

# Solar

## What Is Solar Energy?

**Solar energy** is radiant energy that is produced by the sun. Every day the sun radiates, or sends out, an enormous amount of energy. The sun radiates more energy in one day than the world uses in one year. For this reason, we consider solar to be a **renewable** resource.

Where does the energy come from that constantly radiates from the sun? It comes from within the sun itself. Like other stars, the sun is a big ball of gases—mostly hydrogen and helium atoms. The hydrogen atoms in the sun's core combine to form helium and generate energy in a process called nuclear **fusion**.

During nuclear fusion, the sun's extremely high pressure and temperature cause nuclei to separate from their electrons. At this extremely energized state, the nuclei are able to fuse, or combine. Hydrogen nuclei fuse to become one helium atom of a higher atomic number and greater mass, and one neutron remains free. This new helium atom, however, contains less mass than the combined masses of the hydrogen isotopes that fused. This **transmutation** of matter results in some mass being lost. The lost matter is emitted into space as **radiant energy**. The process of fusion occurs most commonly with lighter elements like hydrogen but can also occur with heavier nuclei until iron (Fe) is formed. Because iron is the lowest-energy nucleus, it will neither fuse with other elements, nor can it be fissioned (split) into smaller nuclei.

It can take hundreds of thousands of years for the energy in the sun's core to make its way to the solar surface, and then just a little over eight minutes to travel the 93 million miles to Earth. The solar energy travels to the Earth at a speed of 186,000 miles per second, the speed of light ( $3.0 \times 10^8$  meters per second).

Only a small portion of the energy radiated by the sun into space strikes the Earth, one part in two billion. Yet this amount of energy is enormous. Each hour the sun provides enough energy to supply our nation's energy needs for one year.

Where does all this energy go? About 30 percent of the sun's energy that hits the Earth is reflected back into space. Another 25 percent is used to evaporate water, which, lifted into the atmosphere, produces rainfall. Solar energy is also absorbed by plants, the land, and the oceans. The rest could be used to supply our energy needs. Currently, solar energy accounts for just under 2 percent (1.54%) of our total energy consumed.

## History of Solar Energy

People have harnessed solar energy for centuries. As early as the seventh century B.C., people used simple magnifying glasses to concentrate the light of the sun into beams so hot they would cause wood to catch fire. More than 100 years ago in France, a scientist used heat from a solar collector to make steam to drive a steam engine. In the beginning of this century, scientists and engineers began researching ways to use solar energy in earnest. One important development was a remarkably efficient solar boiler invented by Charles Greeley Abbott, an American astrophysicist, in 1936.

The solar water heater gained popularity at this time in Florida, California, and the Southwest. The solar industry started in the early 1920s and was in full swing just before World War II. This growth lasted until the mid-

## Solar at a Glance, 2021

### Classification:

- renewable

### Major Uses:

- light\*, heat\*, electricity

### U.S. Energy Consumption:

- 1.501 Q
- 1.54%

### U.S. Energy Production:

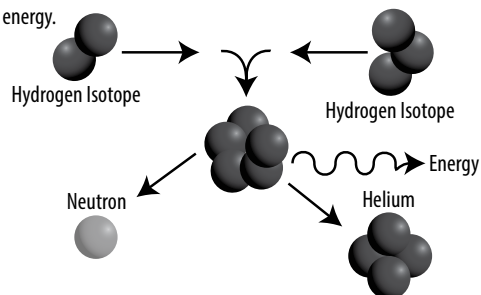
- 1.501 Q
- 1.54%

\*Most of the solar energy we use for light and passive solar heating cannot be measured and is not included in this data. Only harnessed energy is included.

Data: Energy Information Administration

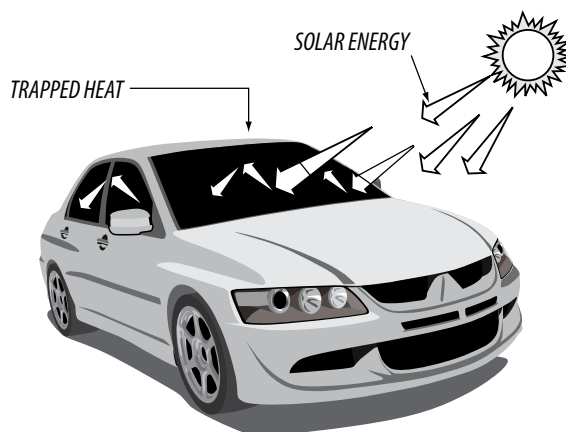
## Fusion

The process of fusion most commonly involves hydrogen isotopes combining to form a helium atom with a transformation of matter. This matter is emitted as radiant energy.



## Solar Collector

On a sunny day, a closed car becomes a solar collector. Light energy passes through the window glass, is absorbed by the car's interior, and converted into heat energy. The heat energy becomes trapped inside.



1950s when low-cost natural gas became the primary fuel for heating American homes.

The public and world governments remained largely indifferent to the possibilities of solar energy until the oil shortages of the 1970s. Today, people use solar energy to heat buildings and water and to generate electricity. Over 65 percent of the solar energy used by the U.S. goes to electricity generation. Much of the rest is used by homes and businesses for heating.

## Solar Collectors

Heating with solar energy is not as easy as you might think. Capturing sunlight and putting it to work is difficult because the solar energy that reaches the Earth is spread out over such a large area.

The sun does not deliver that much energy to any one place at any one time. How much solar energy a place receives depends on several conditions, including the time of day, season of the year, latitude of the area, and cloudiness of the sky.

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

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

- allows sunlight in through the glass (or plastic);
- absorbs the sunlight and changes it into heat; and
- traps most of the heat inside.

## Solar Space Heating

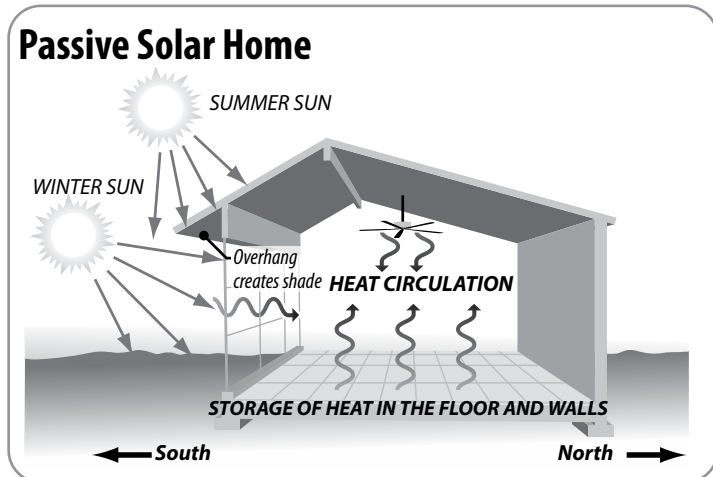
**Space heating** means heating the space inside a building. Today, many homes use solar energy for space heating. There are two general types of solar space heating systems: passive and active. **Hybrid solar systems** are a combination of passive and active systems.

### ▪ Passive Solar Homes

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

A passive solar home converts solar energy into heat just as a closed car does. Sunlight passes through a home's windows and is absorbed in the walls and floors. To control the amount of heat in a passive solar home, the doors and windows are closed or opened to keep heated air in or to let it out. At night, special heavy curtains or shades are pulled over the windows to keep the daytime heat inside the house. In the summer, awnings or roof overhangs help to cool the house by shading the windows from the high summer sun.

Heating a house by warming the walls or floors is more comfortable than heating the air inside a house. It is not so drafty. Passive buildings are quiet, peaceful places to live. A passive solar home can get 30 to 80 percent of the heat it needs from the sun. Many homeowners install equipment (such as fans to help circulate air) to get more out of their passive solar homes. When special equipment is added to a passive solar home, the result is called a hybrid solar system.



### ▪ Active Solar Homes

Unlike a passive solar home, an **active solar home** uses mechanical equipment, such as pumps and blowers, and an outside source of energy to help heat the house when solar energy is not enough.

Active solar systems use special solar collectors that look like boxes covered with glass. Dark-colored metal plates inside the boxes absorb the sunlight and change it into heat. (Black absorbs more sunlight than any other color.) Air or liquid flows through the collectors and is warmed by this heat. The warmed air or liquid is then distributed to the rest of the house just as it would be with an ordinary furnace system.

Solar collectors are usually placed high on a roof where they can collect the most sunlight. They are also put on the south side of the roof in a location where no tall trees or tall buildings will shade them.

## Storing Solar Thermal Energy

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

In passive solar homes, thermal energy is stored by using dense interior materials that retain heat well—masonry, adobe, concrete, stone, or water. These materials absorb surplus thermal energy and radiate it back into the room after dark. Some passive homes have walls up to one foot thick.

In active solar homes, thermal energy can be stored in one of two ways—a large tank filled with liquid can be used to store the heat, or rock bins beneath a house can store the heat by heating the air in the bins.

Houses with active or passive solar heating systems may also have furnaces, wood-burning stoves, or other supplemental heating devices to provide heat during extremely cold temperatures or long periods of cold or cloudy weather. These are called backup systems.

## Solar Water Heating

Solar energy is also used to heat water. Water heating is usually the second largest home energy expense. Heating water can cost the average family around \$300 per year.

Depending on where you live and how much hot water your family uses, a solar water heater can reduce your water heating bill 50 to 80 percent. A well-maintained system can last 20 years, longer than a conventional water heater.

A solar water heater works in the same way as solar space heating. A solar collector is mounted on the roof or in an area of direct sunlight. It collects sunlight and converts it to heat. When the collector becomes hot enough, a thermostat starts a pump. The pump circulates a fluid, called a heat transfer fluid, through the collector for heating.

### SOLAR WATER HEATER



The heated fluid then goes to a storage tank where it heats water. The hot water may then be piped to a faucet or showerhead. Most solar water heaters that operate in winter use a heat transfer fluid, similar to antifreeze, that will not freeze when the weather turns cold.

In addition to heating homes and water, solar energy can be used to produce electricity. Two ways to generate electricity from solar energy are photovoltaics and solar thermal systems.

## Photovoltaic Cells

Photovoltaic comes from the words *photo*, meaning “light”, and *volt*, a measurement of electricity. Sometimes **photovoltaic cells** are called PV cells or **solar cells** for short. You are probably already familiar with solar cells. Solar-powered calculators, toys, and telephone call boxes all use solar cells to convert light into electricity.

There are four major steps involved in generating electricity from the silicon in PV cells (see page 42). Current PV cell technology is not very efficient. Today’s PV cells convert only about 20–25 percent of the radiant energy into electrical energy. Thermal power plants, on the other hand, convert about 35 percent of their fuel’s energy into electrical energy.

The cost per kilowatt-hour to produce electricity from PV cells can sometimes be as much as three times higher than conventional sources. However, PV cells make sense for many uses today, such as providing power in remote areas or other areas where electricity is difficult to provide. Scientists are researching ways to improve PV cell technology to make it more competitive with conventional sources, and costs per kilowatt-hour from PV cells are expected to continue to decrease.

## Concentrated Solar Power

Like solar cells, solar thermal systems use solar energy to make electricity. **Concentrated solar power (CSP)** technologies focus heat in one area to produce the high temperatures required to make electricity. Since the solar radiation that reaches the Earth is so spread out and diluted, it must be concentrated to produce the high temperatures required to generate electricity. There are several types of technologies that use mirrors or other reflecting surfaces to concentrate the sun’s energy up to 2,000 times its normal intensity.

**Parabolic troughs** use long reflecting troughs that focus the sunlight onto a pipe located at the focal line. A fluid circulating inside the pipe collects the energy and transfers it to a heat exchanger, which produces steam to drive a turbine. One of the world’s largest parabolic trough power plants is located in the Mojave Desert in California. This collection of plants has a total generating capacity of 310 megawatts (MW), one-third the size of a large nuclear power plant. The largest facility of this type was recently constructed in Morocco and can generate up to 510 MW.

**Solar power towers** use a large field of rotating mirrors to track the sun and focus the sunlight onto a thermal receiver on top of a tall tower. The fluid in the receiver collects the heat and either uses it to generate electricity or stores it for later use. The world’s largest solar thermal power tower system is also located in California. The Ivanpah Solar Electric Generation Station can generate enough electricity to power 140,000 homes per year.

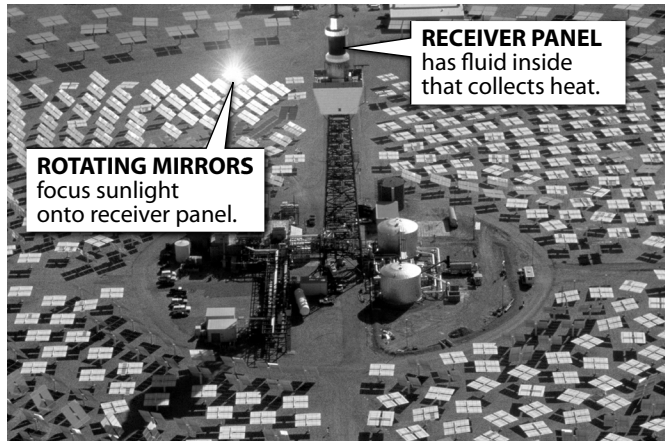
**Dish/engine systems** are like satellite dishes that concentrate sunlight rather than signals, with a heat engine located at the focal point to generate electricity. These generators are small mobile units that can be operated individually or in clusters, in urban and remote locations.

Concentrated solar power technologies require a continuous supply of strong sunlight, like that found in hot, dry regions such as deserts. Developing countries with increasing electricity demand may look to use CSP technologies on a large scale.

## Solar Energy and the Environment

Using solar energy produces no air or water pollution, and it is a free and widely available energy source. Manufacturing the photovoltaic cells to harness that energy, however, consumes silicon and produces some waste products. In addition, large solar thermal farms can harm desert ecosystems if not properly managed. Most people agree, however, that solar energy, if it can be harnessed economically, is one of the most viable energy sources for the future. Today, solar provides the U.S. with 2.79 percent of its electricity and is expected to continue to increase.

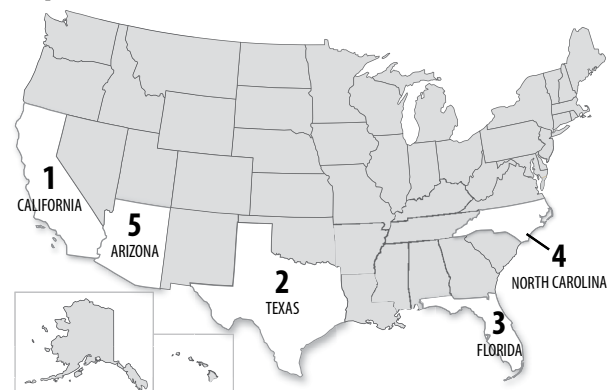
### Solar Power Tower



### SOLAR HOUSE



### Top Solar States (Net Generation), 2021



Data: Energy Information Administration



## How a Photovoltaic Cell Works

### Step 1

A slab (or wafer) of pure silicon is used to make a PV cell. The top of the slab is very thinly diffused with an “n” **dopant** such as phosphorous. On the base of the slab a small amount of a “p” dopant, typically boron, is diffused. The boron side of the slab is 1,000 times thicker than the phosphorous side. Dopants are similar in atomic structure to the primary material. The phosphorous has one more electron in its outer shell than silicon, and the boron has one less. These dopants help create the electric field that motivates the energetic electrons out of the cell created when light strikes the PV cell.

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

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

### Step 2

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

When both sides of the silicon slab are doped, there is a negative charge in the p-type section of the junction and a positive charge in the n-type section of the junction due to movement of the electrons and “holes” at the junction of the two types of materials. This imbalance in electrical charge at the p-n junction produces an electric field between the p-type and n-type silicon.

### Step 3

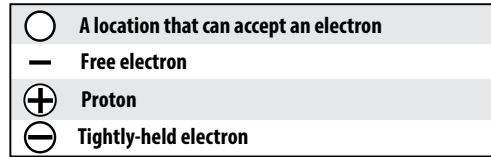
If the PV cell is placed in the sun, **photons** of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-type silicon and repelled by the negative charge in the p-type silicon. Most photon-electron collisions actually occur in the silicon base.

### Step 4

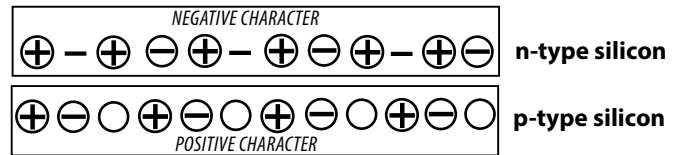
A conducting wire connects the p-type silicon to an electrical **load**, such as a light or battery, and then back to the n-type silicon, forming a complete **circuit**. As the free electrons are pushed into the n-type silicon they repel each other because they are of like charge. The wire provides a path for the electrons to move away from each other. This flow of electrons is an electric current that travels through the circuit from the n-type to the p-type silicon.

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

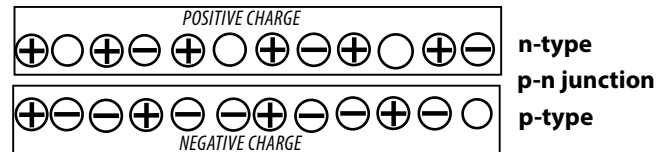
## From Silicon to Electricity



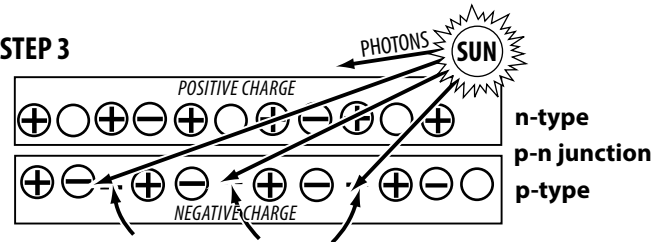
### STEP 1



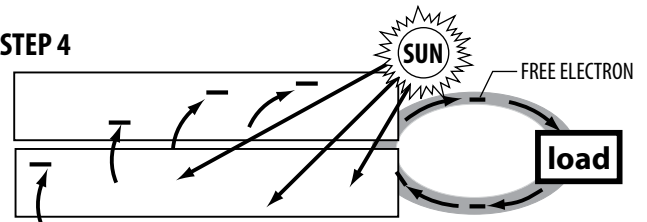
### STEP 2



### STEP 3



### STEP 4



## PHOTOVOLTAIC CELLS

