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**Renewable**

# Solar

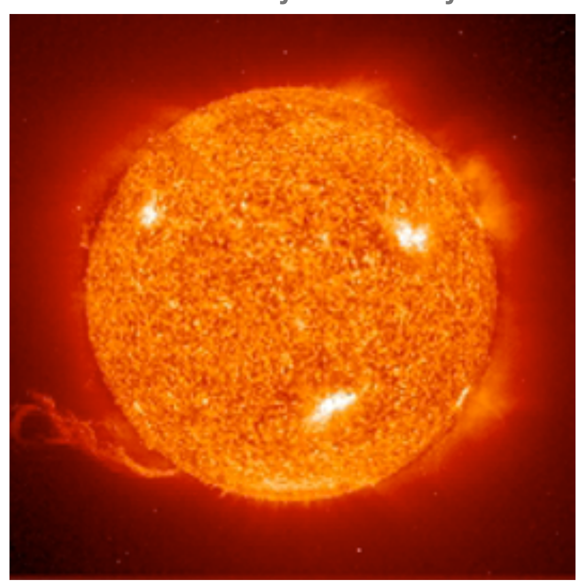
## Solar Basics

### Energy from the Sun

The sun has produced energy for billions of years. Solar energy is the sun’s rays (solar radiation) that reach the Earth. This energy can be converted into other forms of energy, such as heat and electricity.

In the 1830s, the British astronomer John Herschel famously used a solar thermal collector box (a device that absorbs sunlight to collect heat) to cook food during an expedition to Africa. Today, people use the sun's energy for lots of things.

**Radiant energy from the sun has powered life on Earth for many millions of years.**



Source: NASA

### Solar Energy Can Be Used for Heat and Electricity

When converted to **thermal (or heat) energy**, solar energy can be used to:

- Heat water — for use in homes, buildings, or swimming pools
- Heat spaces — inside homes, greenhouses, and other buildings
- Heat fluids — to high temperatures to operate a turbine to generate electricity

Solar energy can be converted to electricity in two ways:

- **Photovoltaic (PV devices) or "solar cells"** change sunlight directly into electricity. Individual PV cells are grouped into panels and arrays of panels that can be used in a wide range of applications ranging from single small cells that charge calculator and watch batteries, to systems that power single homes, to large power plants covering many acres.
- **Solar Thermal/Electric Power Plants** generate electricity by concentrating solar energy to heat a fluid and produce steam that is used to power a generator. In 2010, solar thermal-power generating units were the main source of electricity at 13 power plants in the United States:
    - 11 in California
    - one in Arizona
    - one in Nevada

The main benefits of solar energy are:

- Solar energy systems do not produce air pollutants or carbon-dioxide
- When located on buildings, they have minimal impact on the environment

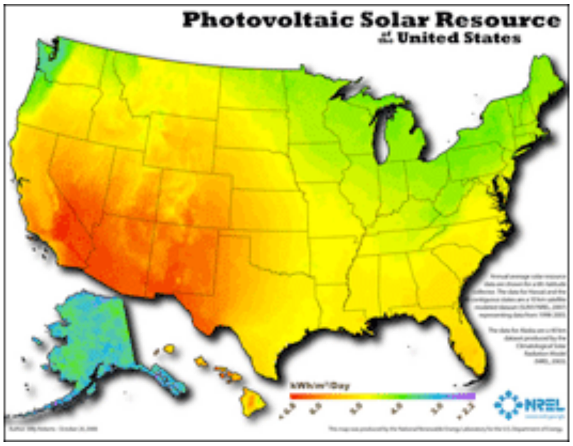
Two limitations of solar energy are:

- The amount of sunlight that arrives at the Earth's surface is not constant. It varies depending on location, time of day, time of year, and weather conditions.
- Because the sun doesn't deliver that much energy to any one place at any one time, a large surface area is required to collect the energy at a useful rate.

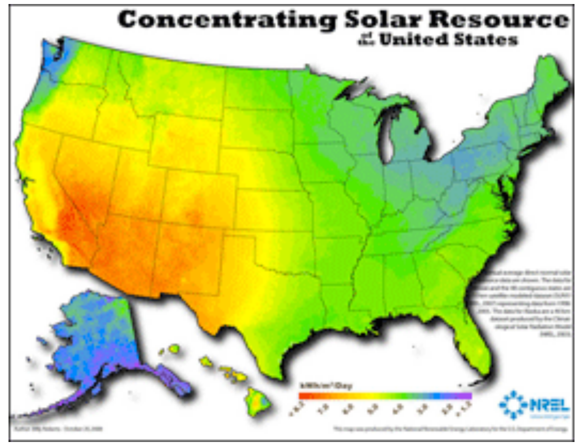
## Where Solar is Found

### Solar Energy Is Everywhere the Sun Shines

Solar energy is by far the Earth's most available energy source. Solar power is capable of providing many times the total current energy demand. But it is an intermittent energy source, meaning that it is not available at all times. However, it can be supplemented by thermal energy storage or another energy source, such as natural gas or hydropower.

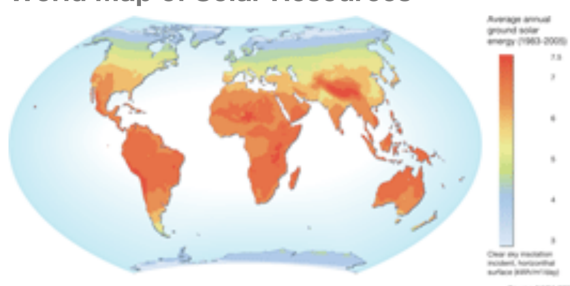



Source: National Renewable Energy Laboratory, U.S. Department of Energy




Source: National Renewable Energy Laboratory, U.S. Department of Energy

**World Map of Solar Resources**



Source: [United Nations Environment Programme (UNEP)](), NASA Surface meteorology and Solar Energy (SSE), 2008.

## California Has the World’s Biggest Solar Thermal Power Plants

Nine solar power plants, in three locations in California's Mojave Desert, comprise the Solar Energy Generating Systems (SEGS). SEGS VIII and IX (each 80 megawatts), located in Harper Lake, are, individually and collectively, the largest solar thermal power generating plants in the world. The SEGS plants are concentrating solar thermal plants.

Concentrating solar power technologies use mirrors to reflect and concentrate sunlight onto receivers that collect the solar energy and convert it to heat. This thermal energy can then be used to produce electricity via a steam turbine or heat engine driving a generator.

### Photovoltaic Systems Provide Small to Large Amounts of Power

Another solar generating technology uses photovoltaic cells (PV) to convert sunlight directly into electricity. PV cells are made of semiconductors, such as crystalline silicon or various thin-film materials. Photovoltaics can provide tiny amounts of power for watches, large amounts for the electric grid, and everything in between.

Thousands of houses and buildings around the world have PV systems on their roofs. Many multi-megawatt (MW) PV power plants have also been built, including a 200 MW plant in China and a 97 MW plant in Canada. The largest PV power plant in the U.S. at the end of 2010 was a 48 MW facility in Nevada. Construction started in 2011 on several plants in California with capacities ranging from 200 to 550 MW.

### Solar Power Can Be Used Almost Anywhere at a Variety of Scales

Low-temperature solar collectors also absorb the sun's heat energy, but instead of making electricity, use the heat directly for hot water or space heating in homes, offices, and other buildings.

Even larger plants than exist today are proposed for construction in the coming years. Covering 4% of the world's desert area with photovoltaics could supply the equivalent of all of the world's electricity. The Gobi Desert alone could supply almost all of the world's total electricity demand.

## Solar Photovoltaic

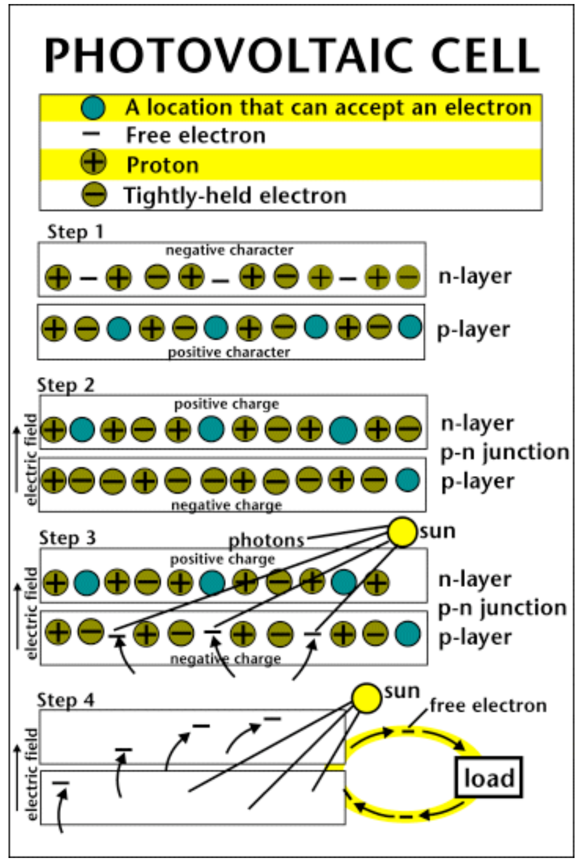
### Photovoltaic Cells Convert Sunlight into Electricity

A photovoltaic cell, commonly called a solar cell or PV, is the technology used to convert solar energy directly into electrical power. A photovoltaic cell is a nonmechanical device usually made from silicon alloys.

### Photons Carry Solar Energy

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 photovoltaic cell, they may be reflected, pass right through, or be absorbed. Only the absorbed photons provide energy to generate electricity. When enough sunlight (energy) is absorbed by the material (a semiconductor), electrons are dislodged from the material's atoms. Special treatment of the material surface during manufacturing makes the front surface of the cell more receptive to free electrons, so the electrons naturally migrate to the surface.




Source: National Energy Education Development Project (Public Domain)

## The Flow of Electricity

When the electrons leave their position, holes are formed. When many electrons, each carrying a negative charge, travel toward the front surface of the cell, the resulting imbalance of charge between the cell's front and back surfaces creates a voltage potential like the negative and positive terminals of a battery. When the two surfaces are connected through an external load, such as an appliance, electricity flows.

## How Photovoltaic Systems Operate

The photovoltaic cell is the basic building block of a photovoltaic system. Individual cells can vary in size from about 0.5 inches to about 4 inches across. However, one cell only produces 1 or 2 watts, which isn't enough power for most applications.

To increase power output, cells are electrically connected into a packaged weather-tight module. Modules can be further connected to form an array. The term array refers to the entire generating plant, whether it is made up of one or several thousand modules. The number of modules connected together in an array depends on the amount of power output needed.

## Weather Affects Photovoltaics

The performance of a photovoltaic array is dependent upon sunlight. Climate conditions (such as clouds or fog) have a significant effect on the amount of solar energy received by a photovoltaic array and, in turn, its performance. The efficiency of most commercially available photovoltaic modules in converting sunlight to electricity ranges from 5% to 15%. Researchers around the world are trying to achieve efficiencies up to 30%.

## Commercial Applications of Photovoltaic Systems

The success of PV in outer space first generated commercial applications for this technology. The simplest photovoltaic systems power many of the small calculators and wrist watches used every day. More complicated systems provide electricity to pump water, power communications equipment, and even provide electricity to our homes.

Some advantages of photovoltaic systems are:

1. Conversion from sunlight to electricity is direct, so that bulky mechanical generator systems are unnecessary.
2. PV arrays can be installed quickly and in any size.
3. The environmental impact is minimal, requiring no water for system cooling and generating no by-products.

Photovoltaic cells, like batteries, generate direct current (DC), which is generally used for small loads (electronic equipment). When DC from photovoltaic cells is used for commercial applications or sold to electric utilities using the electric grid, it must be converted to alternating current (AC) using inverters, solid state devices that convert DC power to AC.

## History of the Photovoltaic Cell

The first practical photovoltaic (PV) cell was developed in 1954 by Bell Telephone researchers examining the sensitivity of a properly prepared silicon wafer to sunlight. Beginning in the late 1950s, PV cells were used to power U.S. space satellites. PV cells were next widely used for small consumer electronics like calculators and watches and to provide electricity in remote or "off-grid" locations were there were no electric power lines. Technology advances and government financial incentives have helped to greatly expand PV use since the mid-1990s.

U.S. shipments (includes imports, exports, and domestic shipments) of PV cells and panels by U.S. industry in 2010 was the equivalent of about 2,644 Megawatts, about 200 times greater than the shipments of about 13 Megawatts in 1989. Since about 2004, most of the PV panels installed in the United States have been in "grid-connected" systems on homes, buildings, and central-station power facilities. There are now PV products available that can replace conventional roofing materials.

## Solar Thermal Power Plants

### Solar Thermal Power Uses Solar Energy Instead of Combustion

Solar thermal power plants use the sun's rays to heat a fluid to very high temperatures. The fluid is then circulated through pipes so it can transfer its heat to water to produce steam. The steam, in turn, is converted into mechanical energy in a turbine and into electricity by a conventional generator coupled to the turbine.

So solar thermal power generation works essentially the same as generation from fossil fuels except that instead of using steam produced from the combustion of fossil fuels, the steam is produced by the heat collected from sunlight. Solar thermal technologies use concentrator systems to achieve the high temperatures needed to heat the fluid.

**A Parabolic Trough Power Plant**

Source: Stock photography

The three main types of solar thermal power systems are:

(copyrighted)

1. Parabolic trough (the most common type of plant).
2. Solar dish
3. Solar power tower

## Types of Solar Thermal Power Plants

### Parabolic Troughs

Parabolic troughs are used in the largest solar power facility in the world located in the Mojave Desert at Kramer Junction, California. This facility has operated since the 1980s and accounts for the majority of solar electricity produced by the electric power sector today.
A parabolic trough collector has a long parabolic-shaped reflector that focuses the sun's rays on a receiver pipe located at the focus of the parabola. The collector tilts with the sun as the sun moves from east to west during the day to ensure that the sun is continuously focused on the receiver.

Because of its parabolic shape, a trough can focus the sun at 30 to 100 times its normal intensity (concentration ratio) on the receiver pipe located along the focal line of the trough, achieving operating temperatures over 750°F.

**A Solar Dish**

The "solar field" has many parallel rows of solar parabolic trough collectors aligned on a north-south horizontal axis. A working (heat transfer) fluid is heated as it circulates through the receiver pipes and returns to a series of "heat exchangers" at a central location. Here, the fluid circulates through pipes so it can transfer its heat to water to generate high-pressure, superheated steam. The steam is then fed to a conventional steam turbine and generator to produce electricity.  When the hot fluid passes through the heat exchangers, it cools down, and is then recirculated through the solar field to heat up again.

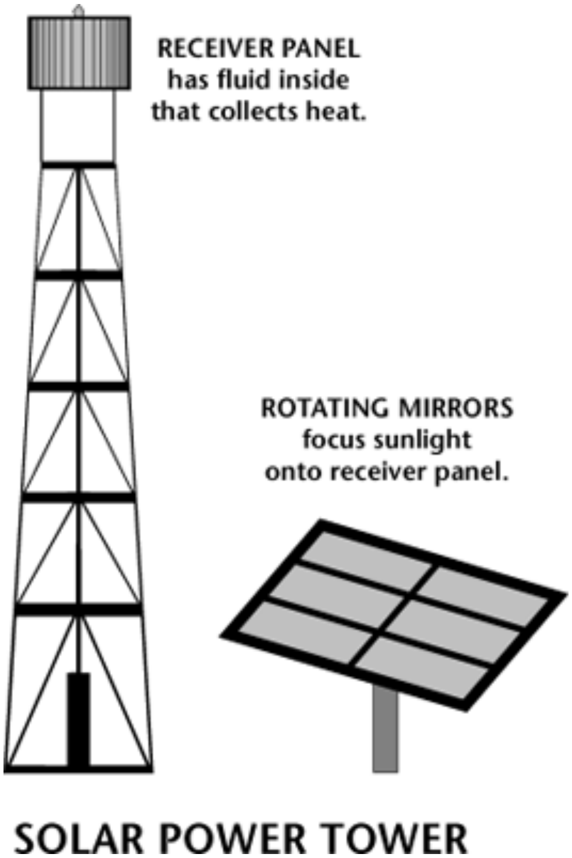
The plant is usually designed to operate at full power using solar energy alone, given sufficient solar energy. However, all parabolic trough power plants can use fossil fuel combustion to supplement the solar output during periods of low solar energy, such as on cloudy days.

Source: Stock photography (copyrighted)

**Solar Dish**

A solar dish/engine system uses concentrating solar collectors that track the sun, so they always point straight at the sun and concentrate the solar energy at the focal point of the dish. A solar dish's concentration ratio is much higher than a solar trough's, typically over 2,000, with a working fluid temperature over 1380°F.  The power-generating equipment used with a solar dish can be mounted at the focal point of the dish, making it well suited for remote operations or, as with the solar trough, the energy may be collected from a number of installations and converted to electricity at a central point.

The engine in a solar dish/engine system converts heat to mechanical power by compressing the working fluid when it is cold, heating the compressed working fluid, and then expanding the fluid through a turbine or with a piston to produce work.  The engine is coupled to an electric generator to convert the mechanical power to electric power.




**Solar Power Tower**

A solar power tower or central receiver generates electricity from sunlight by focusing concentrated solar energy on a tower-mounted heat exchanger (receiver). This system uses hundreds to thousands of flat sun-tracking mirrors called heliostats to reflect and concentrate the sun's energy onto a central receiver tower. The energy can be concentrated as much as 1,500 times that of the energy coming in from the sun.

Energy losses from thermal-energy transport are minimized as solar energy is being directly transferred by reflection from the heliostats to a single receiver, rather than being moved through a transfer medium to one central location, as with parabolic troughs.

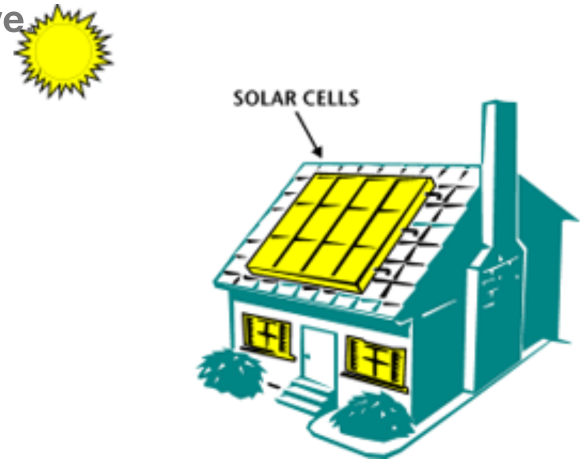
Power towers must be large to be economical. This is a promising technology for large-scale grid-connected power plants. Though power towers are in the early stages of development compared with parabolic trough technology, a number of test facilities have been constructed around the world.

The U.S. Department of Energy, along with a number of electric utilities, built and operated a demonstration solar power tower near Barstow, California, during the 1980s and 1990s. Learn more about the history of solar power in the Solar Timeline.

## Solar Thermal Collectors

### Heating With the Sun's Energy

Solar thermal (heat) energy is often used for heating water used in homes and swimming pools and for heating the insides of buildings ("space heating"). Solar space heating systems can be classified as **passive** or **active**.




Source: National Energy Education Development Project (Public Domain)

**Passive** space heating is what happens to your car on a hot summer day. The sun's rays heat up the inside of your car. In buildings, the air is circulated past a solar heat surface and through the building by convection (meaning that less dense warm air tends to rise while denser cool air moves downward). No mechanical equipment is needed for passive solar heating.

**Active** heating systems require a **collector** to absorb and collect solar radiation. Fans or pumps are used to circulate the heated air or heat absorbing fluid. Active systems often include some type of energy storage system.

## Solar Collectors Are Either Nonconcentrating or Concentrating

**Nonconcentrating collectors** — The collector area (the area that intercepts the solar radiation) is the same as the absorber area (the area absorbing the radiation). **Flat-plate collectors** are the most common type of nonconcentrating collector and are used when temperatures below about 200°F are sufficient. They are often used for heating buildings.

There are many flat-plate collector designs but generally all consist of:

- A flat-plate absorber that intercepts and absorbs the solar energy
- A transparent cover(s) that allows solar energy to pass through but reduces heat loss from the absorber
- A heat-transport fluid (air or water) flowing through tubes to remove heat from the absorber, and a heat insulating backing

**Concentrating collectors** — The area intercepting the solar radiation is greater, sometimes hundreds of times greater, than the absorber area.

## Solar Energy & the Environment

Using solar energy produces no air or water pollution and no greenhouse gases, but does have some indirect impacts on the environment. For example, there are some toxic materials and chemicals, and various solvents and alcohols that are used in the manufacturing process of photovoltaic cells (PV), which convert sunlight into electricity. Small amounts of these waste materials are produced.

An Array of Solar Panels Supplies Energy for Use at Marine Corps Air Ground Combat Center in Twentynine Palms, California

Source: U.S. Marine Corps photo by Pfc. Jeremiah Handeland/Released (Public Domain)

In addition, large solar thermal power plants can harm desert ecosystems if not properly managed. Birds and insects can be killed if they fly into a concentrated beam of sunlight, such as that created by a "solar power tower." Some solar thermal systems use potentially hazardous fluids (to transfer heat) that require proper handling and disposal.

Concentrating solar systems may require water for regular cleaning of the concentrators and receivers and for cooling the turbine-generator. Using water from underground wells may affect the ecosystem in some arid locations.