Solar Energy Research: Making Solar After the Nuclear Model?

A point about solar energy that government planners seem to have trouble grasping is that it is fundamentally different from other energy sources. Solar energy is democratic. It falls on everyone and can be put to use by individuals and small groups of people. The public enthusiasm for solar is perhaps as much a reflection of this unusual accessibility as it is a vote for the environmental kindliness and inherent renewability of energy from the sun.

But the federal program to develop new energy technology is giving only belated recognition to solar energy's special characteristics. Despite the diffuse nature of the resource, the research program has emphasized large central stations to produce solar electricity in some distant future and has largely ignored small solar devices for producing on-site power—an approach one critic describes as "creating solar technologies in the image of nuclear power." The program contains virtually no significant projects to develop solar energy as a source of fuels and only modest efforts to exploit it as a source of heat. The massive engineering projects designed by aerospace companies which dominate much of the program seem to have in mind the existing utility industry—rather than individuals or communities—as the ultimate consumer of solar energy equipment.

This is the first in a series of Research News articles examining recent developments in solar energy research.

One consequence of this R & D emphasis on large-scale, long-range systems is to distort economic and policy assessments of solar energy based on the current program, both within the Energy Research and Development Administration (ERDA) and in higher levels of the government. Indeed, the potential of solar energy is still regarded with skepticism by many government energy officials and publicly discounted by spokesmen for oil and electric utility companies. Funds for solar research are leveling off, because of cuts made by the outgoing Ford Administration and confirmed, with minor overall changes but some shift in emphasis, by the Carter Administration. Agency officials concede that even the present federal program—representing an investment less than one-half of that for new coal technologies and a small fraction of that committed to the nuclear field—has survived only because of the immense popular appeal of solar energy and consequent pressure from Congress.

In contrast to this official skepticism is the virtual explosion of optimism and activity elsewhere. Dozens of pieces of proposed solar legislation and hundreds of companies now manufacturing solar components reflect this interest. The number of solar-heated houses built in the United States has doubled approximately every 8 months since 1973, and the rate shows no signs of slackening. The rapid buildup of a fledgling industry has been matched or even exceeded by a staggering rate of technical innovation in designs for solar equipment and in research on advanced methods for capturing and using solar energy. Measured by the number of new ideas or the rate of progress, solar energy has become the hottest property and the most sought-after action in the energy field. The burden of criticism from the solar energy community and from independent analysts is that the federal program has lagged rather than led many of these developments and that it has directed its research toward goals that betray a lack of understanding of the solar resource.

Coming to Grips with Solar

The government's difficulty in coming to grips with solar energy is understandable because the solar program was born, in an institutional sense, only about 5 years ago. The early work on solar energy was scattered among various government agencies, but much of it was an outgrowth of the National Aeronautics and Space Administration (NASA) effort to find practical spin-offs from space technology. After the 1969 Apollo moon landings, four different NASA labs began to do modest amounts of solar energy research. In 1972 the National Science Foundation (NSF) became the lead agency for solar energy research, which was funded at only $2 million per year. Many of the early program managers came from NASA and much of the contracted research went to aerospace companies.

In early 1975, all the solar research programs were shifted from the NSF, which has not been organized for commercial technology development, to the newly formed Energy Research and Development Administration, where solar was cast into competition with the nuclear breeder, the government's newly invigorated coal program, and the growing program for fusion. In its first 2 years the ERDA solar program was greatly understaffed and overworked—at one time 60 percent of the mail for the entire agency concerned solar energy. But in spite of institutional handicaps, the program grew rapidly because Congress authorized large increases in the solar research budget—as much as 80 percent above what the agency officially requested.

The program under ERDA moved into a mode of design, construction, and testing of various types of solar power pilot plants on an aggressive timetable. Feeling pressure to build up the solar program rapidly, ERDA delegated a large—some critics would say dominant—role to its national laboratories and to various NASA laboratories. The different subprograms were evaluated in a series of "mission analysis" studies, largely performed by aerospace contractors, and new priorities were set. Much of the evaluation was based on the capability of various solar technologies to approach base-load electric power supply—under the assumption that anything else would fall short of a major contribution. During this crucial period of solidification, the program had no regular review by an outside advisory board and there were no congressional oversight hearings. One of the strongest outside influences on the shape of the program, according to well-informed observers, was the utility industry.

Today, government solar research is a $290 million effort spread among four subprograms for electric applications, one for fuels, and two for heating, cooling, and related direct applications, with a professional staff of about 70 persons. In fiscal 1978, the program recommended by the Carter Administration will grow only modestly to $320 million. Because the various solar technologies are generally unrelated to each other, there is not a great deal of overlap between the research bases needed for the subprograms. The result is that the different solar options are at an even greater disadvantage vis-à-vis other energy programs than the total solar research budget would indicate.

The largest allotment of ERDA funds and staff resources has been for solar electric technologies. The concept which the utility's research arm—the Electric Power Research Institute—sees as the most likely candidate for central electricity generation is the power tower, a system with a boiler on a high tower heated by the sunlight reflected from a field of hundreds or thousands of sun-following mirrors. The power tower with its related solar thermal systems is still the leading subprogram in dollar priority—$79 million in fiscal 1977. Next is research on photovoltaic power systems—an effort to develop low-cost versions of the silicon cells used on space satellites for converting sunlight directly to electricity. Wind-power research, although it is the solar electric technology closest to being economically competitive, receives only about 8 percent of the solar budget. Approximately 5 percent goes to develop methods of extracting energy from the small temperature differences between surface and deep seawater—a concept usually referred to as OTEC (ocean thermal energy conversion) and conceived to produce electricity or perhaps an energy-intensive chemical in a huge floating plant that would provide about 200 megawatts of power. Still less money presently goes to the solar resource that could be most versatile of all—plant matter or biomass, which can be converted into either heat, fuels, or electricity. ERDA officials are generally agreed that biomass is one area in which they have yet to get a strong and coherent program under way.

The solar heating and cooling subprogram is funded at $86 million at present and $96 million in the fiscal 1978 budget. Solar home and hot water heating is nearly competitive in some areas of the country already. However, the ERDA program has paid little attention before now to the benefits of passive solar heating—the capture of solar heat that can be achieved from a well-sealed south-facing window as opposed to a rooftop solar collector used with a water or airflow system to carry the heat downstairs. Such systems are now widely thought to be capable of filling a large fraction of the winter heating needs in many areas at costs generally less than those of active systems.

As the Carter Administration prepares to shift energy research to yet another agency—the proposed Department of Energy—solar energy is still in search of a proper institutional home. Noting that skepticism of the solar program is one of the proper functions of ERDA's management, Henry Marvin, solar program director, nevertheless says that the program has been subject to tight controls by the agency's upper echelons and by the Office of Management and Budget. In his words, "Congress has been the corrective factor" in the growth of the program. According to Marvin, the solar program now has all the money it needs, "but we are still somewhat staff limited and travel-money limited—that has been the mechanism of OMB control." He foresees a program that may have already reached its broadest extent and will focus more narrowly as early decisions are made about solar hardware development projects in 1978 to 1981 and successful technologies are transferred to private industry.

Marvin is credited by several observers with having sought to limit the role in the program of the national laboratories—which, he says, "are not natural stopping places" enroute to developing commercial technologies—and with having managed the program competently within the guidelines set by the agency.

Centralized versus On-site Solar

But critics believe those guidelines still reflect the narrow set of preconceptions with which the program began. One of these preconceptions is the preferred role of centralized energy systems. Several pieces of evidence suggest that the ERDA program has given inadequate attention to the issue of the appropriate scale for solar technologies and, in so doing, has failed to exploit the most promising characteristic of solar systems. A report recently issued by the Congressional Office of Technology Assessment (OTA), for example, points out that federal research on electric generating equipment of all kinds has been focused almost exclusively on a centralized approach and has neglected what OTA sees as a significant potential for on-site power production. The report—one of the most comprehensive studies of emerging solar technologies yet made—concludes that "devices having an output as small as a few kilowatts can be made as efficient as larger devices" and that on-site solar systems capable of generating electricity at prices competitive with those charged by utilities may be available "within 10 to 15 years." "Onsite solar energy," the report declares, "must be regarded as an important option."

The solar thermal subprogram provides an instance of how ERDA's choices of scale were established. Initially, the subprogram was conceived of exclusively in terms of central power stations, as large as possible. Charles Grosskreutz, an analyst with the engineering firm of Black and Veatch during the period when it was involved in the initial program analysis of power towers for ERDA, says that "everyone started by considering a 1000 megawatt size and quickly scaled it down to about 100 megawatts" when it became clear that the tower height and the land acquisition problem were impractical for the larger sizes. "To my knowledge," he says, "there are no good studies of the optimum size of these facilities." Little serious consideration appears to have been given to solar thermal generating facilities in conjunction with community-scale energy systems or biomass fuel refineries—applications for which the optimum size, according to Princeton University physicists Robert Williams and Frank von Hippel, will probably be much less than 10 megawatts. According to Marvin at ERDA, "it may well be that 10 megawatts is the unit size for the power tower—we used 100 megawatts for our calculations."

Likewise, the wind-power program, according to early program documents, did not look carefully at the prospects for improved versions of small wind turbines for distributed applications, or at the potential economies of mass production that might apply to small devices but not to large ones. Instead, the program plunged ahead to build a large, 100-kilowatt prototype as a first step toward a commercial size conceived to be as large as possible with the materials available—1.5 to 2 megawatts.

Williams and his colleagues point out that the ERDA solar program throughout concentrates its main efforts on the largest and smallest scales of energy production, but they contend that an intermediate size may turn out to be the natural scale for many solar technologies. Their analysis points to community-size systems, equivalent to a few hundred or a few thousand houses, as the most cost-efficient, in that they would allow storage of solar energy on an annual basis—something impractical for an individual house—and would also allow the coproduction of solar heat and electricity in a manner that would be impractical for large central power plants.

Other independent analyses have come to similar conclusions. The noted British radio astronomer Martin Ryle, in a study of the applicability of solar energy to that country, concludes that a distributed network of small wind turbines provides the best match of potential supply to demand and would be competitive with coal-fired or nuclear generating stations. Ryle concluded that windpower, used with storage systems, could provide a substantial part of the power needs of the British Isles.

Another criticism of the solar program is that its management has been unnecessarily restrictive. During the last 2½ years, while ERDA has directed the program, it has been guided by a management philosophy of "aggressive sequential" development. In practice, this has meant a policy of giving priority to one solar technology in each subprogram, such as the power tower in the solar thermal program, and pushing it to quickly develop hardware and test its feasibility. What the policy has ruled out—reportedly because of skepticism from the agency leadership and budget-cutting by the Office of Management and Budget—is the parallel development of competing concepts. It is, of course, possible that the best candidates were not chosen initially, but nevertheless a whole solar subprogram could be phased out because of poor performance by an ill-advised solar concept. In particular, features such as scale and type of application have been heavily influenced by the original choices for development, and there is considerable danger that values derived from those choices will be the ones on which engineering and economic evaluations of future support will be made. It is just such considerations that lead environmentalists to make the charge that solar energy is being "set up" to fail.

Commenting on the desirability of pursuing parallel concepts, Marvin says that "it is not clear that we would not be more productive if we could pursue multiple paths." But he believes that it would be disruptive, if not politically impossible, to stop existing programs. He says he has attempted to correct what may be imbalances by bringing in a new group of managers (two of whom just arrived this month), and by supporting some of the neglected options as secondary, follow-on efforts when the budget allows. For instance, the fiscal 1978 budget includes $8 million for small-scale windmills. Marvin notes, however, that "it doesn't gain us time lost."

Another problem with the solar program has been lack of flexibility, leading to too little integration of different solar technologies with each other and with the energy needs they might ultimately satisfy. Storage is a problem with many solar systems, but the program has given little attention to applications in which biomass fuels would provide the storage element, or in which the need for storage is obviated by using solar energy in conjunction with another energy source. Solar-coal and solar-hydroelectric systems offer tantalizing possibilities for combinations that could approach around-the-clock power, and there is some evidence that direct solar energy and wind energy might complement each other well. Little attention has been given to on-site application of photovoltaic and solar-thermal devices, in which the utility grid could be used as a buffer and thus storage would not be required. In addition, a generally acknowledged problem with the ERDA program is that its sharply divided subprogram structure has limited the development of systems that serve two purposes at once, such as total energy systems that produce both heat and electricity with a considerable improvement over the efficiency of single-purpose system. The program has only belatedly begun to look at projects that do not fall into any of the predefined categories, such as solar irrigation, which ERDA developed no sooner than did the state of Guanajuato, Mexico.

The organizational structure of the energy agency, moreover, appears to be at cross-purposes with many novel or noncentralized applications. The solar energy division, for example, is effectively prohibited from working on community-scale solar systems because the agency management has decreed community-oriented projects to be in the domain of the conservation directorate.

Cost is the stumbling block most often cited by solar skeptics, and there is no doubt that few of the solar options are competitive today. But current cost estimates are almost certainly deceptive, in the absence of a real market. Furthermore, no one really knows what the costs of small-scale systems will be because so little research has been done on them. The conventional wisdom at the solar program planning office is that, compared to electricity at current prices, wind generators are competitive today or within a factor of 2 of being competitive, biomass fuels are a factor of 2 to 4 away from a competitive price, ocean thermal power systems a factor of 4 to 5, power towers a factor of 5 to 10, and photovoltaics a factor of 20 to 40 away. The opportunities for price reduction among these different technologies are controlled by quite different factors, however. Even the technologies for which a market does exist—hot water heating, for example—do not yet benefit from the kinds of implicit subsidies enjoyed by most other energy sources or the advantages of mass production by a well-established industry.

Probably no question about solar energy is more controversial than whether it can become a major energy source in the near term or should be regarded (and funded) as a limited, long-range option. Assessments of this question tend to get swept up into what has become a highly polarized debate between environmental advocates and the defenders of coal and nuclear power—a debate whose terms are more nearly philosophical or ethical than economic. The one view holds that a transition to a predominantly solar economy is not only feasible but *necessary*—to avert climatic disaster from the buildup of carbon dioxide that would accompany massive use of coal, and to prevent the danger of nuclear warfare attendant on the proliferation of the plutonium economy. The other dismisses solar energy and holds that coal and nuclear are essential on the grounds that even if costs were to drop dramatically, it would still be many decades before enough solar-heated houses and solar power stations could be built to make any dent in this country's huge and growing appetite for energy.

But these tactical positions obscure a number of things that tend to argue the importance of solar energy on purely economic grounds, as well as some substantial problems. One of the key problems is that solar equipment tends to be capital-intensive, with high initial costs that are a deterrent to consumers unaccustomed to making decisions on a life-cycle basis. Another is that many existing institutional arrangements, from building codes to utility rate structures to federal tax policies, discriminate against unconventional energy sources. But some institutional barriers are being removed by legislation, and the prices of many solar components are already dropping sharply in response to steadily growing demand. It seems evident that the growth of distributed solar systems, for which equipment can be mass-produced, can be far more rapid than the growth of centralized power plants, which must be laboriously assembled in the field. Frost and Sullivan, a respected market research firm, predicts that 2.5 million U.S. homes will be solar heated by 1985. The government itself may become a major market for solar energy—a Department of Defense report done for the Federal Energy Administration estimates that a DOD market for up to 100 megawatts of photovoltaic devices a year may exist at the prices expected to prevail in the early 1980's.

Political fortunes may also play a role in determining the short- or long-term impact. Solar energy fared badly under a Republican administration. President Ford had many opportunities to attend solar project ribbon cuttings but did not do so. Under his administration, the OMB strenuously opposed and nearly gutted the major short-term elements of the government's solar energy program—the demonstration projects for solar heating. ERDA appealed to President Ford but, according to one observer, had the misfortune to argue its case during a week in which Ford was preoccupied with the Angolan crisis. In any case, the OMB position largely prevailed—a circumstance that apparently contributed substantially to the resignation of ERDA assistant administrator John Teem—and the proposed demonstration program, modest though it was, was drastically cut back.

The government program is having some effect—ERDA's work on photovoltaics and wind has stimulated some private investment. And quite apart from the government's program there appears to be a remarkable amount of momentum in solar thermal devices, wood burning stoves and boilers, and other components of a solar energy industry.

After 5 years of rapid but uneven development, solar energy is in need of reassessment. The present federal program has been as much the product of institutional happenstance and various technical predilections as it has been the product of coherent planning. In a broader perspective, the government policy under Republican administrations characterized solar energy as a long-term option comparable to fusion and the breeder, but in fact it has little in common with these potential leviathans. Solar technology is more diverse, and even the most difficult technologies, such as photovoltaics, may be closer to commercial realization. Many solar technologies already work, even though the best designs have not been found, and they are already facing the economic challenges that other long-range options have yet to confront. It is arguably time to reconsider solar priorities and ask whether the distribution of research resources among nuclear, fossil, and solar options reflects a rational policy.

ALLEN L. HAMMOND and
WILLIAM D. METZ

Human Evolution: Hominoids of the Miocene

As long as there have been fossils to study, investigators have devised scenarios to describe the history of the human lineage. This history has been pushed back further and further so that now many anthropologists are searching for traces of the human line among hominoids that lived as long as 14 million years ago. Recent fossil finds in Pakistan and eastern Europe are providing new evidence on which to base scenarios and are leading to new scenarios. Another consequence of these finds is that some investigators are beginning to question some previously accepted ideas about the diversity of species that existed at the time the human line evolved.

As they reexamine anthropological dogma in light of their most recent data some anthropologists are concluding that they have let certain scenarios get the better of them—that they have developed casts of mind that impede their attempts to understand the past. They are now trying to free themselves of these preconceived ideas of how hominoid evolution occurred (the superfamily Hominoidea includes the great apes, humans, and fossils resembling them) and are suggesting new interpretations of their data. Some anthropologists and geologists are concentrating on the influence of the environment on hominoid evolution. Another anthropologist suggests that birth-spacing patterns may have played a major role in this evolution. Still others are considering the most recent data and are using it to defend the classic view that tool use led to the distinction between human and ape ancestors.

One result of the recent finds of Miocene hominoids is the growing realization among anthropologists that these species were far more diverse than was previously realized. For example, David Pilbeam of Yale University and his associates found three species of these hominoids living in the same area of Pakistan during the Middle Miocene (from 17 to 7 million years ago). These species, known as *Sivapithecus*, *Ramapithecus*, and *Gigantopithecus*, are referred to by Pilbeam as the sivapithecids. He says that it is impossible to point to any one of these species as the human ancestor.

Pilbeam's analysis of his recent data from Pakistan contrasts with previous analyses of hominoid fossils. Previously, anthropologists tried to divide all extinct hominoids into two groups: those of human lineage and those of ape lineage. Many investigators further assumed that once the ape and human lineages arose from their common ancestor, these species gradually and continuously evolved toward their present-day forms.

The assumption that Miocene hominoids could be divided into two groups led anthropologists to the assumption that simple markers, such as thickness of tooth enamel, could be used to classify the species. Since present-day humans have thick enamel and present-day apes have thin enamel, hominoids with thin enamel were said to be of human lineage and those with thick enamel were said to be of ape lineage. These markers turned out to be not only uninformative but also misleading, Pilbeam says. Anthropologists developed erroneous notions of how evolution proceeded. The Miocene hominoids share features of both humans and apes and cannot be accommodated by the dichotomous classification scheme, according to Pilbeam.

New clues to the lives and fates of the early hominoids are arising from attempts by geologists and anthropologists to reconstruct the environments of these animals. Their results lead them to propose that the sivapithecids appeared during the Miocene when some heavily forested areas gave way to mixed environments consisting of dense forest, savanna woodlands, and more open areas. The sivapithecids differ substantially from the previously existing group of hominoids known as the dryopithecids. Dryopithecids lived both before and during the Miocene in heavily forested areas of Africa and Europe. It now seems likely that they never left these areas for more open environments. The sivapithecids, on the other hand, seem to have lived on the boundary between the forests and the open areas and to have exploited both.

Evidence that some of the Miocene hominoids lived in mixed environments is not extensive, but many anthropologists find it convincing. For example, Judith Harris Van Couvering of the University of Colorado points out that there are no counterexamples to this hypothesis. Sivapithecids were not present among assemblages of savanna-dwelling animal fossils found in China, Greece, and Iran. Nor were these hominoids found in the typical forested environments of Europe and Africa during the Miocene. The earliest well-dated *Ramapithecus* remains were found at Fort Ternan in Kenya, and they date to a time, about 14 million years ago, when this area changed from forest to a mixed environment.