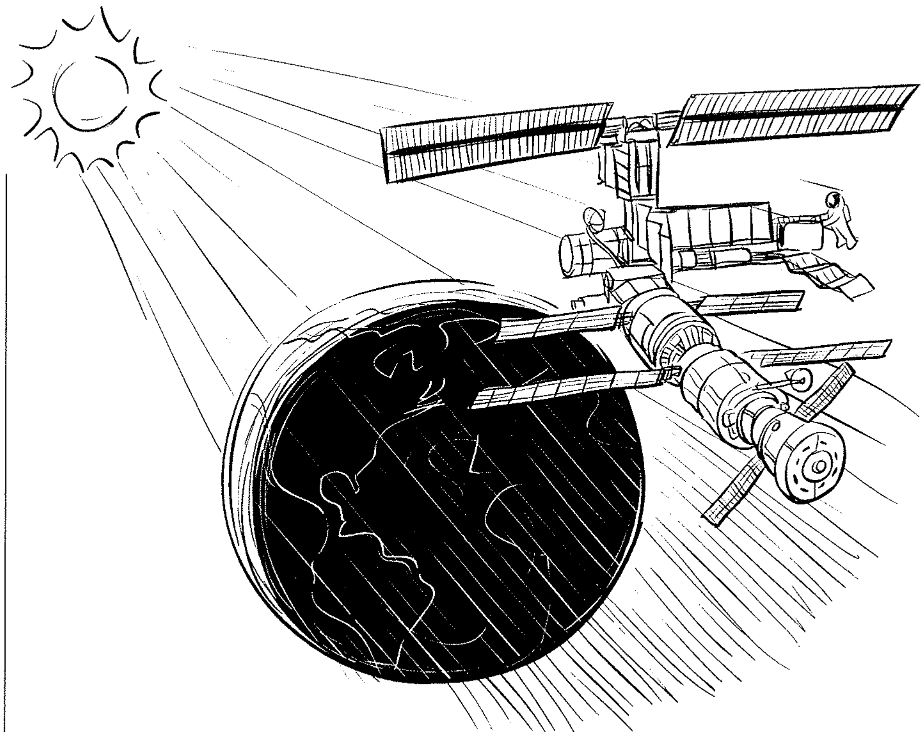

# Renewable Energy Source: SOLAR



**VOCABULARY**

array
central receiving tower
Concentrating Solar Power (CSP)
electromagnetic spectrum
heliostat
infrared
module
parabolic trough
photon
photoelectric effect
photovoltaic
radiant energy
silicon
solar cell
solar dish engine
solar panel
spectrum
ultraviolet

**WITH SOLAR ENERGY, THE SKY'S THE LIMIT.** Our sun is the world's most widely used energy resource. Plants began capturing the sun's energy millions of years ago, and members of the animal kingdom have always basked in its warmth. Human dwellings have long included openings that let in the sun's light and heat. Glass windows were used as early as 79 A.D., as revealed in the archeological ruins of Pompeii and Herculaneum (Roman cities completely preserved under layers of ash from a volcanic eruption). Now, our use of windows to capture the sun's radiation is such a common practice that we don't even think about it. Today we also use the heat of the sun to heat water. And, with technology ranging from tiny solar cells to huge power plants shimmering with rows of curved mirrors, we make electricity.

## THE SOLAR RESOURCE

We all know that our sun gives off radiating waves of heat and light energy. Without these, our planet would not have life. The sun also emits many other kinds of radiation (called the electromagnetic spectrum), such as X-rays and ultraviolet waves. All the waves emitted from the sun move rapidly as tiny bundles of energy called photons. These photons travel vast distances from the sun through the vacuum of space and bathe our planet with solar energy every day.


## Shedding Light on the Solar Spectrum

The sun emits many kinds of radiation besides X-rays and ultraviolet waves. Altogether, the range of different energy waves from the sun is called the "Solar Spectrum." Forty-five percent of the sun's energy that reaches the surface is what we call light because we can see it. Almost all the rest we do not see (although we can detect and measure it), yet it all delivers energy. For example, ultraviolet radiation, though we can't see it, can tan or burn our skin. A small part of the radiation that reaches the earth as "heat" (infrared radiation) is mostly absorbed in our atmosphere. The heat you feel on your skin is actually generated by your skin as it absorbs the solar light!

Some parts of the earth receive more solar radiation than others. In general, the areas at or near the equator receive the most solar radiation. For example, the tropics get about two and a half times more heat, or infrared, radiation than the poles. Any area that receives a steady supply of solar radiation, whether a little or a lot, can make use of the energy pouring in from our sun.

We use just a fraction of our enormous solar resource.* The total solar radiation received each year is about 3,000 times all the energy used globally.

## GENERATING ELECTRICITY FROM SOLAR RESOURCES

In this section we discuss solar energy only as a source of electricity. In Chapter 5 we discuss "direct" (non-electric) uses of solar energy – "active" direct uses such as heating water, and "passive" direct uses such as designing sun-friendly homes.

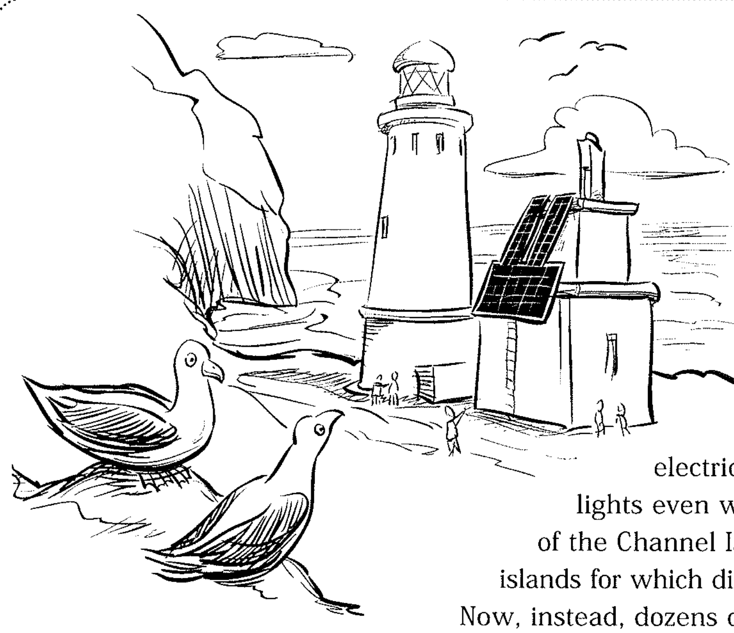
## Photovoltaics (PV)

In the 1950s, American engineers sought a method to power U.S. space satellites. They found it in an existing process called photovoltaics (PV). We still use photovoltaics to energize orbiting satellites, space stations, and the Hubble telescope. Back on the earth, PV is widely used for everything from roadside call boxes to large power plants.

### UP ON THE ROOFTOP

Today there is a slimmer version of PV technology, something called thin film PV. Thin film PV can be used to replace some of the regular shingles on a building's rooftop. Operating in the same way that flat plate PV does, thin film shingles are as durable and protective as regular asphalt shingles. These solar shingles are textured to fit right in with the architectural design of buildings.

*Statistics buffs, take note: The total amount of solar radiation received by the earth is 1.73 x $10^{17}$ watts at any one time. This is enough to warm our entire globe, fuel all of the earth's photosynthesizing plants, and create global climatic systems that drive the winds, the waves, and the water cycle.*

## POWER SKETCH: Lighting the Way on a Foggy Day

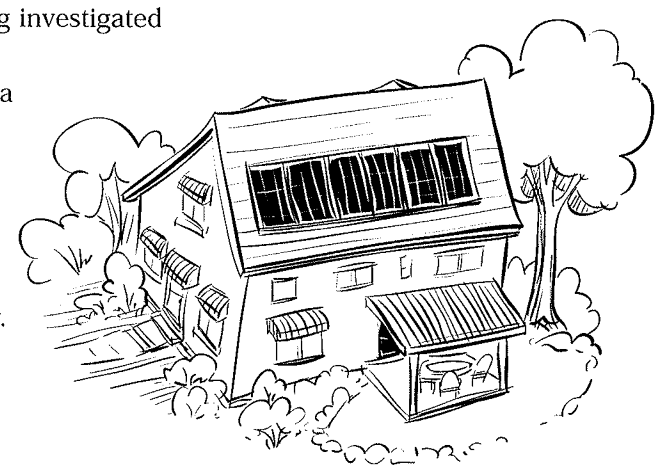
On foggy days along the coast of Ventura, California, a lone lighthouse shines its lights and sounds its foghorn for maritime travelers. Though far from the mainland's electrical connections, the Anacapa Island lighthouse operates entirely on electricity. The source of electricity is a large group of solar panels on the roof that converts sunlight into electricity. This electricity also charges batteries to operate the lights even when the sun doesn't shine. Anacapa is part of the Channel Islands National Park system, a series of islands for which diesel generators once provided the electricity.* Now, instead, dozens of solar panels are powering operations around the islands, including a naval installation on Santa Cruz Island.

**Some of the generators remain, now using cleaner-burning biodiesel, but only as a back-up resource.*

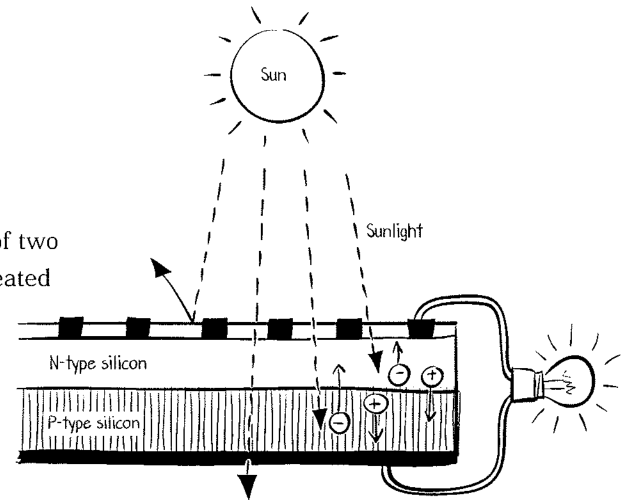
In photovoltaics, photons of sunlight react with specially designed materials in a process that results in electricity. *Photo* means light, and *voltaic* refers to the electrical current. The smallest unit is a photovoltaic cell, made of wafer-thin layers that react to sunlight to create electricity. The most common material in use today is silicon, either in crystalline form or thin films, but other materials are being investigated (see "Inside a Solar Cell," next page).

Usually, about 40 solar cells are wired together into a module. About 10 modules are combined together to make up a solar panel. Between 10 to 20 PV panels are collectively known as a PV array and can provide enough electricity for a household. Hundreds of arrays (known as an array field) are grouped together for use by a large commercial or industrial facility or by a utility.

PV systems can be stand-alone (not connected to electric transmission lines) or grid-connected. With grid-connected PV systems some homeowners can sell their extra electricity to their local utility.



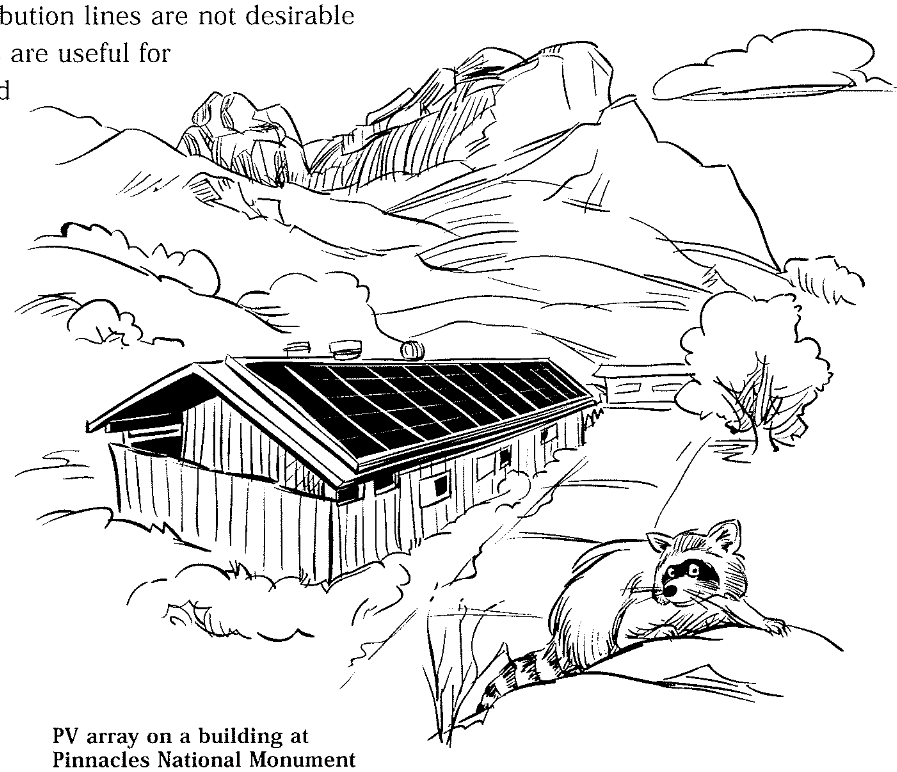
**PV panels on the roof of a house**


## INSIDE A SOLAR CELL

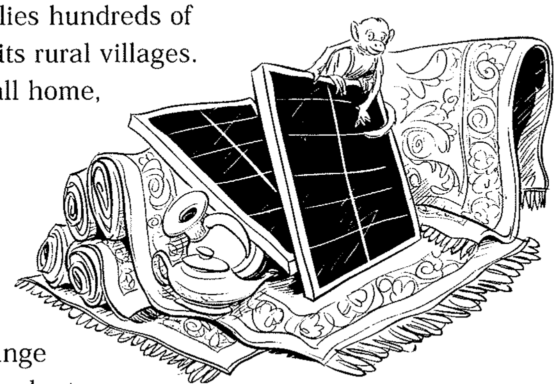
A solar, or photovoltaic, cell is a "sandwich" made of two slightly different, super-thin layers of specially treated crystals. When a photon of light from the sun strikes a solar cell, it frees electrons from some of the atoms of the treated silicon materials. These freed electrons zoom away from their "parent" atoms, leaving behind "holes." Because of the types of materials found in each layer, the electrons, which are negatively charged, tend to collect in what's called the N-layer (N for negative), and the positively charged "holes" collect in the P-layer (P for positive). When wires connect the two layers, electrons flow through the wire circuit in an orderly way. This is because negative and positive charges attract each other. This flow creates a current of electricity. (The freeing of electrons in solar cells by photons of light from the sun is called the "photoelectric effect." Albert Einstein won a Nobel Prize for describing it.)

**Stand-alone PV.** Photovoltaic systems are very handy for remote locations where transmission and distribution lines are not desirable or practical. These stand-alone systems are useful for lighting highway signs (energy is stored in batteries for use at night), roadside call boxes, and unmanned research installations in remote areas. They are also frequently found in rural areas or in national parks for lighting, battery charging, driving electric motors, water pumping, and more. The airport at Glen Canyon National Recreation Area, Utah, for example, is powered entirely by PV. Pinnacles National Monument in California uses solar cells for all operations including the ranger station, residences, and campground.



**PV array on a building at Pinnacles National Monument**


Globally, stand-alone PV is providing electricity in many developing areas without widespread transmission lines. Indonesia, a nation of 17,000 islands, is turning to PV electricity rather than trying to connect all the islands with transmission wires. India supplies hundreds of complete PV "kits" (called Solar Home Systems) to its rural villages. These include everything needed to light up a small home, including solar panels, wiring, and even the lights themselves. In Morocco on the edge of the North African desert, solar panels are often found at bazaars, where they are sold right alongside exotic Moroccan rugs and tin ware.



**Grid-connected PV.** Grid-connected PV systems range from small rooftop home set-ups to large PV power plants. Today, many U.S. government and privately owned buildings are being fitted with PV as part of the government's Million Solar Roofs program. Meanwhile, a number of private businesses, such as warehouse-type stores, are making use of their expansive rooftops to install solar panels. Hundreds of utilities are including PV in their operations. The Sacramento Municipal Utility District in California, for instance, has more than 1,100 PV systems (including 800 to 900 homes with PV roofs) that together can produce about 11 MW. The first neighborhood to put PV on the roofs of all of its homes is in Gardner, Massachusetts. These were installed in the 1980s.

California is the largest user of grid-connected PV. Arizona, Texas, and Colorado are also making wide use of grid-connected PV systems. Globally, millions of small PV systems are in use. Large-scale PV power plants that generate at least 1 MW or more of solar electricity are operating in the United States, Germany, Spain, Italy, India, and Japan.

**REMINDER**

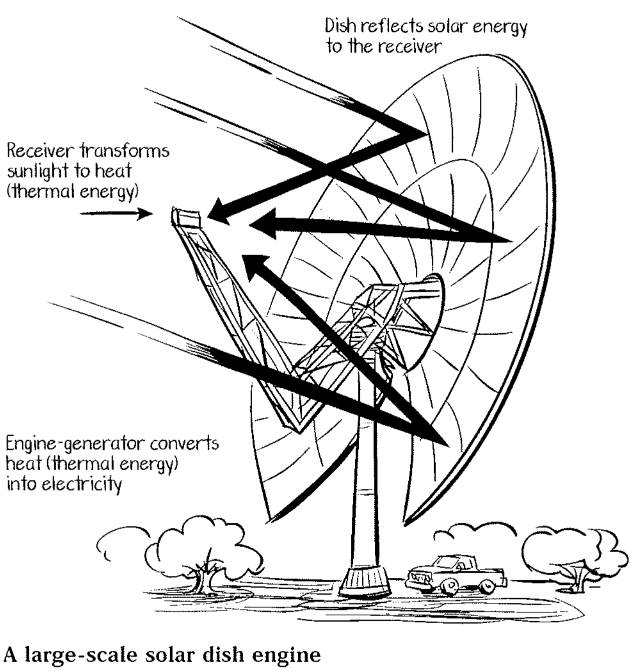
**W** = watt
**kW** = kilowatt = 1,000 watts
**MW** = megawatt = 1,000 kilowatts
1 megawatt serves about 1,000 homes in the United States.


## Solar Thermal: Concentrating Solar Power (CSP)

CSP systems use mirrors to concentrate the energy from the sun to heat liquids held in pipes and containers. Using a heat exchanger (see "Heat Exchangers," page 63) these hot liquids can then produce steam to drive the turbine that makes electricity. CSP works best with a clear, dry sky and a high concentration of the sun's rays. In the United States, the sunny southwestern states have been actively exploring this technology. Sun-drenched areas such as India, Morocco, Egypt, and Mexico are also very interested in CSP. These range from small individual 5 kW units suitable for a remote facility, to huge, utility-scale systems that can produce up to 200 MW.

All CSP systems have two main parts, one that concentrates solar energy's heat, and another that converts this heat energy to electricity. The three main types of CSP systems are solar dish engines, parabolic troughs, and central towers (central receivers).

**Solar Dish Engines.** Solar dish engines, presently under development, may turn out to be the best option for remote and rural locations. They are composed of two parts: a curved (parabolic) mirror that concentrates the sun's heat, and a "Stirling engine" that uses the heat to generate electricity. Dish engines can be used individually, providing between 5 to 25 kW, which is enough power for a farm or village, or can be combined for large-scale, grid-connected operations.




**A large-scale solar dish engine**

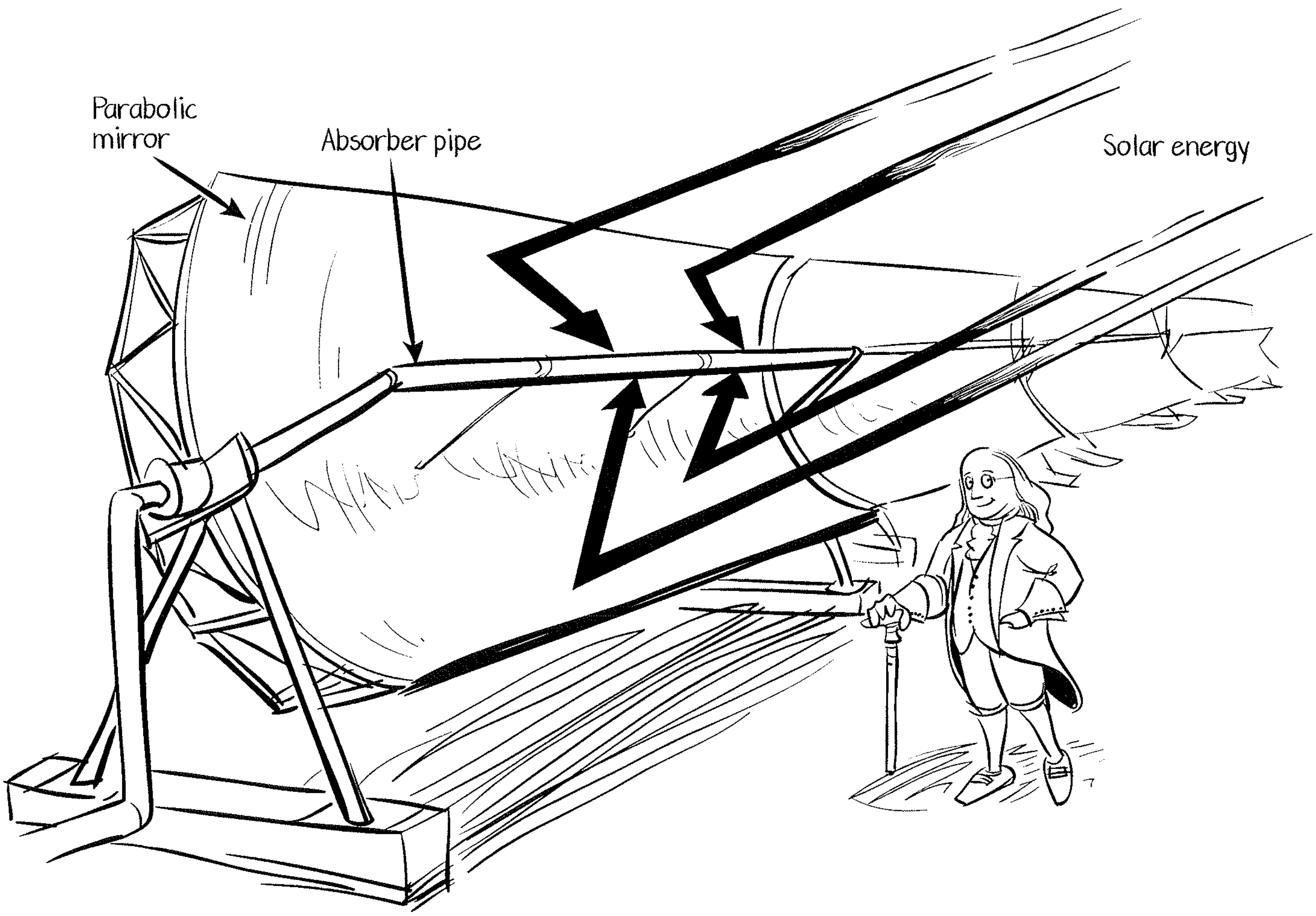
### STORING SOLAR ENERGY

Batteries aren't just for *supplying* electrical energy, but also for *storing* electrical energy. This storage capacity is very useful in solar energy systems, since sunlight isn't always available. The same process that provides an electric charge in a battery will also work in reverse. The inflow of electrons from the solar cell causes chemical substances in the battery to recombine and change. This "stores" the energy by charging the battery. When electricity is needed, the battery is activated, causing another chemical reaction that results in a flow of electrons – generating an electrical current.

There are other ways to store the sun's energy. One of these is collecting and holding the sun's heat. Concentrating Solar Power systems use materials that hold a large amount of heat and then release it very slowly. One material is molten salt, which reaches very high temperatures and retains the heat for long periods of time. When the sun stops shining, this "set-aside heat" continues to run the CSP equipment that generates electricity.


**Parabolic Troughs.** Parabolic troughs are long, trough-shaped reflectors that focus the sun's energy on a pipe running along the mirror's curve. The concentrated heat warms up an oil flowing through the pipe. Heat energy from the oil is transferred through a heat exchanger (see "Heat Exchangers," page 63) to boil water to create the steam that drives the turbine.

Parabolic troughs rotate from side to side, so they can track the sun as it moves from east to west. They are normally located in many parallel rows. The Mojave Desert is home to the world's largest parabolic trough facility, where nine power plants feed around 350 MW of electricity to southern California homes and businesses.




**A parabolic trough uses a type of clear oil in pipes that absorb heat reflected off the trough. The heat from the oil flows through a heat exchanger to heat water to make steam for electrical generation.**