



Solar Energy

Earth receives enormous amounts of radiant energy from the Sun, which directly or indirectly sustains all living things. Anxiety about dwindling supplies of fossil fuels and about the problems that accompany nuclear power has led to rapidly growing interest in the possible ways of harnessing solar energy in ways useful to humans.

Energy available

The Sun radiates energy at a constant rate of 3.8×10^{20} MW (380 million million million MW). This prodigious amount of energy is generated by nuclear fusion reactions deep in the heart of the Sun. The nuclei of hydrogen atoms are smashed together at a temperature of about 27 million °F (15 million °C) to build the element helium. However, an atom of helium is lighter than the sum of the hydrogen nuclei used to build it. The mass discrepancy appears as radiated energy, the exact amount given by Einstein's famous equation $E = mc^2$, where c is the speed of light. The staggering scale of the continual fusion processes in the Sun can be appreciated when it is realized that the Sun turns about 4 million tons (3.6 million tonnes) of its mass into energy every second.

The orbit of Earth around the Sun is not a circle but an ellipse, so the solar intensity just outside the atmosphere varies slightly from 1,399 MW per 0.38 sq. mile (1 km^2) at the closest (January 3) to 1,309 MW at the farthest (July 4). The energy distribution in sunlight as seen outside Earth's atmosphere approximates fairly closely to a blackbody radiator at 6000 K, but this spectrum is modified as the sunlight passes through Earth's atmosphere. (A blackbody is one that absorbs and radiates energy perfectly.) The ultraviolet component is cut down by absorption in the ozone layer at about 30 miles (50 km) altitude, and parts of the infrared are absorbed by water vapor and carbon dioxide. Moreover, some light is scattered out of the beam by dust particles and molecules of the air. Most of this scattered light reaches the ground in diffuse form, however, and since short-wavelength light is the most strongly scattered, the sky generally appears blue. The extent of all these effects depends on the height of the Sun above the horizon and local atmospheric conditions. The insolation, or solar intensity, at any point on Earth's surface therefore varies with the season and the time of day in a regular way and irregularly with cloud cover. The maximum intensity, about 1,000 MW per 0.38 sq. mile (1 km^2), occurs when the Sun is overhead in a clear sky, but average figures are lower than this. Highest annual insolation occurs in the tropical desert areas (near the equator insolation is somewhat reduced by high humidity).

Solar water heating

When solar energy falls on a black object, which absorbs the light, the object is warmed, and in this way, radiant energy can be readily transformed into low-temperature heat. One of the simplest, as well as the most widespread, applications of solar heat is the provision of domestic hot water, using flat plate collectors. The units generally consist of a metal plate with a blackened surface through or over which water flows in pipes or corrugations. The plate is insulated behind to prevent heat loss by conduction, and in front of it, there is an air gap of an inch or so and then one or two glass cover plates, which help to prevent convective heat loss.

Solar radiation (both direct and diffuse) passes through the glass cover plate and warms the metal surface, which in turn warms the water flowing through the plate. The water is circulated from the hot-water storage tank either by convection or by a small pump. With appropriate thermostat controls to switch the system off when the insolation is too weak to make a useful contribution, solar water heaters can readily provide a reliable and virtually cost-free domestic supply of hot water in consistently sunny areas of the world.

SOLAR-HEATED WATER SYSTEM

Solar collectors, mounted on the roof of a house, use the energy from sunlight to heat water. The water flows in channels under a black plate and is heated by the Sun. Above the black plate is a layer of glass, which prevents the loss of infrared radiation emitted by the plate, while insulation under the plate prevents heat loss into the roof, thus increasing the system's efficiency. After the water passes through the plate, it circulates to the hot-water tank where it may be stored. A supplementary boiler is usually fitted into solar-heated water systems to provide heat on cloudy days. Systems such as these are increasingly common in countries such as Israel and Australia.

The average thermal efficiency—the ratio of heat falling on them to useful heat extracted—of these collectors is generally in the region of 45 to 65 percent. The main heat losses occur from the front surface of the collector itself, provided all other parts of the system are well lagged. The glass cover assists in minimizing these losses, since glass is transparent to visible radiation but opaque to infrared. Thus, solar radiation passes through it, but the long-wave thermal radiation from the warm collector plate cannot pass outward through the glass. The system can be made more efficient by means of a vacuum between the glass and the metal plate, so that heat is not lost through conduction or convection through the air (just as a thermos bottle keeps hot), and by using suitable spectrally selective surfaces on the metal. These are surfaces with properties opposite to those of glass. They absorb visible radiation efficiently, so they are black to sunlight, but they do not absorb infrared radiation appreciably. Consequently, they do not emit the latter wavelengths either and so cannot radiate heat, and therefore a spectrally selective superblackbody reaches a higher temperature in sunlight than does a normal uniformly blackbody.

It is also possible to use solar water heaters to provide space heating and cooling in a building. Larger areas of collectors than needed simply to provide hot water are required, and the solar-warmed water is stored in large tanks for circulation in the central heating system. In climates where summertime cooling is required and night skies are generally clear, the same collectors can be used to chill the water very effectively during the night by pumping it through the

collectors, which radiate heat to the sky. The chilled water can then, through an appropriate heat exchange system, be used to cool the house the next day.

A similar system, which uses a shallow reservoir of water on the roof of the building, has been developed in California. When winter heating is required, the reservoir is covered during the day by a black sheet that absorbs solar energy and warms the water beneath. Thermal insulation is rolled over this sheet at night to prevent upward heat loss to the sky, so the warm water warms the house beneath. During the summer, this insulation, which is white, is placed over the pond during the day to prevent the water from being warmed by the Sun, but it is rolled back at night, and the water is chilled by radiation loss and evaporation, and the house is subsequently cooled as interior heat is transferred to the cool reservoir.

Other thermal uses

Solar distillation of brackish or saline water (desalination) is carried out quite successfully on a small or medium scale in several countries, and solar water or air heaters are in use for crop drying and timber curing. To obtain higher temperatures, it is necessary to focus sunlight by means of lenses or curved mirrors. Only direct sunlight, not diffuse daylight, can be focused in this way. In consistently sunny parts of the world, there is some use of focused collectors to boil water to raise steam. The steam can then be used to generate electricity by conventional means or to provide mechanical power, for example, for uses such as pumping irrigation water.

A similar arrangement, such as that at White Cliffs solar power station in Australia, is used to focus sunlight onto solar cells to provide large amounts of electricity.

Solar furnaces are another means of harnessing solar energy in which sunlight is reflected by mirror onto a concave reflector, which then focus the light onto a small area. This technique may produce temperatures capable of melting metal and so is often used in high-temperature research. The largest solar furnace in the world is in France at Odeillo and is over 130 ft. (40m) high. This facility is capable of producing temperatures in excess of 7200°F (4000°C).

Making electricity

The necessity for continuous electric power generation on space satellites led to the development in the 1950s of the solar cell at the Bell Telephone Laboratories in the United States. These devices, which are generally made from thin slices of highly pure single-crystal silicon, produce electric power from radiant energy. Wavelengths in the range 400 to 1100 nm (nanometers) are the most effective, and about half the solar spectrum falls in this range. The actual conversion efficiency of silicon cells is, however, much less than 50 percent, owing to various internal losses. The best cells available today are made from gallium indium phosphide or gallium arsenide and convert sunlight to electric power with an efficiency of about 32 percent (the remainder of the energy is degraded to heat in the cell and lost). This rate is still, however, a big improvement on the solar cells most commonly used, which are often capable of only around 18 percent efficiency. These improved cells, potentially useful for powering satellites, were developed by the National Renewable Energy Laboratory (NREL) in conjunction with Spectrolab in California. Scientists hope to be able to further increase efficiency to around 40 percent in the next few years.

These cells contain added dopants (usually boron and arsenic) in small amounts to create in the crystal slice a junction between an *n*-type and a *p*-type semiconductor region. This junction creates a gradient of electric potential within the crystal, and when light falls on the crystal and excites electrons in it, creating electron-hole pairs, the junction separates the electrons and the holes, and a DC current flows. These cells have no storage capacity, and for terrestrial applications, they are used in conjunction with electric storage batteries. They are at present too expensive for widespread use on Earth, though new manufacturing methods being developed in the United States may greatly reduce their cost.

Even if the cost were low, one disadvantage would still be the low efficiency. To operate a 500 W electric heater would require 27 sq. ft. (2.5 m^2) of cells even with maximum sunlight shining directly on them. Unless a large-scale method of energy storage or transmission of electricity is employed, this power would have to be used fairly close to its source of production, where it is probably not needed anyway. One possible solution to this problem in the future may be to equip a satellite with large arrays of solar panels generating power that would be transmitted to Earth by means of microwaves. These microwaves could be picked up by receiving stations consisting of arrays of wires even on cloudy days at fairly high latitudes, where the energy is required.

Solar-powered vehicles

Solar cells have been used to power piloted aircraft such as the Solar Challenger, which flew across the English Channel in 1981. The problem, however, with using a pilot to control the aircraft is that the pilot's weight adds a considerable burden to the amount of power the solar cells need to provide. Therefore, one of the most important areas of development in solar-powered vehicles is the use of solar cells on unpiloted aircraft. Recent research has shown great improvements in the design and performance of such experimental aircraft. In 2001, for example, the NASA Dryden Flight Research Center successfully flew its prototype Helios aircraft to an altitude of 96,500 ft. (29,410 m), breaking the altitude record for a propeller-driven craft held by another experimental NASA craft, the Centurion. In ideal conditions, Helios is expected to reach altitudes of more than 102,000 ft. (31,000 m). The Helios is basically a remote-controlled flying wing, which at 256 ft. (78 m) in length has a longer wingspan than a Boeing 747. The upper surface of the wing is covered in 65,000 bifacial solar cells, which, under conditions of flight, are around 19 percent efficient in converting solar energy to electricity and provide a maximum output of around 35 kW, enough to power the wing's 14 propellers. NASA hopes to reach still higher altitudes with this craft and to be able to fly the Helios for months at a time without landing. During the night, power will be provided by hydrogen-oxygen fuel cells charged during the day by the solar cells. If such long flights are sustainable, solar-powered aircraft could be used as semipermanent weather satellites or communication satellites. NASA is also working with UCLA and Rockwell to create smaller pilotless solarpowered aircraft that would fly in a V formation, like migrating geese. This arrangement takes advantage of certain aerodynamic effects that reduce the amount of energy necessary to sustain flight. These aircraft could also be used for communication and weather prediction.

See also: [ENERGY RESOURCES](#); [ENERGY STORAGE](#); [HEATING AND VENTILATION SYSTEMS](#); [MIRROR](#); [SEMICONDUCTOR](#).

Citation:

"Solar Energy." *How It Works*. Marshall Cavendish Digital. 2009. 21 July 2009
<<http://www.marshallcavendishdigital.com/articledisplay/7/2035/20158>>.

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