 0.4 volt output.
- Two 5-inch pieces of 22-gauge stranded wire (optional)
- Soldering irons and solder (optional)
- Stiff backing materials such as thick cardboard (optional)
- Small motor (approx. 1 volt DC) or small flashlight bulb (0.5 volt DC)
- A bright, directional light source such as a shaded desk lamp or a clip on reading lamp with a 100 watt bulb (optional)

Most materials can be obtained at an electronics supply store or from a science supply catalog.

If possible, obtain solar cells with wires already attached to them. Some cells come with clips or hooks around which you can manually twist wire. If your cells do not, you may need to solder a 5-inch (12.5 cm) wire to each side of the cell (22-gauge stranded wire is recommended). Because solar cells are fragile, you may want to attach the cells to a stiff backing material, such as thick cardboard. As an option, you may want to have students connect or solder wires and attach stiff backings to the cells.

Connect the ends of the wire up to the motor or flashlight bulb. Point the panel to the sun (as an alternative, you could do the experiments in the classroom using bright, directional light sources such as desk lamps or clip on reading lamps with 100 watt bulbs). If the motor does not run, adjust the wires and secure the connections.

## Attaching Wires to a Solar Cell



# How a Solar Cell Produces Electricity

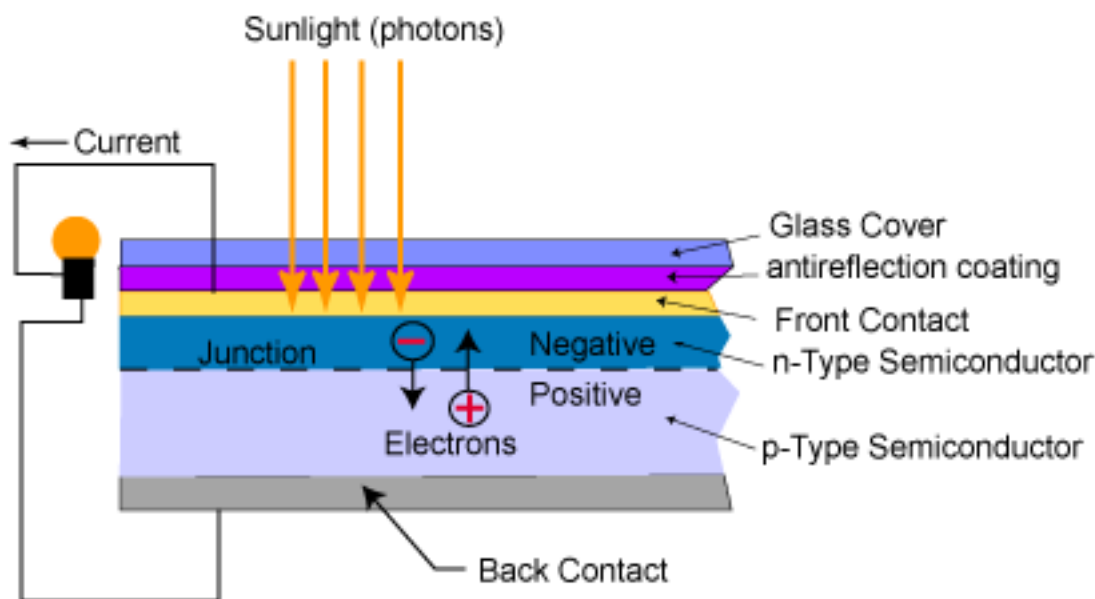
## Introduction

Look at the solar cell your teacher has given you. Hold it in your hand. It does not appear to have much substance; it's just a thin wafer of solid material, with one side colored dark blue or black and the other colored a silvery gray. On many cells, the dark blue-black side may have thin wires on it. The cell weighs very little, has no moving parts, and does not feel warm. In fact, the solar cell does not look like it could do anything, yet it is capable of producing electricity. How does it work?

## How Solar Cells Are Made

Look again at your solar cell. Even though it is very thin, it is made up of two layers of semiconductor material. A semiconductor is a solid substance which conducts electricity better than an insulator but not as well as other metals. They have distinct electrical characteristics which make them very useful in electronic devices. The semiconductor layers in most solar cells are made of silicon, although solar cells can be made from other materials as well.

## Parts of a Solar Cell



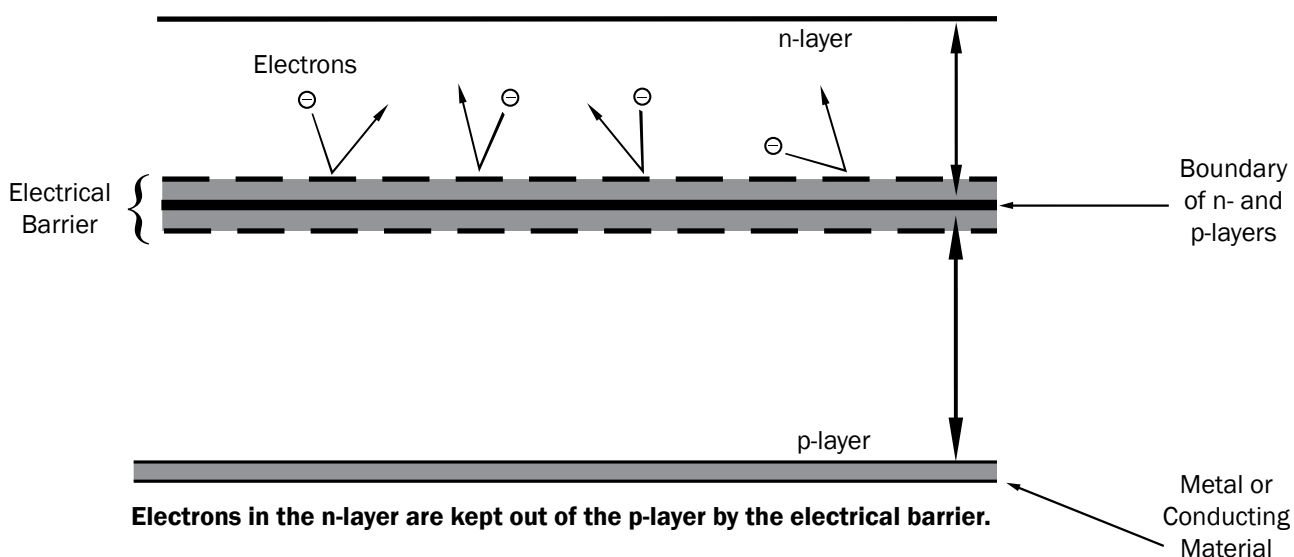
Source: [mysolarprojects.com/solar101.html](http://mysolarprojects.com/solar101.html)

Silicon is used to make solar cells because it can be mixed with other substances to change its electrical behavior in a certain way. Look at the side that appears dark blue or black. This side is called the n-layer. The “n” stands for “negative” because it is made by mixing silicon with substances that have more electrons than it has. Underneath the n-layer is the p-layer. The “p” stands for positive because it is made by mixing silicon with substances that have fewer electrons than it has. You cannot see the p-layer by looking at the back of the solar cell because it is covered by a silvery gray material and may also have a stiff backing material attached to it. The silvery gray material helps the cell conduct electricity when it is connected to an electrical circuit. The stiff backing supports the cell and keeps it from breaking.

# How a Solar Cell Produces Electricity

When the n-layer and the p-layer are placed together, a few of the electrons from the n-layer move into the p-layer. When this movement happens, an electrical barrier is automatically created, keeping the rest of the electrons in the n-layer separated from the p-layer. This barrier, which is only a few millionths of an inch thick, is formed at the boundary of the n- and p-layers when the solar cell is manufactured.

## Electrical Barrier Formed at the Boundary of the n- and p-Layers of a Solar Cell

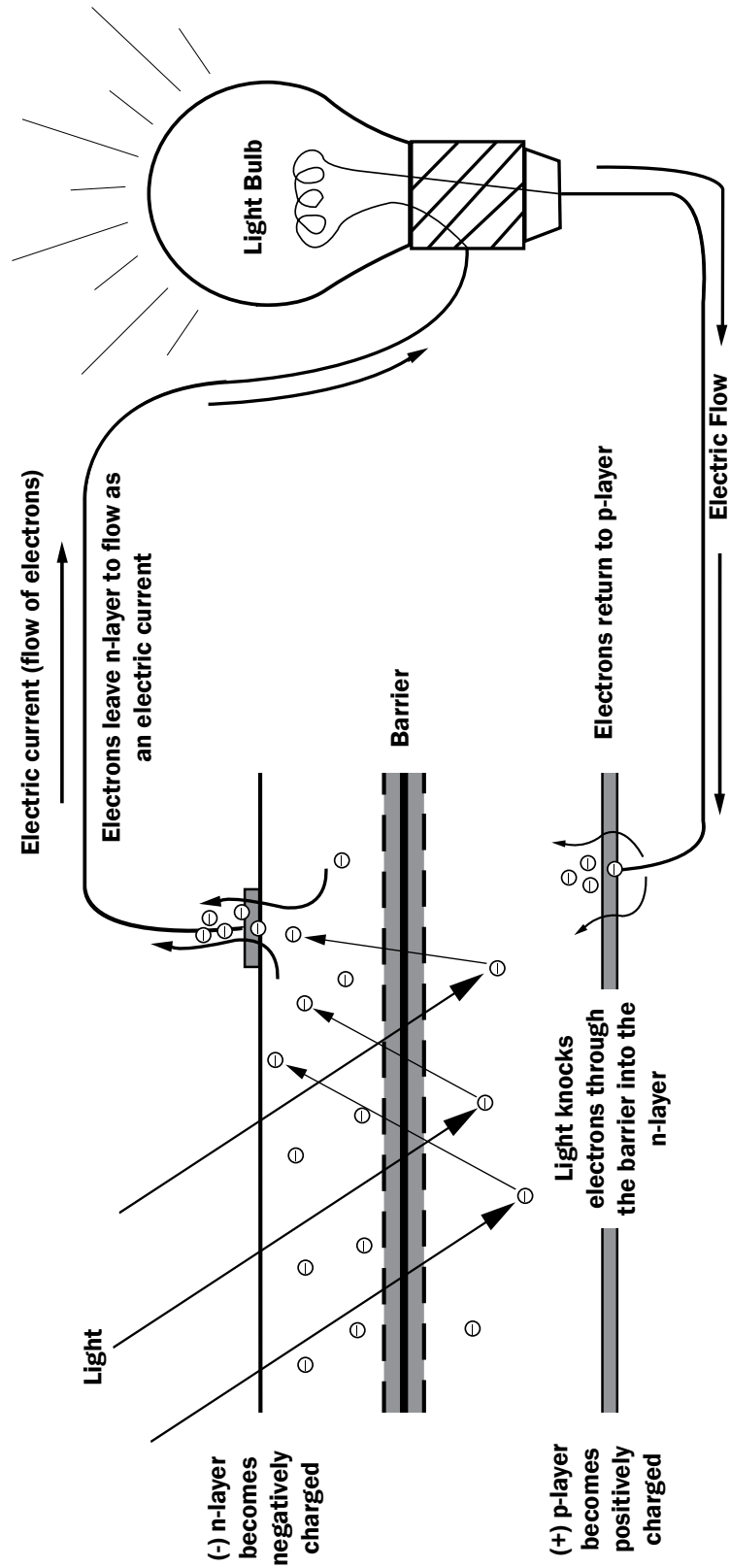


## Using Light to Produce Electricity

What happens when light shines on the solar cell? The light knocks electrons loose in the p-layer and sends them into the n-layer. The barrier, which acts like a one-way door, lets the electrons cross into the n-layer, but stops them from going back to the p-layer. This gives the n-layer a negative charge and the p-layer a positive charge. It is as if light were turning the solar cell into a kind of battery.

When the solar cell is connected in a circuit with, for example, a small light bulb, the electrons flow as electric current from the n-layer, through the wire and the bulb, to the p-layer. As electrons arrive at the p-layer of the cell, light sends them back into the n-layer, where they again flow through the circuit. Electric current will continue to flow as long as light is shining on the cell. The current can be used not only to light a small bulb, but also to run a small electric motor or a radio. Groups of solar cells can also be connected into circuits to produce larger amounts of current than can be produced by a single cell.

# Solar Cell in a Circuit



# Demonstrating How a Solar Cell Produces Electricity

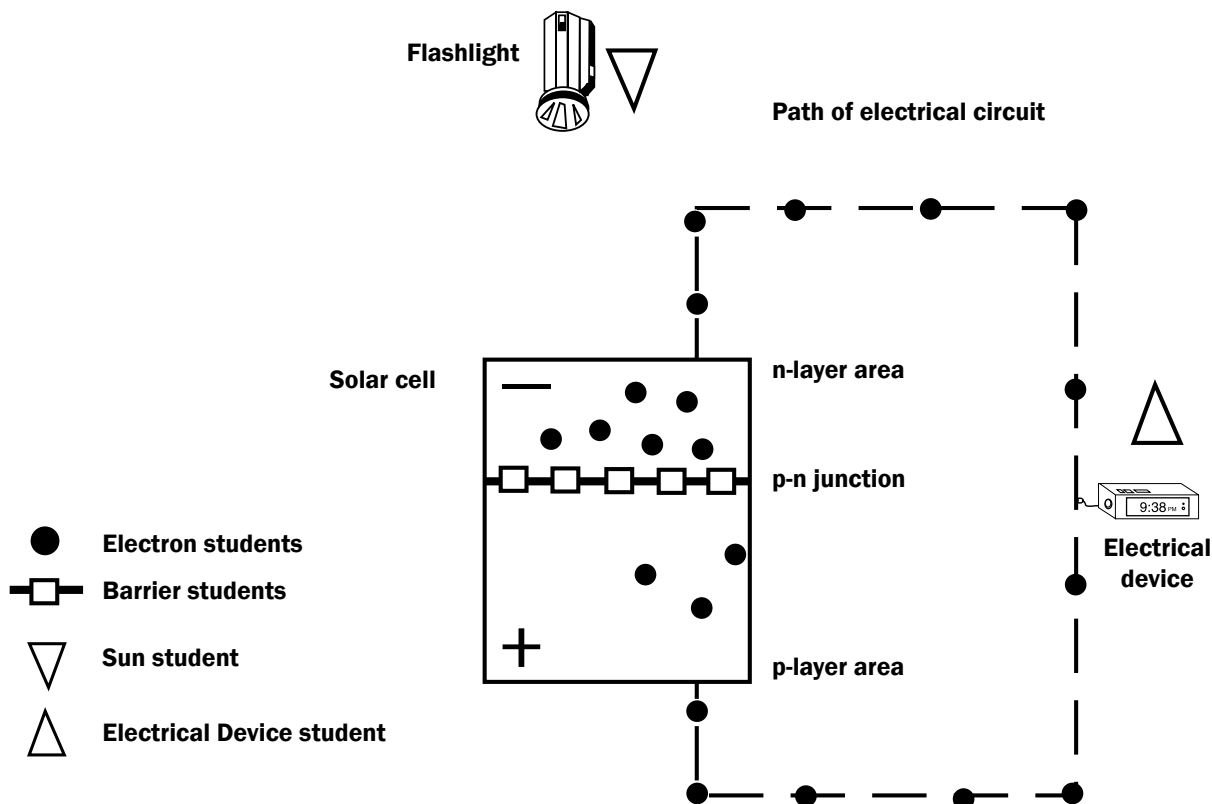
## Introduction

Another way to help students understand how a solar cell produces electricity is to have them play the role of electrons in a solar cell connected to an electrical circuit. Refer to **How a Solar Cell Produces Electricity** for further background discussion.

## Setting up the Demonstration (Diagram 1)

Mark off a portion of the classroom floor with two areas connected together. These areas represent the n-layer and the p-layer of the solar cell, with the boundary between them being the p-n junction. Mark the p-layer area with a "+" sign and the n-layer area with a "-" sign. Mark off a path around the classroom from the top of the n-layer to the bottom of the p-layer. This path represents the wire of an electric circuit connected to the solar cell (connecting an electrical device to the circuit is discussed later on).

## Setting up the Demonstration in the Classroom (Diagram 1)



Choose eight students to be electrons in the solar cell. Have three electrons stand in the area representing the p-layer, and five electrons stand in the area representing the n-layer.

Set up a row of chairs or stools that represent the barrier that forms the p-n junction. This barrier acts like a one-way door through which electrons can pass from the p-layer into the n-layer (and cannot pass from the n-layer to the p-layer). If necessary, students can sit on the chairs and prevent electrons from passing the wrong way.



# Demonstrating How a Solar Cell Produces Electricity

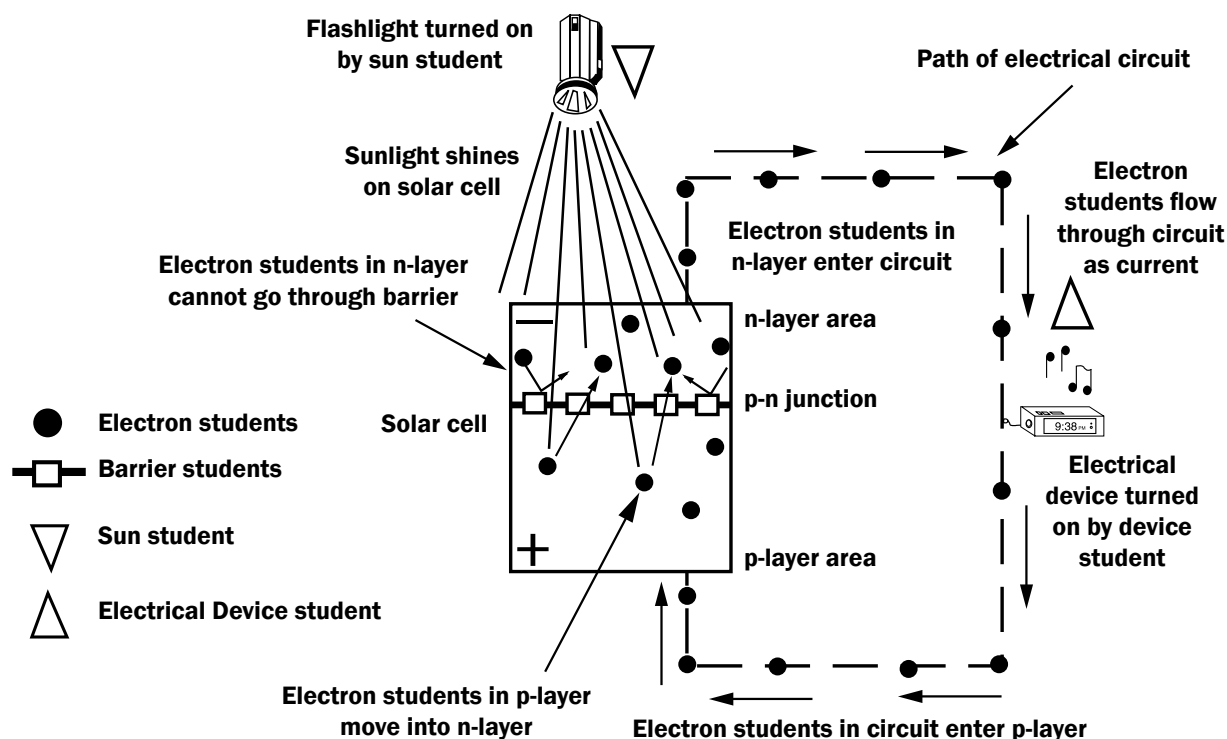
Give an additional student a flashlight to represent the sun. Have the sun stand facing the n-layer so that the barrier and the p-layer are directly behind it. The flashlight is not to be turned on until everyone is ready. Select another student to be an electrical device. Have this student hold an electrical device that turns on and off easily. Examples of electrical devices include radios, cassette tape decks, small fans, or toys. A flashlight or small desk lamp may be acceptable as long as students do not confuse it with the flashlight that represents the sun. Have the electrical device stand somewhere alongside the circuit, but not too close to the solar cell. He or she is not to turn on the electrical device until electrons start moving through the circuit.

Have the remaining students be electrons in the circuit wire and position them evenly along the path that represents the circuit.

## Demonstrating How the Solar Cell Works (Diagram 2)

When everyone is ready, have the sun shine the flashlight onto the solar cell so that the light passes through the n-layer and barrier into the p-layer. When light shines on the electrons in both layers, they should begin moving around. Light shining on the electrons in the p-layer causes them to move one by one toward the n-layer. The barriers allow these electrons to pass into the n-layer momentarily. However, the barriers prevent or block excited electrons in the n-layer and any electrons that just crossed over from the p-layer into the n-layer from moving into the p-layer.

## Setting up the Demonstration in the Classroom (Diagram 2)





# Demonstrating How a Solar Cell Produces Electricity

By now the n-layer is getting crowded with electrons who are repelling each other because they all have the same negative charge. Since they can't get past the barriers, the only place for them to go is into the circuit. Have the first electron enter the circuit. The instant this happens, the electron in the circuit who is nearest to the p-layer should step into the p-layer area. Doing so signals all the electrons in the circuit to begin walking single file (not in clumps) along the circuit path toward the p-layer. After electrons enter the p-layer from the circuit, they should stay there momentarily until it is their turn to enter the n-layer.

At the same time that the electrons start to move, the electrical device turns on the device being held. The electrical device should be turned on as long as the sun is shining and electrons are flowing as electrical current in the circuit.

With practice, the electrons should move smoothly (flow as current) from the p-layer, to the n-layer, through the circuit, and back to the p-layer. When electrons have learned to flow as current through the solar cell and the circuit, have them alternately flow and stand still as the flashlight is turned on and off. This corresponds to exposing the solar cell to sunlight and then suddenly covering it, reinforcing the idea that light causes the solar cell to produce electricity. The electrical device should also turn the device on and off accordingly.

# Read and Explain in Pairs

It's often more effective to ask students to read assigned material in cooperative pairs than individually. The expected criterion for success is that both members be able to explain the meaning of the assigned material correctly. The task is for the pairs to ascertain the meaning of each section and the assigned material as a whole (a "section" is text covering a specific topic and introduced by a section heading shown in bold type). The cooperative goal is for both members to agree on the meaning of each section, formulate a joint summary, and be able to explain their answer.

## Here's How It Works

1. Assign a high reader and a low reader to be a reading pair, telling them what specific pages (passages) that you want them to read.
2. Students read all section headings for an overview.
3. Students silently read the first section and then take turns acting as summarizer and accuracy coach. They rotate roles after each section.
4. The summarizer outlines in her own words the content of the section to her partner.
5. The accuracy coach listens carefully, corrects any misstatements, adds anything that was left out, and explains how the material relates to something they already know.
6. The students then move on to the next section and repeat the procedure. They continue until they have read all assigned material. At that point, they come to an agreement on the overall meaning of the assigned material.

During the lesson, systematically monitor each reading pair and assist students in following the procedure. To ensure individual accountability, randomly ask students to summarize what they have read so far. Remind students that there is intergroup cooperation—whenever it is helpful, they should check procedures, answers, and strategies with another group, or if they finish early, they should compare and discuss answers with another group.

Adapted from Johnson, David W., Roger T. Johnson, and Edythe J. Holubec. "Read and Explain Pairs" pp. 66–67 in *Cooperative Learning in the Classroom*. Alexandria, Va.: Association for Supervision and Curriculum Development. Copyright © 1994 ASCD. Used by permission. All rights reserved.

# Facts about Solar Energy: Solar Electricity

## Introduction

Harnessing energy from the sun holds great promise for meeting future energy needs because solar energy is a renewable and clean energy resource. Fossil fuels will eventually run out and the future of nuclear power is uncertain. For these reasons, other energy sources need to be harnessed. Solar energy is one of these sources.

Solar energy is produced by the sun, which is essentially a gigantic nuclear fusion reactor running on hydrogen fuel. The sun converts five million tons of matter into energy every second. Solar energy reaches the Earth's surface as ultraviolet (UV) light, visible light, and infrared light. Many other electromagnetic waves are stopped in the upper parts of the atmosphere. Scientists expect that the sun will continue to provide light and heat energy for the next five billion years.



## Solar Energy Potential

The amount of solar energy that strikes Earth's surface per year is about 29,000 times greater than all of the energy used in the United States. Put another way, in one hour more energy from the sun falls on the earth than is used by everyone in the world in an entire year. The solar energy falling on Wisconsin each year is roughly equal to 844 quadrillion Btu of energy, which is almost 550 times the amount of energy used in Wisconsin.

Although the amount of solar energy reaching Earth's surface is immense, it is spread out over a large area. There are also limits to how efficiently it can be collected and converted into electricity and stored. These factors, in addition to geographic location, time of day, season, local landscape, and local weather, affect the amount of solar energy that can actually be used.

## Producing Solar Electricity

Solar electricity is measured like most electricity, in kilowatt-hours, a unit of energy. Solar cells convert sunlight directly into electricity, and many solar-powered devices have been in use for decades, including wrist watches and calculators. Traditional cells are made of silicon, a material that comprises 28 percent of the Earth's crust. One solar cell measuring four inches across can produce one watt of electricity on a clear, sunny day. However, its efficiency can be affected by many factors including the wavelength of light, the temperature, and reflection. To produce more electricity, cells are wired together into panels (about 40 cells), and panels are wired together to form arrays.

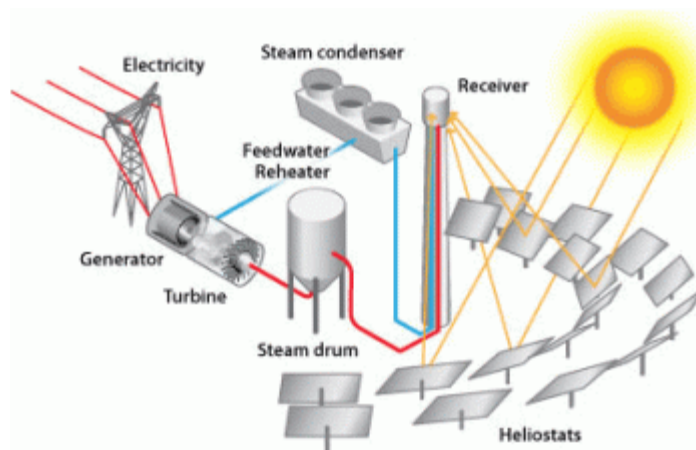
Solar cells are reliable and quiet, and they can be installed quickly and easily. They are also mobile and easily maintained. They provide an ideal electrical power source for satellites, outdoor lighting, navigational beacons, and water pumps in remote areas. In the United States, more than 784,000 homes and businesses have 'gone solar.'

# Facts about Solar Energy: Solar Electricity

## Concentrated Solar Power (CSP)

Solar energy can be used to heat a fluid to produce steam that spins a turbine connected to an electrical generator. These systems are called solar thermal electric systems. Concentrated solar power systems use mirrors to reflect and concentrate sunlight onto a small area. The concentrated sunlight heats a fluid and creates steam, which then powers a turbine generating electricity.

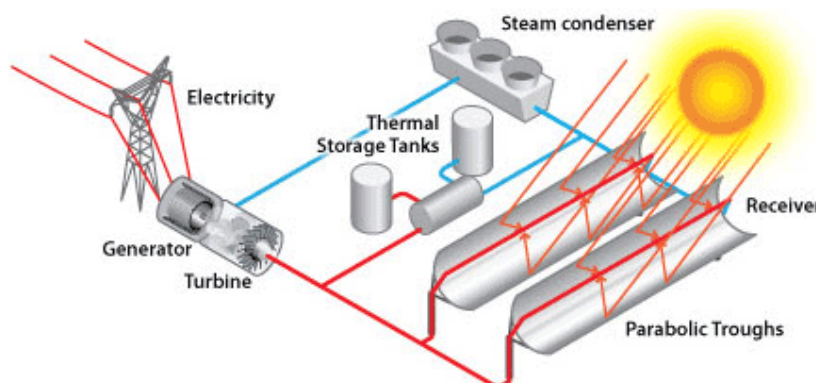
One type of solar thermal electric system, the solar power tower, uses mirrors to track and focus sunlight onto the top of a heat collection tower (see Fig. 1.1). An experimental 10-megawatt solar power tower called Solar Two was tested in the desert near Barstow, California. It was used to demonstrate the advantages of using molten salt for heat transfer and thermal storage. The experiment showed that this type of solar energy production was efficient in collecting and dispatching energy. The world's largest operating power tower system is the Ivanpah Solar Electric Generating System in the Mojave Desert of California. Ivanpah currently runs 69 percent below operating capacity, lacking thermal storage. It cannot compete with PV panels which have undergone a huge price reduction and can be installed on homes.



**Fig. 1.1 Power Tower Power Plant**

Source: [energy.gov/eere/energybasics/articles/power-tower-system-concentrating-solar-power-basics](https://energy.gov/eere/energybasics/articles/power-tower-system-concentrating-solar-power-basics)

A second type of solar thermal electric system is called a parabolic trough. It is a linear concentrator system and uses curved, mirrored collectors shaped like troughs. The concentrated sunlight heats a working fluid running through the pipes that is then used as a heat source to generate electricity (see Fig 1.2). The largest system of this type is located in northern San Bernadino County in California with a capacity of 354 MW combined from three locations.

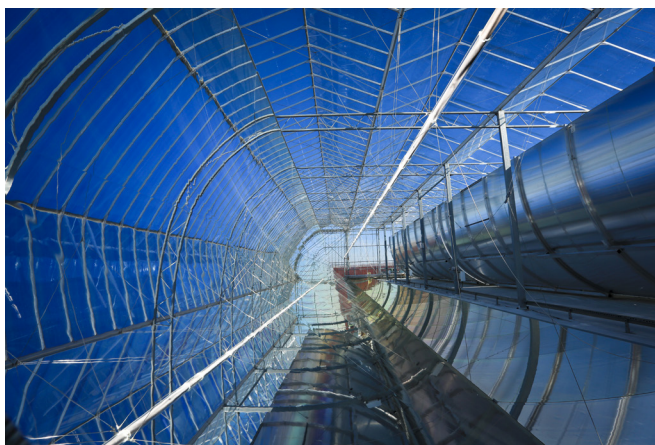


**Fig. 1.2 Linear Concentrator Power Plant using Parabolic Trough Collectors**

Source: [energy.gov/eere/energybasics/articles/linear-concentrator-system-basics-concentrating-solar-power](https://energy.gov/eere/energybasics/articles/linear-concentrator-system-basics-concentrating-solar-power)

# Facts about Solar Energy: Solar Electricity

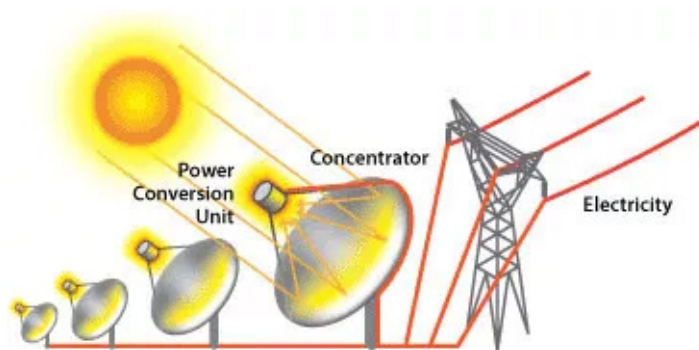
A third type of solar thermal electric system is an enclosed trough which use mirrors encapsulated in glass like a greenhouse to focus sunlight on a tube containing water, yielding high-pressure steam (see Fig. 1.3). This system was designed to produce heat for enhanced oil recovery.



**Fig. 1.3 View from inside the enclosed-trough parabolic solar mirrors, used to concentrate sun and generate steam for enhanced oil recovery (EOR).**

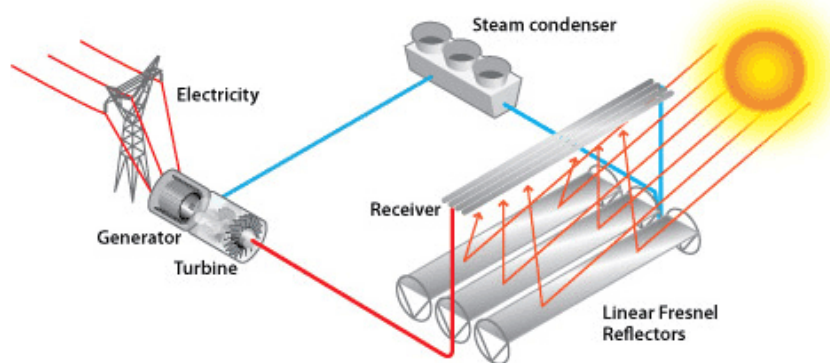
Source: [commons.wikimedia.org/wiki/File:3AInside\\_an\\_enclosed\\_CSP\\_Trough.jpg](https://commons.wikimedia.org/wiki/File:3AInside_an_enclosed_CSP_Trough.jpg)

A fourth type of solar thermal electric system is a Dish Stirling system which uses a mirrored dish similar in appearance to a satellite dish (see Fig. 1.4). This system, like the others, uses mirrors to concentrate and reflect solar energy and the heat generated is used to produce electricity by concentrating sunlight onto a receiver—located at the dish's focal point—containing a working fluid that powers a Stirling Engine.



**Fig. 1.4 Dish/Engine Power Plant**

Source: [energy.gov/eere/energybasics/articles/dishengine-system-concentrating-solar-power-basics](https://energy.gov/eere/energybasics/articles/dishengine-system-concentrating-solar-power-basics)



**Fig. 1.5 Linear Fresnel Power Plant**

Source: [energy.gov/eere/sunshot/downloads/linear-fresnel-power-plant-illustration](https://energy.gov/eere/sunshot/downloads/linear-fresnel-power-plant-illustration)

A fifth type of solar thermal electric system called Fresnel reflectors are long, thin segments of mirrors that focus sunlight onto a fixed absorber located at a common focal point of the reflectors (see Fig. 1.5). Flat mirrors allow more reflective surface than parabolic reflectors and are much cheaper.



# Facts about Solar Energy: Solar Electricity

## Solar Electricity Production

Of the total electricity production in the United States, solar energy provides less than 2 percent. In Wisconsin only about 0.4 percent of total electricity production is from solar energy. A negligible amount of electricity from solar energy is currently being generated by individual homeowners and businesses.

## Effects

Solar electricity has many benefits. Solar electric systems have no fuel costs, low operating and maintenance costs, produce virtually no emissions or waste while functioning, and even raise the value of homes.

Solar electric systems can be built quickly and in many sizes. They are well-suited to rural areas, developing countries, and other communities that do not have access to centrally generated electricity.

Solar electricity also has limitations. It is not available at night and is less available during cloudy days, making it necessary to store the produced electricity. Backup generators can also be used to support these systems. During the manufacturing process of photovoltaic cells, some toxic materials and chemicals are used. Some systems may use hazardous fluids to transfer heat. Adverse impacts can be experienced in areas that are cleared or used for large solar energy generating sites. Large-scale solar electric systems need large amounts of land to collect solar energy. This may cause conflicts if the land is in an environmentally sensitive area or is needed for other purposes. Deaths of birds and insects may occur if they happen to fly directly into a beam of light concentrated by a CSP.

Sometimes large-scale solar electric systems are placed in deserts or marginal lands. CSP developments are common in the southwestern United States (Colorado and Mojave Deserts); however, these locations are not without conflict either. For example, the Mojave desert tortoise is a threatened species that is in decline due to a complex array of threats including habitat loss and degradation.

Another idea is to place solar cells on rooftops, over parking lots, in yards, and along highways, and then connect the systems to an electric utility's power-line system. As the use of solar electric systems increases, laws may be needed to protect peoples' right to access the sun.



Source: [Hanwha Q CELLS USA](#).

# Facts about Solar Energy: Solar Electricity

## Outlook

The sun is expected to remain much as it is today for another five billion years. Because we can anticipate harvesting the sun's energy for the foreseeable future, the outlook for solar energy is optimistic. Continued growth in utility-scale solar power generation is expected. The flexibility and environmental benefits of solar electricity make it an attractive alternative to fossil and nuclear fuels. Although the cost of solar panels has dropped significantly, other solar installations (such as CSP) are relatively expensive when compared to the amount of electricity they generate. Land issues and the need for electricity storage or backup systems are also obstacles, of which many experts are confident can be overcome. Incentives are increasingly offered at the utility, county, state, and federal levels. The U.S. Department of Energy's SunShot Initiative has launched an effort to make solar energy more cost-competitive with other types of energy. Incentives such as these will ultimately assist in the continued growth of solar energy.

In the near future, the use of solar electric systems will likely continue to increase in the Southern and Western parts of the United States where sunshine is plentiful. Solar energy growth in Wisconsin has been slower than that of Southern and Western states but currently has 22 MW of solar energy installed, equivalent to what is needed to power 3,000 homes. A number of homeowners and businesses in Wisconsin have already demonstrated that solar electric systems can meet their needs, and it is reasonable to expect growth of solar electric power in Wisconsin as well.

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U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy: [energy.gov/eere/office-energy-efficiency-renewable-energy](http://energy.gov/eere/office-energy-efficiency-renewable-energy)

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Wisconsin Office of Energy Innovation: [psc.wi.gov/Pages/Programs/OEI.aspx](http://psc.wi.gov/Pages/Programs/OEI.aspx)

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The Wisconsin K-12 Energy Education Program is supported through funding from



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