# Solar Energy

*Technology will allow radiation from the sun to provide nonpolluting and cheap fuels, as well as electricity*

by William Hoagland

Every year the earth's surface receives about 10 times as much energy from sunlight as is contained in all the known reserves of coal, oil, natural gas and uranium combined. This energy equals 15,000 times the world's annual consumption by humans. People have been burning wood and other forms of biomass for thousands of years, and that is one way of tapping solar energy. But the sun also provides hydropower, wind power and fossil fuels—in fact, all forms of energy other than nuclear, geothermal and tidal.

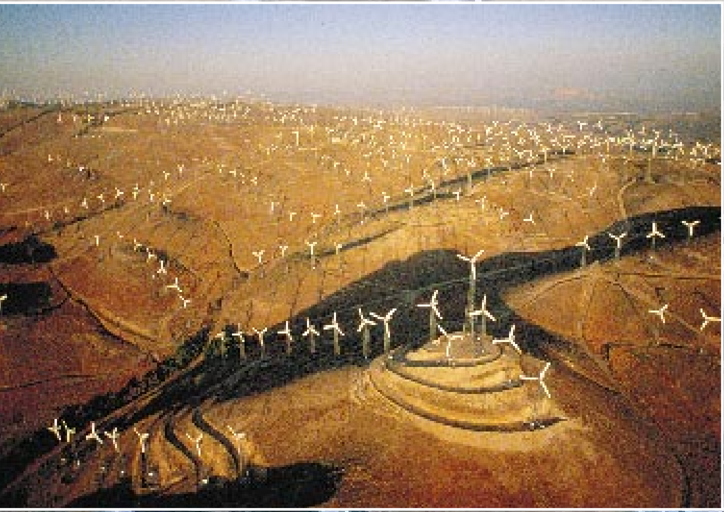
Attempts to collect the direct energy of the sun are not new. In 1861 a mathematics instructor named Augustin-Bernard Mouchot of the Lycée de Tours in France obtained the first patent for a solar-powered motor. Other pioneers also investigated using the sun's energy, but the convenience of coal and oil was overwhelming. As a result, solar power was mostly forgotten until the energy crisis of the 1970s threatened many major economies.

Economic growth depends on energy use. By 2025 the worldwide demand for fuel is projected to increase by 30 percent and that for electricity by 265 percent. Even with more efficient use and conservation, new sources of energy will be required. Solar energy could provide 60 percent of the electricity and as much as 40 percent of the fuel.

Extensive use of more sophisticated solar energy technology will have a beneficial impact on air pollution and global climatic change. In developing countries, it can alleviate the environmental damage caused by the often inefficient practice of burning plant material for cooking and heating. Advanced solar technologies have the potential to use less land than does biomass cultivation: photosynthesis typically captures less than 1 percent of the available sunlight, but modern solar technologies can, at least in the laboratory, achieve efficiencies of 20 to 30 percent. With such efficiencies, the U.S. could meet its current demand for energy by devoting less than 2 percent of its land area to energy collection.

It is unlikely that a single solar technology will predominate. Regional variations in economics and the availability of sunlight will naturally favor some approaches over others. Electricity may be generated by burning biomass, erecting wind turbines, building solar-powered heat engines, laying out photovoltaic cells or harnessing the energy in rivers with dams. Hydrogen fuel can be produced by electrochemical cells or biological processes—involving microorganisms or enzymes—that are driven by sunlight. Fuels such as ethanol and methanol may be generated from biomass or other solar technologies.

a



b

Solar energy also exists in the oceans as waves and gradients of temperature and salinity, and they, too, are potential reservoirs to tap. Unfortunately, although the energy stored is enormous, it is diffuse and expensive to extract.

### Growing Energy

Agricultural or industrial wastes such as wood chips can be burned to generate steam for turbines. Such facilities are competitive with conventional electricity production wherever biomass is cheap. Many such plants already exist, and more are being commissioned. Recently in Värnamo, Sweden, a modern power plant using gasified wood to fuel a jet engine was completed. The facility converts 80 percent of the energy in the wood to provide six megawatts of power and nine megawatts of heat for the town. Although biomass combustion can be polluting, such technology makes it extremely clean.

Progress in combustion engineering and biotechnology has also made it economical to convert plant material into liquid or gaseous fuels. Forest products, "energy crops," agricultural residues and other wastes can be gasified and used to synthesize methanol. Ethanol is released when sugars, derived from sugarcane or various kinds of grain crops or from wood (by converting cellulose), are fermented.

Alcohols are now being blended with gasoline to enhance the efficiency of combustion in car engines and to reduce harmful tail-pipe emissions. But ethanol can be an effective fuel in its own right, as researchers in Brazil have demonstrated. It may be cost-competitive with gasoline by 2000. In the future, biomass plantations could allow such energy to be "grown" on degraded land in developing nations. Energy crops could also allow for better land management and higher profits. But much research is needed to achieve consistently high crop yields in diverse climates.

Questions do remain as to how useful biomass can be, even with technological innovations. Photosynthesis is inherently inefficient and requires large supplies of water. A 1992 study commissioned by the United Nations concluded that 55 percent of the world's energy needs could be met by biomass by 2050. But the reality will hinge on what other options are available.

### Wind Power

Roughly 0.25 percent of the sun's energy reaching the lower atmosphere is transformed into wind—a minuscule part of the total but still a significant source of energy. By one estimate, 80 percent of the electrical consumption in the U.S. could be met by the wind energy of North and South Dakota alone. The early problems surrounding the reliability of "wind farms" have now been by and large resolved, and in certain locations the electricity produced is already cost-competitive with conventional generation.

In areas of strong wind—an average of more than 7.5 meters per second—electricity from wind farms costs as little as $0.04 per kilowatt-hour. The cost should drop to below $0.03 per kilowatt-hour by the year 2000. In California and Denmark more than 17,000 wind turbines have been completely integrated into the utility grid. Wind now supplies about 1 percent of California's electricity.

One reason for the reduction is that

**DIVERSE DEVICES aid in capturing solar energy. Wind turbines (*a*) draw out the energy stored in the atmosphere through differential heating by the sun. A solar furnace (*b*) uses radiation reflected onto a central tower to drive an engine. Solar panels (*c* and *background*) employ photovoltaic cells to create electricity. And crops such as sugarcane (*d*) tap sunlight by photosynthesis. The sugar can be converted to alcohol, a clean fuel.**

BARRIE ROKEACH; ALEX S. MACLEAN *Landslides* (insets)

*c*

*d*

stronger and lighter materials for the blades have allowed wind machines to become substantially larger. The turbines now provide as much as 0.5 megawatt apiece. Advances in variable-speed turbines have reduced stress and fatigue in the moving parts, thus improving reliability. Over the next 20 years better materials for air foils and transmissions and smoother controls and electronics for handling high levels of electrical power should become available.

One early use of wind energy will most likely be for islands or other areas that are far from an electrical grid. Many such communities currently import diesel for generating power, and some are actively seeking alternatives. By the middle of the next century, wind power could meet 10 to 20 percent of the world's demand for electrical energy.

The major limitation of wind energy is that it is intermittent. If wind power constitutes more than 25 to 45 percent of the total power supply, any shortfall causes severe economic penalties. Better means of energy storage would allow the percentage of wind power used in the grid to increase substantially. (I will return to this question presently.)

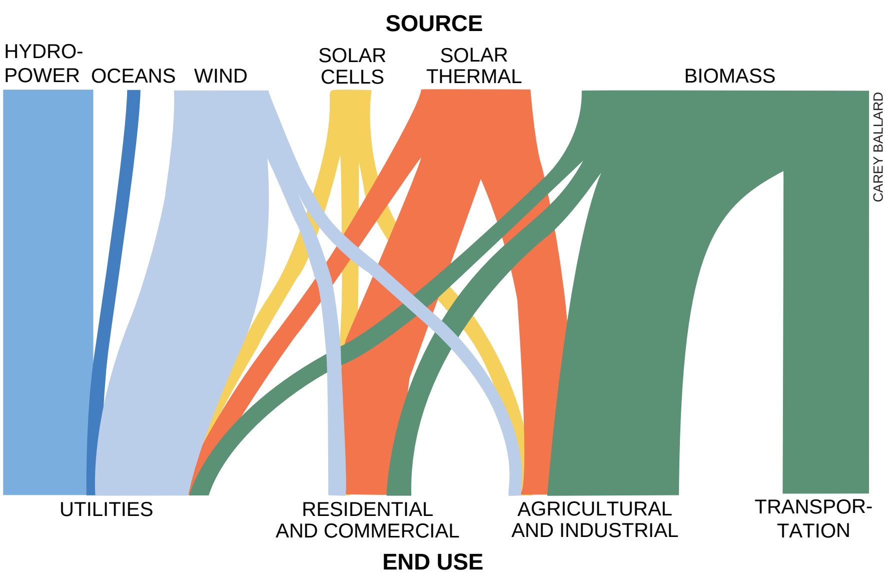
### Heat Engines

One way of generating electricity is to drive an engine with the sun's radiant heat and light. Such solar-thermal electric devices have four basic components, namely, a system for collecting sunlight, a receiver for absorbing it, a thermal storage device and a converter for changing the heat to electricity. The collectors come in three basic configurations: a parabolic dish that focuses light to a point, a parabolic trough that focuses light to a line and an array of flat mirrors spread over several acres that reflect light onto a single central tower.

These devices convert between 10 and 30 percent of the direct sunlight to electricity. But uncertainties remain regarding their life span and reliability. A particular technical challenge is to develop a Stirling engine that performs well at low cost. (A Stirling engine is one in which heat is added continuously from the outside to a gas contained in a closed system.)

Solar ponds, another solar-thermal source, contain highly saline water near their bottom. Typically, hot water rises to the surface, where it cools off. But salinity makes the water dense, so that hot water can stay at the bottom and thus retain its heat. The pond traps the sun's radiant heat, creating a high temperature gradient. Hot, salty fluid is drawn out from the bottom of the pond and allowed to evaporate; the vapor is used to drive a Rankine-cycle engine similar to that installed in cars. The cool liquid at the top of the pond can also be used, for air-conditioning.

A by-product of this process is freshwater from the steam. Solar ponds are limited by the large amounts of water they need and are more suited to remote communities that require freshwater as well as energy. Use of solar ponds has been widely investigated in countries with hot, dry climates, such as in Israel.




**DISTRIBUTION of renewable solar energy projected for the year 2000 shows that many different means of tapping the resource will play a role.**

### Solar Cells

The conversion of light directly to electricity, by the photovoltaic effect, was first observed by the French physicist Edmond Becquerel in 1839. When photons shine on a photovoltaic device, commonly made of silicon, they eject electrons from their stable positions, allowing them to move freely through the material. A voltage can then be generated using a semiconductor junction. A method of producing extremely pure crystalline silicon for photovoltaic cells with high voltages and efficiencies was developed in the 1940s. It proved to be a tremendous boost for the industry. In 1958 photovoltaics were first used by the American space program to power the radio of the *U.S. Vanguard I* space satellite with less than one watt of electricity.

Although significant advances have been made in the past 20 years—the current record for photovoltaic efficiency is more than 30 percent—cost remains a barrier to widespread use. There are two approaches to reducing the high price: producing cheap materials for so-called flat-plate systems, and using lenses or reflectors to concentrate sunlight onto smaller areas of (expensive) solar cells. Concentrating systems must track the sun and do not use the diffuse light caused by cloud cover as efficiently as flat-plate systems. They do, however, capture more light early and late in the day.

Virtually all photovoltaic devices operating today are flat-plate systems. Some rotate to track the sun, but most have no moving parts. One may be optimistic about the future of these devices because commercially available efficiencies are well below theoretical limits and because modern manufacturing techniques are only now being applied. Photovoltaic electricity produced by either means should soon cost less than $0.10 cents per kilowatt-hour, becoming competitive with conventional generation early in the next century.

### Storing Energy

Sunlight, wind and hydropower all vary intermittently, seasonally and even daily. Demand for energy fluctuates as well; matching supply and demand can be accomplished only with storage. A study by the Department of

Energy estimated that by 2030 in the U.S., the availability of appropriate storage could enhance the contribution of renewable energy by about 18 quadrillion British thermal units per year.

With the exception of biomass, the more promising long-term solar systems are designed to produce only electricity. Electricity is the energy carrier of choice for most stationary applications, such as heating, cooling, lighting and machinery. But it is not easily stored in suitable quantities. For use in transportation, lightweight, high-capacity energy storage is needed.

Sunlight can also be used to produce hydrogen fuel. The technologies required to do so directly (without generating electricity first) are in the very early stages of development but in the long term may prove the best. Sunlight falling on an electrode can produce an electric current to split water into hydrogen and oxygen, by a process called photoelectrolysis. The term "photobiology" is used to describe a whole class of biological systems that produce hydrogen. Even longer-term research may lead to photocatalysts that allow sunlight to split water directly into its component substances.

When the resulting hydrogen is burned as a fuel or is used to produce electricity in a fuel cell, the only by-product is water. Apart from being environmentally benign, hydrogen provides a way to alleviate the problem of storing solar energy. It can be held efficiently for as long as required. Over distances of more than 1,000 kilometers, it costs less to transport hydrogen than to transmit electricity. Residents of the Aleutian Islands have developed plans to make electricity from wind turbines, converting it to hydrogen for storage. In addition, improvements in fuel cells have allowed a number of highly efficient, nonpolluting uses of hydrogen to be developed, such as electric vehicles powered by hydrogen.

A radical shift in our energy economy will require alterations in the infrastructure. When the decision to change is made will depend on the importance placed on the environment, energy security or other considerations. In the U.S., federal programs for research into renewable energy have been on a roller-coaster ride. Even the fate of the Department of Energy is uncertain.

At present, developed nations consume at least 10 times the energy per person than is used in developing countries. But the demand for energy is rising fast everywhere. Solar technologies could enable the developing world to skip a generation of infrastructure and move directly to a source of energy that does not contribute to global warming or otherwise degrade the environment. Developed countries could also benefit by exporting these technologies—if additional incentives are at all necessary for investing in the future of energy from the sun.

## A New Chance for Solar Energy

Solar power is getting cheaper—in fact, the cost of filching the sun's rays has fallen more than 65 percent in the past 10 years. It has not become inexpensive enough, though, to rival fossil fuels, so solar energy remains a promising, not yet fully mature alternative. Sales run only about $1 billion annually, as opposed to roughly $800 billion for standard sources, and solar customers still generally reside in isolated areas, far from power grids.

But a new proposal from an American utility may well make solar power conventional—or at least more competitive. Enron Corporation, the largest U.S. supplier of natural gas, recently joined forces with Amoco Corporation, owner of the photovoltaic cell producer Solarex. The two companies intend to build a 100-megawatt solar plant in the Nevada desert by the end of 1996. The facility, which could supply a city of 100,000, will initially sell energy for 5.5 cents a kilowatt-hour—about three cents cheaper on average than the electricity generated by oil, coal or gas. "If they can pull this off, it can revolutionize the whole industry," comments Robert H. Williams of Princeton University. "If they fail, it is going to set back the technology 10 years."

Despite its magnitude, the $150-million plan does not mean that the solar age has finally dawned: Enron's low price is predicated on tax exemptions from the Department of Energy and on guaranteed purchases by the federal government. Nor does it mark a sudden technological breakthrough: Solarex manufactures a conventional thin-film, silicon-based photovoltaic cell that is able to transform into electricity about 8 percent of the sunlight that reaches it. Rather the significance of Enron's venture—should the bid be accepted by the government—is that it paves the way for other companies to make large-scale investments in solar power.

Such investments could bring the price of solar-power technology and delivery down even further—for both large, grid-based markets and for the more dispersed, off-the-grid markets that are the norm in many developing countries. "This marks a shift in approach," explains Nicholas Lenssen, formerly at the Worldwatch Institute in Washington, D.C., and now at E Source in Boulder, Colo. "It allows them to attract lower-risk, long-term capital, not just venture capital, which is very costly." Which all means the Nevada desert may soon be home to a very different, but still very hot, kind of test site. —*The Editors*

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### *Further Reading*

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