Solar Energy: The Largest Resource

Not long ago, proposals for using the sun's energy were apt to be received with considerable skepticism. Within a few agencies of the federal government and at an increasing number of university and industrial laboratories, that is no longer the case. Indeed, perhaps the most impressive testimony to the prospects for this type of energy is the score of prestigious scientists and engineers who have begun working on methods for converting the sun's radiation into forms more useful to man—heat, electricity, or chemical fuels.

Within 5 years, many of these scientists believe, solar-powered systems for heating and cooling homes could be commercially available at prices competitive with gas or oil furnaces and electric air conditioners. Still more significant, but farther in the future, may be means of using heat from the sun to generate electricity; experimental solar-thermal units have been constructed in several countries, and several groups in the United States are designing systems to take advantage of improved materials and manufacturing techniques. Eventually the direct conversion of solar radiation to electricity by means of photovoltaic cells or its bioconversion to wood, methane, or other fuels on a large scale may become economically feasible.

Solar radiation is the most abundant form of energy available to man, and is so plentiful that the energy arriving on 0.5 percent of the land area of the United States is more than the total energy needs of the country projected to the year 2000. Sunlight is diffuse and intermittent, however, and its use on earth requires large areas to collect sufficient amounts of energy and, for most applications, the means to store energy. Despite its abundance, solar energy has not been exploited except in a limited way in water heaters, furnaces, and space applications; nor are the technologies that would allow widespread use commercially available. Systems for heating and cooling houses or for generating electricity with sunlight could be built now, but they would cost more than comparable systems that burn fossil fuels. For some applications, however, the disparity in cost may rapidly disappear as solar technology improves and as the costs of fossil fuels rise.

Whether or not solar energy becomes generally available in the near future, there is growing agreement that this source of energy will be important in the long run. That being the case, proponents believe that it is the most underfunded area of research in the energy field, accounting for less than 1 percent of federal research expenditures related to energy.

Of the proposed uses of solar energy, heating and cooling for homes and low-rise commercial buildings are the most developed and will almost certainly constitute the first significant use of solar energy in this country. Solar water heaters are already in commercial use in Florida and in several countries overseas. Experimental houses have been equipped with solar heating systems and preliminary development of cooling systems has begun.

Solar Heating in the Home

For space heating, the solar collector is typically a black metal surface that readily absorbs sunlight and is covered with one to three panes of glass to reduce the heat loss. The glass is transparent to the incoming sunlight, but absorbs the longer wavelength radiation emitted by the hot metal, so that a "greenhouse" effect is created and the effectiveness of the collector is increased. The heat is collected in water or air that is circulated through the collector during the day, and part of it is stored for release at night or in bad weather. Hot water, hot rock, and chemical (change of phase) storage systems have been experimentally tested, depending on the type of heating system envisioned (*1*).

For air conditioning, most investigators believe, refrigeration systems that depend on absorption of the coolant fluid appear to offer the best choice. Experimental cooling units are being developed by several university and industrial research groups. At the University of Delaware, for example, a group headed by K. W. Boer is designing complete household energy systems that would utilize heat pumps for space conditioning. In other prototype systems, such as that developed by Erich Farber at the University of Florida, heat from the sun is used to drive ammonia from an ammonia-water solution, and the ammonia is collected and condensed. When cooling is needed, the liquid ammonia is allowed to evaporate and expand as in a conventional cooling system, and the spent vapor is reabsorbed in water.

For absorption refrigerating systems to work smoothly, temperatures around 120°C or higher will be needed, and thus solar collectors that are more efficient than those for heating purposes alone will be required. One possibility may be surface coatings of the type developed in recent years for space applications, which emit very little of the solar radiation that they absorb and which consequently attain higher temperatures than uncoated metal collectors. If such coatings can be produced on a large scale, their use might help to reduce the cost of solar heating and cooling, since collectors are the most expensive item of a solar energy system. Combined cooling and heating systems, which have not yet been built, are also expected to improve the economic prospects for both because of the joint use of the collector.

Substantial technical problems remain to be solved in the design of cooling systems, in the manufacture of surface coatings for improved solar collectors, and in the optimization of combined solar heating and cooling systems. In most regions of the country backup systems based on conventional fuels will be needed for extended periods of bad weather. Nonetheless, one estimate indicates that if systems were commercially available now, solar heating would be cheaper than electric heating in nearly all of the United States and would be competitive with gas and oil heating when these fuels double in cost (*2*). Proponents believe that solar heating and cooling systems could ultimately supply as much as half of the nearly 20 percent of total U.S. energy consumption that is now used for residential and commercial space conditioning and could reduce the peak use of electricity in summer.

For implementation of this technology, however, some means to overcome what are essentially social problems is likely to be necessary. As Jerry Weingart of the California Institute of Technology put it, "developing the technology is not enough," because the fragmented building industry is traditionally slow to adopt new techniques. Solar heating systems, despite their lower fuel costs, will entail higher initial costs, thus discouraging consumer acceptance; some observers have suggested that governmental encouragement in the form of tax incentives or energy performance construction codes should be part of a national energy policy. The slow rate of replacement of housing, in any case, guarantees that several decades will pass before a new heating system could have a significant impact on total energy use. Given the growing shortage of fossil fuels, however, it seems clearly advantageous to move in that direction.

The generation of electricity with heat from solar energy is a more difficult challenge, and there are conflicting ideas about the best approach to the problem. Some engineers believe that small generating units located where the electricity is to be consumed are the ideal way to utilize a resource that is inherently diffuse and well distributed. This group favors the use of power turbines that would operate at temperatures considerably lower than those common in nuclear or fossil-fuel power plants, despite the low thermal efficiency, between 10 and 15 percent, that these units would have. Others have proposed large solar-thermal facilities modeled on existing central power stations. The two concepts differ both philosophically and technically.

Small vapor turbines that used heat from solar collectors to generate electricity were demonstrated by Harry Tabor of Israel's National Physical Laboratory in Jerusalem at the United Nations conference on new sources of energy, held in Italy in 1961. A miniature solar power plant in Senegal is already in operation, and experimental solar engines have been developed by several investigators in the United States. Typically, these units operate at temperatures below 200°C. Their economic advantages relative to other sources of electricity have not been demonstrated, and the concept has attracted only limited interest, in part because of the difficulty of decentralizing the present electrical generation and distribution system.

Preliminary efforts to develop large central power plants are under way. This concept has attracted considerable interest, although substantial problems remain to be solved before such plants could be economically competitive. Still higher temperatures, between 300° and 600°C, are required to operate modern steam turbines, complicating both collection of solar radiation and the storage of thermal energy. To capture enough energy at these temperatures, mirrors or lenses larger than any yet built will in all probability be needed to concentrate sunlight. Because large areas will be required—in most designs, about 30 square kilometers for a 1000-megawatt power station—the transfer of heat from the far-flung solar collectors to the generating facility is also a complicated process. The cost and endurance of the collecting apparatus under operating conditions is a critical but undetermined factor.

Central Power Station

One design proposed by a group that is headed by Aden Meinel of the University of Arizona would use Fresnel lenses to focus sunlight onto a stainless steel or glass ceramic pipe, thus concentrating the solar flux ten times above its normal value. The pipe is covered with one of several types of selective coatings that emit only a small proportion, between 5 and 10 percent, of the energy they absorb and is enclosed in an evacuated glass chamber to reduce conductive and convective heat losses. Nitrogen gas is pumped through the pipe at velocities of about 4 meters per second to transfer the heat from the collectors to a central storage unit. The Arizona team plans to use a eutectic mixture of salts, mostly sodium nitrate, as a heat storage medium; the heat would be used to produce steam for a turbine as needed. Liquid metal or the molten salt mixture itself, despite the greater difficulty in handling these substances, might also be used to transport heat from the collectors to the storage unit.

A second group, headed by Ernst Eckert of the University of Minnesota and Roger Schmidt of Minneapolis-Honeywell, Inc., has also begun work on the central power station. Their design includes a self-contained, decentralized system for collecting and storing solar heat. A parabolic reflector would concentrate sunlight onto a heat pipe, a device that can transport heat along its length efficiently by convective processes and that does not require a fluid to be pumped through it. The pipe's outer surface would be a selective coating, and the pipe would be enclosed in an evacuated chamber. A small heat storage tank attached to each heat pipe and reflector would complete the unit; no centralized heat storage facility would be used. Underground pipes would bring water to each storage tank and return it as steam directly to a turbine—thus reducing the pumping costs, the Minnesota team claims, compared to the nitrogen system. In addition, they believe, the self-contained system would be easier to construct and maintain.

The effectiveness of the selective coating with which the collecting surface is covered largely controls the temperatures that can be achieved. Two types of selective surfaces are known, both of which absorb much of the incoming radiation—in the visible region of the spectrum—but which emit only a small portion of the infrared heat radiation. Surfaces such as one developed by Minneapolis-Honeywell for the Air Force rely on optical interference between two reflective layers separated by a transparent layer of the correct thickness; thin films of this type have been routinely produced by vacuum coating techniques in the commercial manufacture of tinted glass for the exteriors of new office buildings. A second type of surface, developed by B. Seraphin at Arizona, is composed of silicon or similar materials that naturally have selective properties. Layers of silicon and nonreflecting materials are laid down on a highly reflective substrate by chemical vapor deposition techniques; the silicon absorbs sunlight, but transmits infrared radiation, so that the composite surface has a high reflectance—and hence a low emittance—in the infrared.

These selective coatings are particularly important for solar collectors that are built without mirrors or lenses. Simple planar collectors have several advantages over the concentrating systems in that the concentrating collector must focus sunlight on the absorber and hence must follow the sun's motion in the sky; machinery to allow daily tracking complicates the collector design. In addition, focusing collectors operate only on direct sunlight, whereas planar collectors can utilize diffuse sunlight as well—and thus can function in cloudy or hazy weather. Because the performance of some of the most selective coatings decreases markedly at high temperatures, however, power plants using them would have to operate at temperatures below 350°C, with correspondingly reduced efficiency in the steam turbines. Improved selective coatings may allow planar collectors—which Meinel and his co-workers believe, in principle, to be the most effective in areas of the United States other than the cloudless Southwest—to be used. But most initial designs are based on the assumption that concentration of the sunlight will be necessary, and in these systems the fabrication, cost, and durability of the concentrators are the major concern.

The trade-offs between different types of collectors are not the only feature of the design of solar thermal plants still open to debate. Even with concentrating collectors, it may prove advantageous to operate the system at a reduced temperature, according to the Minnesota team. Their analysis shows increasing efficiency of the collectors, but decreasing efficiency of the thermodynamic cycle of the turbines as the operating temperatures are reduced, with the optimum temperature dependent on detailed design of the system and on the heat storage medium chosen. Heat pipes of the size envisioned have never been built, and other hardware details remain to be considered.

Both groups of investigators believe that the cost of solar-thermal plants will be not more than two or three times what fossil-fueled or nuclear-generating plants cost now, and that rising fuel costs will eventually tip the balance in favor of solar-thermal plants whose fuel is "free." Before accurate estimates of costs can be made, they agree, more detailed engineering studies and some additional research are necessary. But Meinel, at least, believes that full-scale solar-thermal power plants could be built as early as 1985 with an adequate research effort. Other estimates are somewhat less optimistic, but a group of western utility companies is considering the development of a small solar-powered facility that could serve as a prototype for peak load applications.

Although solar energy has probably the fewest potential environmental problems associated with its use of any of the major sources of energy, some problems, none of which appear to be insuperable, do exist. Collecting surfaces absorb more sunlight than the earth does, and while this is not likely to alter the local thermal balance in household or other small-scale use, the larger expanse of collecting surface in a central power plant might. Thermal pollution will also be a problem if water-cooled turbines are used—indeed, more so than with nuclear power plants because solar installations are expected to have even lower thermal efficiencies. If waste heat is returned to the atmosphere, it could help to restore the local thermal balance. The effects of small changes in the thermal balance would depend on the local meteorological conditions, but are expected to be small. The lack of particulate emissions or radiation hazards might allow solar-thermal power plants to be built close enough to towns or industrial sites so that their waste heat could be put to use. Finally, like other industrial facilities, large-scale plants would also carry some risk of accidents, with the attendant possibility of leaking heat transfer or storage media into the environment.

Yet another option for generating electricity with sunlight is direct conversion by means of photovoltaic cells. But the cells available now—which were developed for space applications—are relatively inefficient and very expensive to manufacture. As a long-term prospect, however, both cadmium sulfide and silicon cells are attracting considerable attention. This option, and the bioconversion of sunlight to fuels, will be discussed in future articles.

Space heating and cooling with solar energy are not available today. Solar-thermal power plants have yet to be built on any but the smallest scale, and key elements of the necessary technology have not been adequately demonstrated. But both options appear to be close enough to practical tests of their economic feasibility to warrant increased efforts. The ancient dream of power from the sun may not, after all, turn out to be impossible.

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References

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Air Pollution Instrumentation (II): The Glamour of Lasers

The development of the laser has revitalized—some would say revolutionized—the optical sciences: holography and optical communications are but two of the many subject areas in which the laser has precipitated an unprecedented rate of development. Now a growing number of scientists are arguing that laser techniques will engender an even greater revolution in the detection and measurement of air pollutants. The narrow spectral width and high intensity of laser radiation, they contend, offer exceptionally high resolution when combined with conventional spectroscopic techniques. The low divergence of laser beams and their ability to transfer large amounts of electromagnetic energy over great distances, furthermore, suggest a tremendous potential for the measurement of the average concentration of pollutants over a long distance or from a remote location.

For the present, however, laser spectrometers remain little more than a promise, their development hindered by a variety of problems including the need for more sensitive photodetectors and for simple, tunable lasers. The apparent glamour of laser instruments and the inordinate attention devoted to their application in remote monitoring, moreover, have largely overshadowed two other developments that may prove far more significant—the use of lasers in point-monitoring applications, and refinements in correlation and Fourier transform spectroscopy.

Conventional optical spectrometers typically monitor gaseous pollutants by measuring attenuation of ultraviolet or infrared energy at a wavelength that is absorbed by the pollutant and comparing the attenuation to that observed at an adjacent wavelength where absorption is minimized. This simple technique is highly susceptible to interference, however: absorption bands are seldom unique, and it is generally quite difficult to find an acceptable reference wavelength.

This interference problem can be overcome very effectively if one obtains the complete absorption spectrum of the sample within a suitable wavelength interval and compares (correlates) this spectrum with that of the pollutant being measured. Correlation spectrometers based on this principle are generally divided into two classifications depending on whether or not the spec-