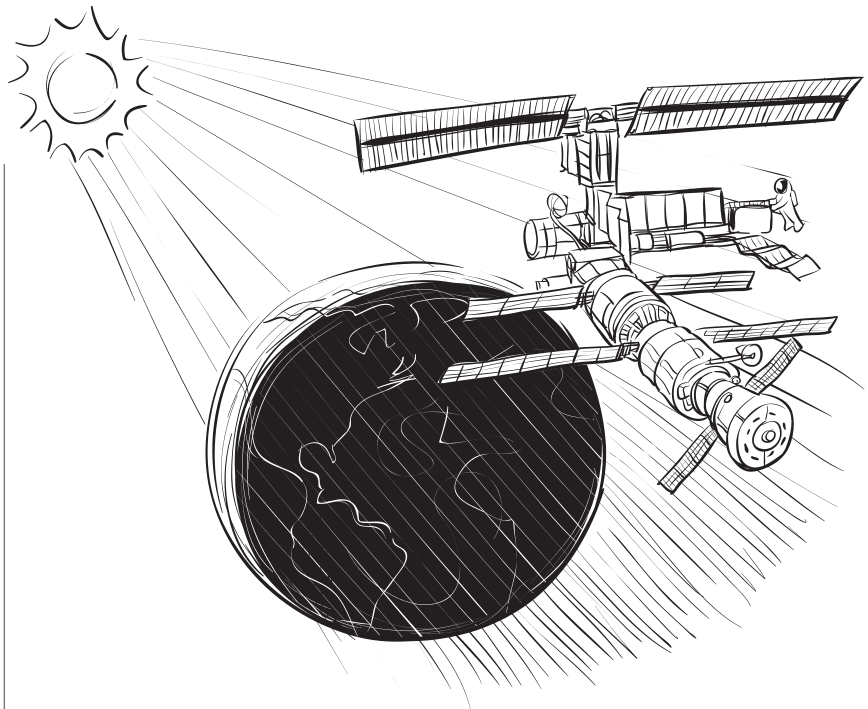
Renewable Energy Source: SOLAR



TERMS IN GLOSSARY

array
central receiving tower
Concentrating Solar Power (CSP)
electromagnetic spectrum
heliostat
infrared
module
parabolic trough
photon
photoelectric effect
photovoltaic (PV)
radiant energy
semi-conductors
silicon
solar cell
solar dish engine
solar panel
spectrum
thin film PV
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 admit the sun's radiation is such a common practice that we don't even think about it. And today, with technology ranging from tiny solar cells to huge power plants shimmering with rows of curved mirrors, we use solar energy to 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's waves move rapidly — at the speed of light — 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

All the sun's radiant energy waves form the solar electromagnetic spectrum. Forty-five percent of the radiation of the solar spectrum that reaches the earth's surface is visible light. 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. And we're all familiar with the sun's infrared, or thermal (heat), radiation. Infrared radiation is what keeps the earth (and us) warm.

Some parts of the earth receive more solar radiation than others. In general, the areas at or near the equator receive the most. For example, the tropics get about two and a half times more infrared radiation than the north and south poles. However, 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.* More energy from sunlight strikes Earth in one hour than all the energy consumed on the planet in a year.

GENERATING ELECTRICITY FROM SOLAR RESOURCES

In this section we discuss solar energy strictly 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.

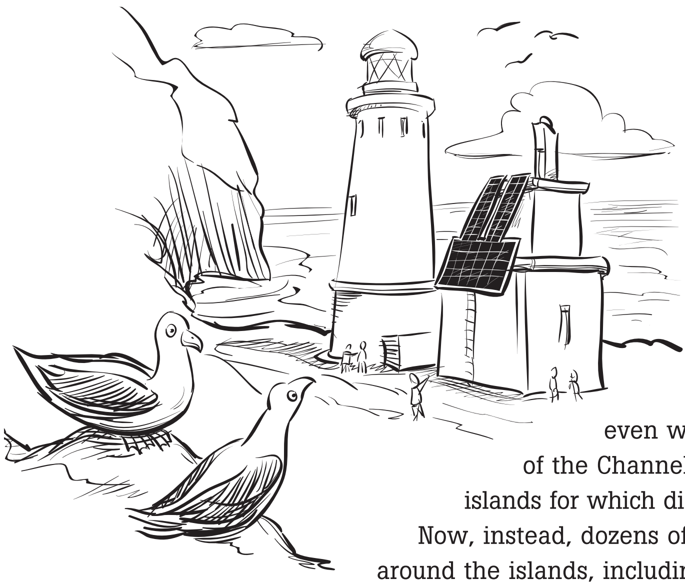
Photovoltaics (PV)

In the 1950s, American engineers sought a method to power U.S. space satellites. They found it in a technology called photovoltaics (PV). We still use PV to energize orbiting satellites, space stations, and the Hubble telescope. Back on Earth, PV is widely used for everything from roadside call boxes to utility-scale power plants, though the most widespread application is for on-site power generation.

THIN FILM PV

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. Ultra-thin versions of thin film PV may also be applied to windows and the sides of skyscrapers.

** Statistics buffs, take note: The total amount of solar radiation received by the earth is 1.73×10^{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

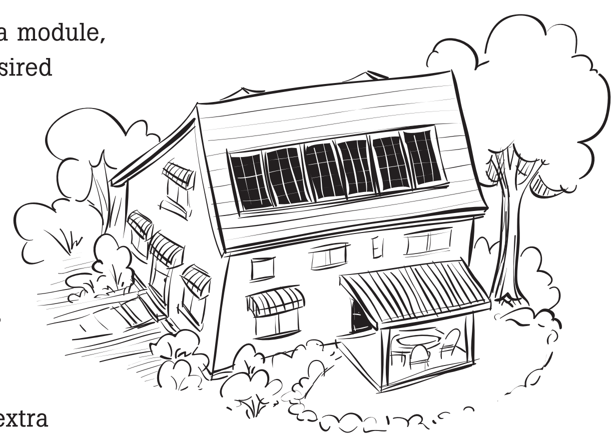
On foggy days off the coast of Ventura, California, a lone lighthouse shines its lights and sounds its foghorn for maritime travelers. Though far from the mainland's electrical connections, the Anacapa Island lighthouse operates entirely on electricity coming from a large group of solar panels. This electricity converted from sunlight 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.*

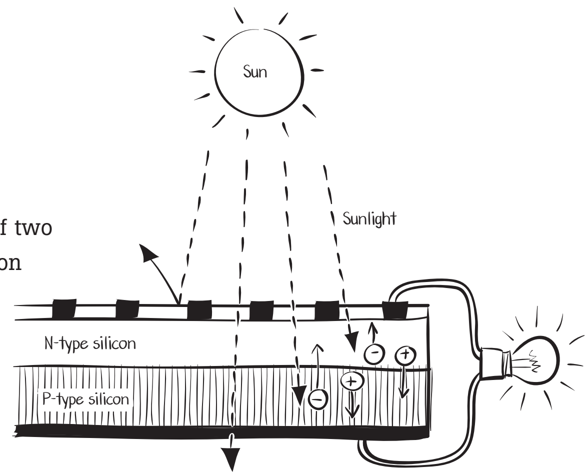
In PV, photons of sunlight react with specially designed semiconductors in a process that results in electricity. *Photo* means light; *voltaic* refers to the electrical current. The smallest unit is a photovoltaic cell, made of wafer-thin layers that react to sunlight to create electricity. The most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

Usually, about 40 solar cells are wired together into a module, or panel. A number of PV modules, depending on the desired amount of electricity to be produced, are then wired together into a PV system known as a solar array to provide electricity for a household or business. A typical household array might have between 10–25 modules, depending on the size of the home. 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 (see chapter 5).



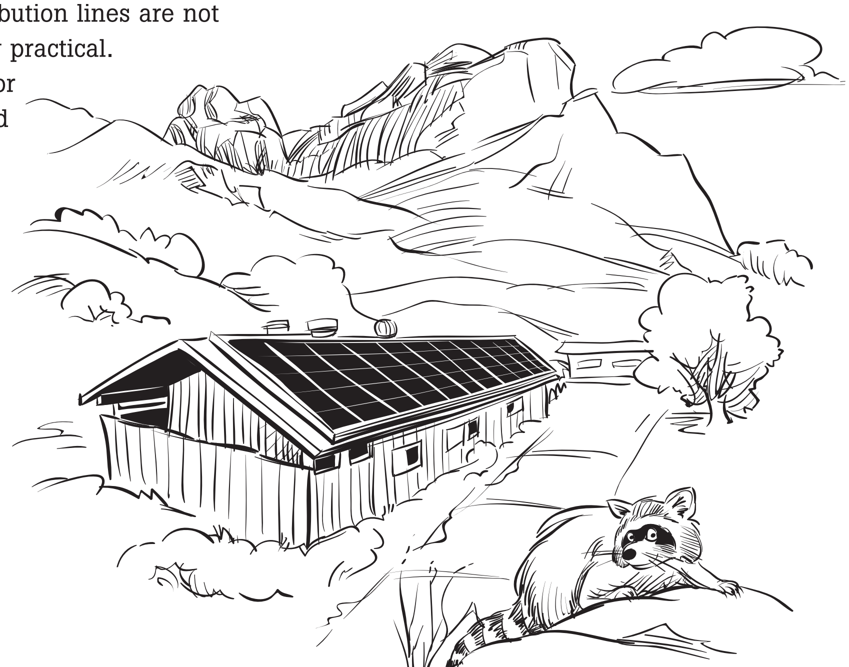
PV panels on the roof of a house



INSIDE A SOLAR CELL

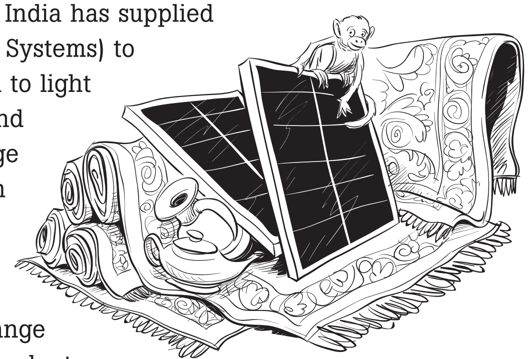
A solar, or photovoltaic, cell is a "sandwich" made of two slightly different, super-thin layers of treated silicon crystals. When a photon of light from the sun strikes a solar cell, it frees electrons from some of the atoms of the treated silicon materials. These freed electrons zoom away from their "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 environmentally desirable or financially 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 that have no 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 has supplied 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 have often been 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, thousands of public and private buildings are being fitted with PV. Many businesses, such as warehouse-type stores, are making use of their expansive rooftops to install solar panels and now represent the largest segment of the U.S. PV market. 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.

Worldwide Use of PV

In the U.S., California is the largest user of grid-connected PV. New Jersey, Illinois, Ohio, New York, Arizona, Texas, and Colorado are also making wide use of grid-connected PV systems. Globally, millions of small PV systems are in use. 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. In fact, in Japan over 40,000 PV systems were installed in the year 2002 alone. The fastest growth has been in Germany, where from 1990 to 2001 PV use increased 58 percent. By the end of 2008, total PV capacity globally reached more than 15,000 MW. The three leading countries are Germany, Japan and the U.S. Together, these countries produce almost 90 percent of the world's total PV power.

REMINDER

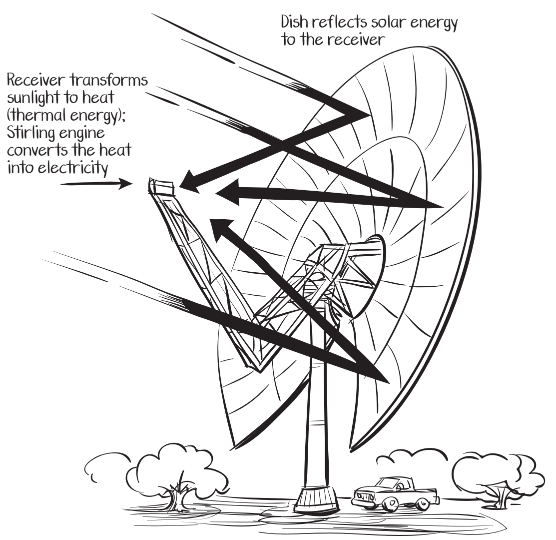
W = watt
kW = kilowatt = 1,000 watts
MW = megawatt = 1,000 kilowatts
Using solar energy, 1 megawatt serves about 500 homes in the U.S.

Solar Thermal: Concentrating Solar Power (CSP)

CSP systems use mirrors to concentrate the energy from the sun to heat liquids held in pipes and tanks. Using a heat exchanger (see "Heat Exchangers," page 53) these hot liquids are vaporized to drive a turbine to generate 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. CSP systems range from small individual 5 kW units suitable for a remote facility, to huge, utility-scale systems that can produce 200 MW or more.

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. Though not yet widely used, 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 (see "A Stirling Idea," page 21) 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

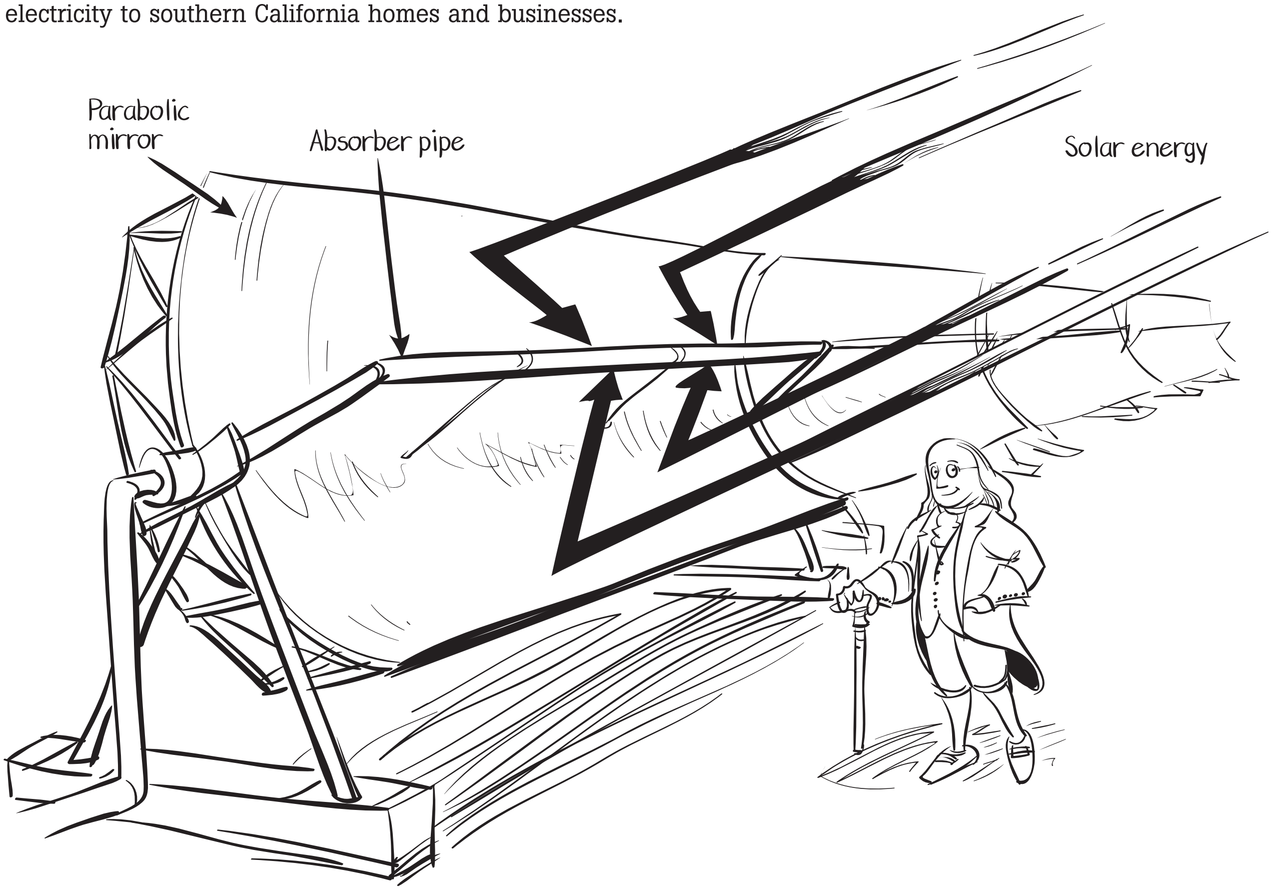
STORING SOLAR ENERGY

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 (CSP) systems use materials that hold a large amount of heat and then release it very slowly. One material often used 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. Salt is also used to hold the sun's heat in large outdoor pools called solar ponds.

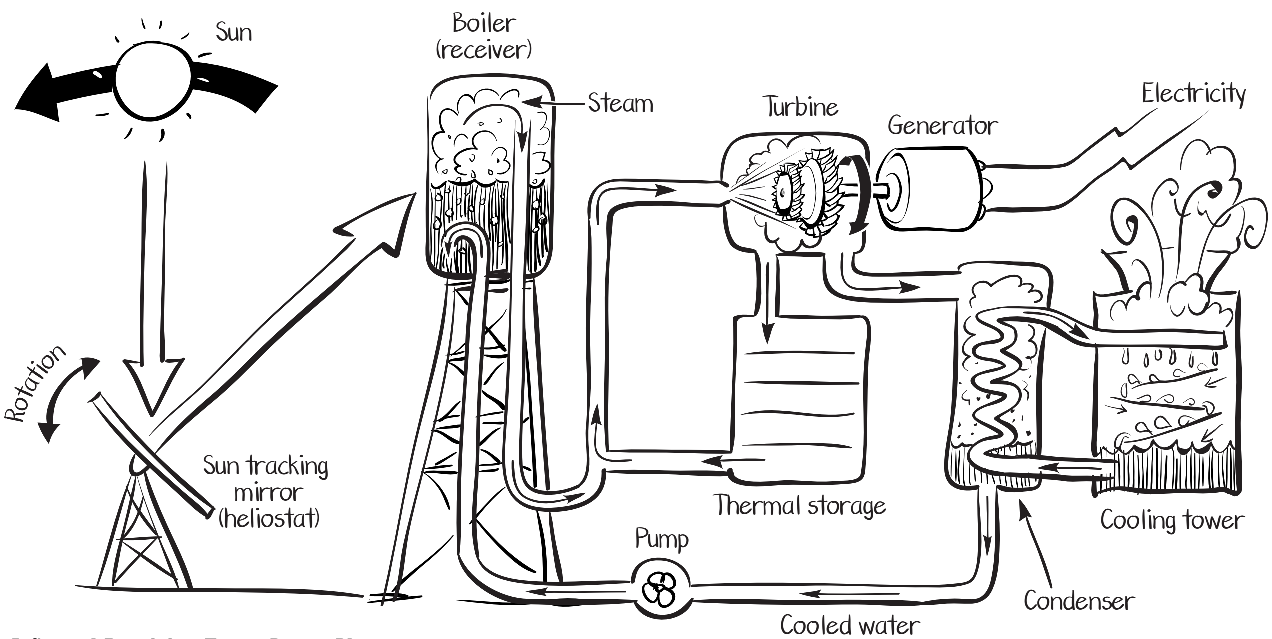
Parabolic Troughs. Parabolic troughs are long, trough-shaped reflectors that focus the sun's energy on a pipe running along the mirror's curve. The concentrated heat warms up an oil flowing through the pipe. Heat energy from the oil is cycled through a heat exchanger (see "Heat Exchangers," page 53) to boil water to create the steam that drives the turbine. Most parabolic troughs are large, but smaller "roof-top" models are also being developed. Spain is researching a very promising system that boils water for steam directly at the parabolic trough.

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 pipes containing clear oil that absorbs heat reflected off the trough. The heat from the oil flows through a heat exchanger to heat water to make steam for electrical generation.

Central Receiving Towers. Central receiving towers, often called "power towers," are tall structures with a boiler on top that houses a liquid suitable for heating, such as water (as shown below), molten salt, or liquid metal. Surrounding the tower are many rows of mirrors, called heliostats, which turn to face the sun and focus its rays onto the tower boiler throughout the day. The concentrated sunlight from these mirrors heats the liquid to as high as 2,700°F (1,482°C). This produces boiling water, which makes steam for electricity generation. A thermal storage system ensures that even more power can be generated by producing heat even after the sun goes down. (See "Storing Solar Energy," page 88.) This technology was first tried in Italy and France, but the United States was the first to apply it with two large multi-megawatt commercial power plants in California's Mojave Desert. Although these projects have ended, they sparked worldwide interest, particularly in Spain, Israel, and Australia, and several new "power tower" designs are being installed in California and throughout the Southwest United States.



A Central Receiving Tower Power Plant
Though there is only one mirror shown in this diagram, in reality the tower is surrounded by many sun-tracking mirrors.

CONSIDERATIONS

- Solar energy systems have several attractive features. They are modular (units can be added as needed), make no noise, produce no pollution, and operate during the hours of highest daytime electrical demand.
- There have been two main challenges to the use of solar energy: the availability of sunlight "fuel" and the cost of the technology. Solar resources depend on time of day, the season, the cloud cover, and the location. Today, most of these factors can be addressed with various solar energy storage systems. While cost used to be a major barrier with solar technology, it is dramatically less so today. Costs have dropped in the past two decades, though solar systems are still expensive when compared with other renewables or with coal or natural gas.
- PV panels can be mounted on rooftops or even integrated right into the buildings as walls, skylights, sunshades, shingles and more. PV panels can also act as roofs over parking lots to provide shade and protection from the rain. These systems can take great advantage of otherwise wasted real estate space.
- The rooftops or land area needed to construct a big commercial PV facility is very large. This can present too great a financial challenge with today's technology. Also, large installations can be disruptive to certain sensitive desert habitats, though in most cases, once constructed, they are considered environmentally benign.

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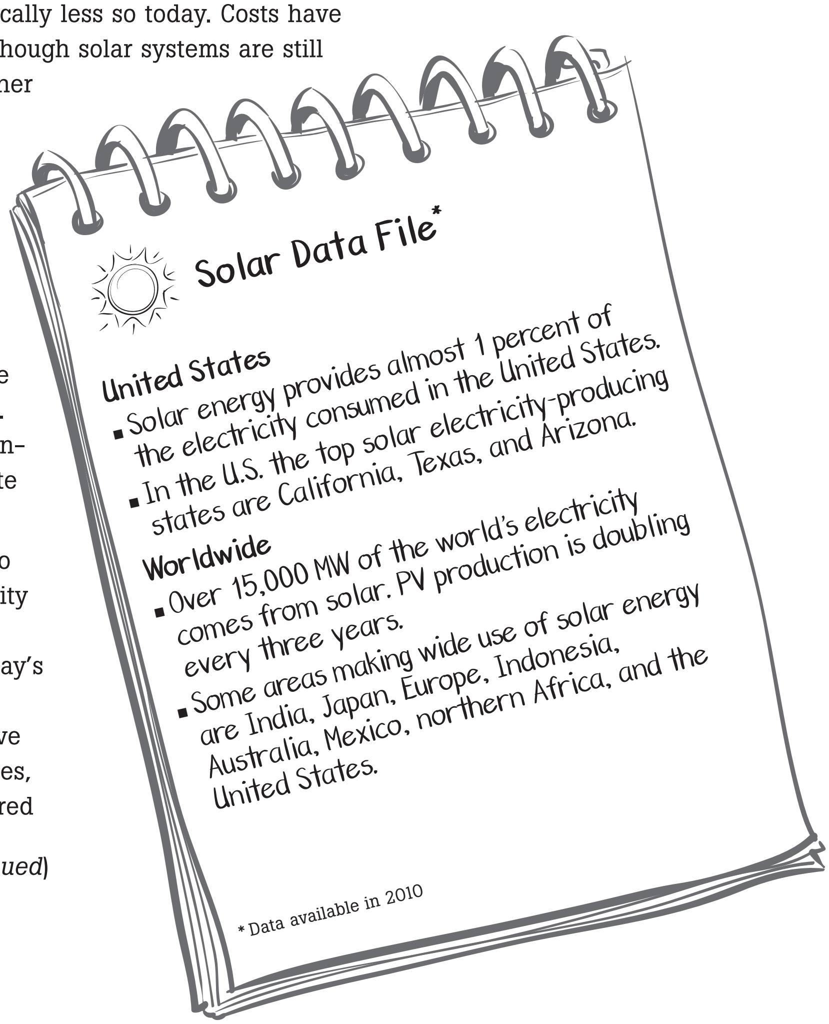
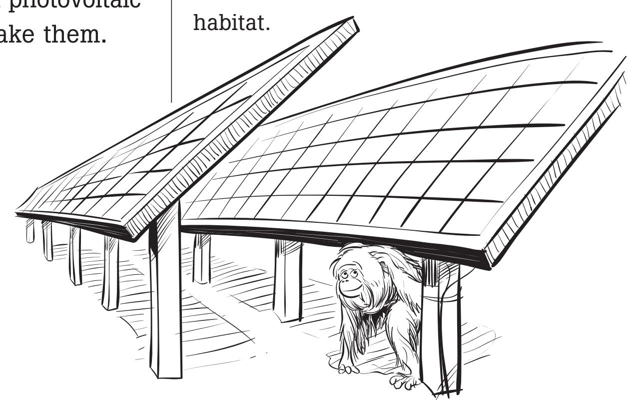


CONSIDERATIONS (continued)

- Large-scale solar power plants — and many other power plants that use renewable energy — tend to be located in remote locations, far from population centers or transmission lines. The challenge is to transport the energy from where it is produced to where it is used. One way would be to use solar (or other renewable) electricity to produce hydrogen from water through the process of electrolysis. The hydrogen could be shipped in containers or piped, just as natural gas is piped, to places where it could be used as a clean-burning fuel. (See "Producing Renewable Hydrogen," page 108.)
- Small Concentrating Solar Power (CSP) units do not take up much space and therefore can be placed in populated areas, especially industrial or commercial locations. These CSP units only work in the world's best solar resource regions.
- Manufacturing photovoltaic cells takes quite a bit of electricity. It takes two to four years to generate enough electricity from photovoltaic cells to compensate for the original electricity used to make them. The cells generally last 20 years or more.
- A solar thermal plant (CSP facility) can run reliably as a baseload power plant through the use of heat storage systems (see "Storing Solar Energy," page 88) or by supplementing solar with other fuels, like natural gas. CSP and PV produce electricity when the sun shines, which generally coincides with times of peak demand.
- Some renewable energy sources — notably solar — have benefited from recent government subsidy and rebate programs. These programs have given solar PV a big boost globally.

NO MONKEY BUSINESS

Solar energy is an attractive alternative for island nations, where geography makes the installation of transmission wires difficult and expensive. Stand-alone PV or solar dish engines could provide populations with electricity and reduce the need to cut down trees for firewood. For example, PV is being installed in many rural villages of the island nation of Indonesia, where it is hoped that orangutans and other threatened animals will benefit from the reduction of logging and its negative effects on their habitat.

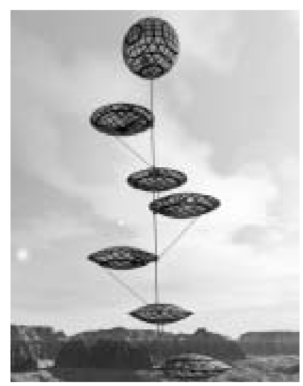


Creating Electricity from Solar Resources

Solar Troughs in Spain
This solar farm in Puertollano uses parabolic troughs — 352 collectors with 120,000 mirrors! — to focus the sun's energy on tubes of water, creating steam to drive turbine generators. *(Photos courtesy of Iberdrola Renovables, Spain)*

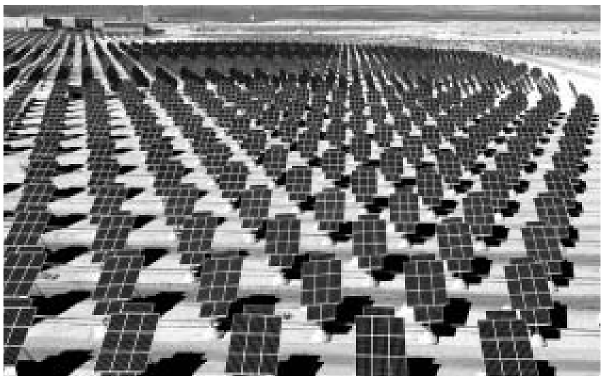
Dish-Stirling Systems
Prototypes of parabolic concentrators in Spain (above, left) track the sun to reflect its rays onto a solar heat exchanger, located at each concentrator. A Stirling engine and generator convert the heat into electricity. The photo on the right shows a different design that uses several concentrators to provide energy for a single engine. *(Photos courtesy of NREL, U.S. Department of Energy)*

Dual Purpose in Canada
These photovoltaic panels at the University of Calgary serve as both electricity generators and creative energy-saving sun shades. *(Photo courtesy of Conergy, Santa Fe, NM)*

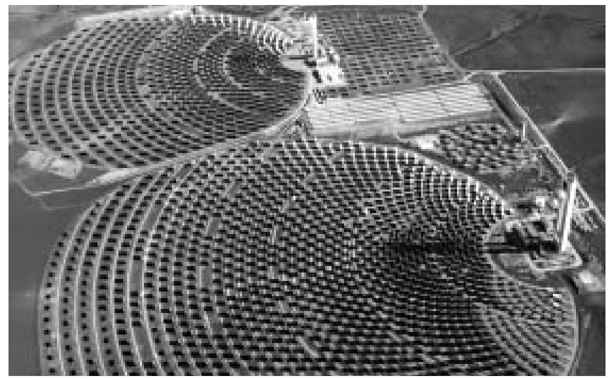


Solar Balloons
This invention is for off-grid uses, such as remote buildings or disaster sites. Filled with helium, a 10-ft. balloon could provide about a kilowatt of electricity. *(Photo courtesy of Dr. Joseph Cory, Geotectura Studio, and Dr. Pini Gurfil, Technion)*

Creating Electricity from Solar Resources

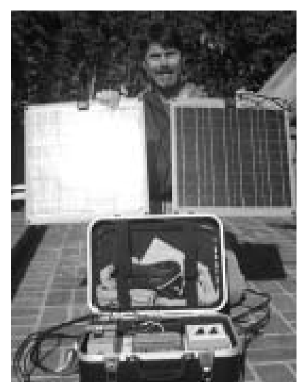


Good Use for the Nevada Desert
At Nellis Air Force Base 140 acres of previously unused land holds over 72,000 photovoltaic panels, built to generate 15 megawatts of electricity. *(Photo courtesy of U.S. Air Force)*



Solar Power Towers
Each 531-ft. solar power tower is the focus of 1,255 mirrored heliostats in Seville, Spain. Each heliostat, with a surface area of 1,291 square feet, reflects solar radiation onto the receiver, making steam to power a turbine generator. *(Photo courtesy of Abengoa Solar)*

Rocky Mountain Solar
Panels can be installed on any building — from a tiny cabin in a remote location to a skyscraper in an urban area. Mounting can be fixed (south-facing) or movable to track the sun. *(Photo courtesy of NREL, U.S. Department of Energy)*



Electricity Reaching Everyone
The photo on the left shows the *Digital Doorway*, a computer kiosk powered by weather-proof, durable solar panels. Units like these provide education and training to people in rural and disadvantaged areas of Uganda that have no electricity. The photo on the right shows a *Solar Suitcase*, a portable, user-friendly solar electric system that provides power for maternity hospitals and clinics in the developing world. The solar suitcase was first used in Nigeria and is now in nine countries. *(Photos courtesy of Sean Blaschke, UNICEF, and Laura Stachel, WE CARE Solar)*