Earth's Renewable Resources

A Special Report on Technology Development

ELECTRIC POWER RESEARCH INSTITUTE

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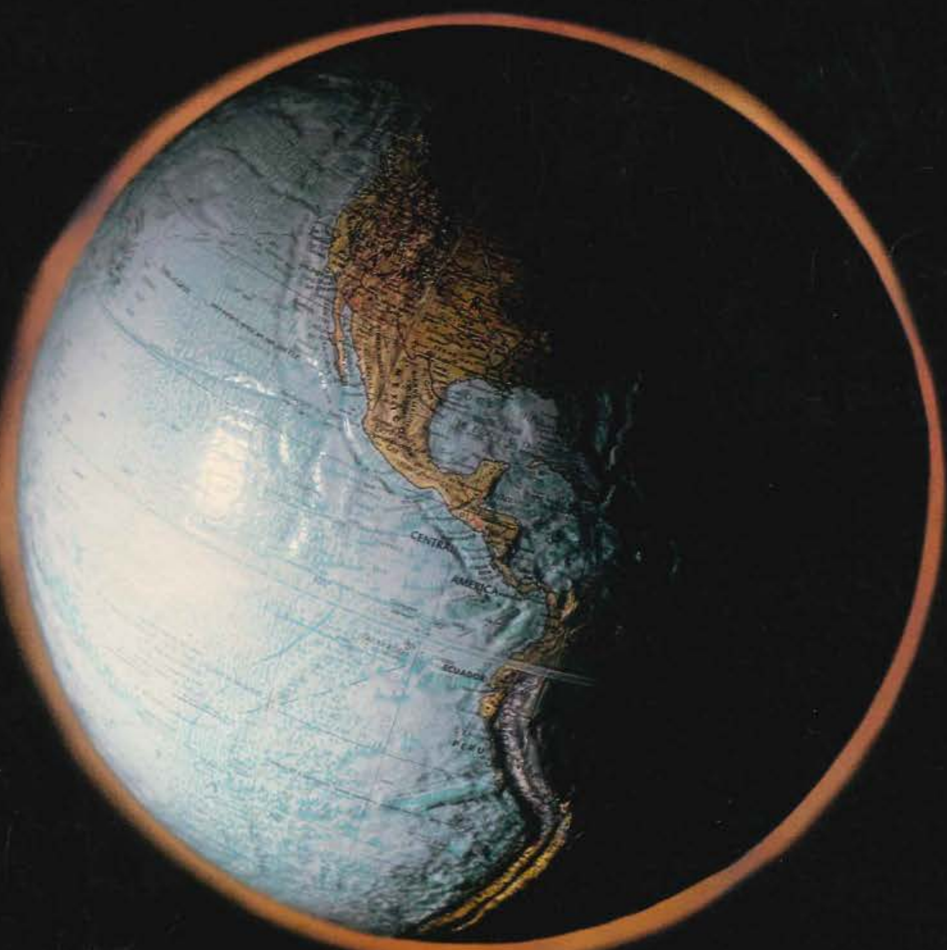

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Cover: Energy flowing into the biosphere from the sun, the earth's interior core, and even the moon has become the object of a broad-based technological search for alternatives to finite fossil fuels.

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Taking Stock of Renewables

What happened to the energy crisis? A short time ago, reliance on oil resources for the nation's energy security was seen by the government and the public as an inadequate solution to a steadily growing problem. Replacement of gaseous and liquid fossil fuels by renewable energy resources became a significant element in an urgent drive for energy self-sufficiency, a goal fostered by a new respect for the dynamics of world energy supply.

Yet in the past year, the new administration has done an about-face, shifting emphasis from the further development of oil-displacing energy technologies to a reliance on increased oil exploration and production. Federal R&D funds earmarked for aiding the commercialization of energy options that could begin to impact our energy supply systems in the early 1990s have been cut drastically, leaving support for mainly high-risk, high-payoff research.

Is the new government direction solving our energy supply problems or merely postponing them? Almost certainly the latter. Gaseous and liquid fossil fuels still represent a finite resource pool, no matter how much we manage to squeeze what is left. The energy crisis is not gone, just submerged in the face of temporarily reduced demand, masked in part by the current recession and the administration's preoccupation with the present state of the economy and budget-balancing exercises. When energy supply problems do reappear, the consequences most probably will be even worse than before—the shortages that startled us in 1972 and 1974 are likely to bite us next time around.

How do renewables fit with the new federal direction? The policy shift forces us to take stock. Fortunately, the course of the 1970s has left us a valuable legacy of perspective and understanding. That decade saw the emergence of an energy ethic in this country, featuring conservation and more efficient use of resources. The awareness of consumption on the personal level has grown in the home and on the highways; this will surely continue. Awareness on the national level not only spurred the search for new energy technology options but also led to the acceptance of using a mix of options for satisfying national energy demand.

The search for new energy options, especially for renewables, turned up a great number of ideas for the mix. When subjected to the rigorous analytic machinery of the R&D process, many were found not to be technically feasible, and of those that were, few are expected to eventually become economical for commercial use. Further, compared with conventional generation technologies, none of the renewable resource technologies identified as good prospects are expected to provide a large fraction of needed power, with the possible exception of fusion, which could have a strong impact sometime in the next century. Nevertheless, in the context of an energy mix, an option does not have to represent a large fraction of the energy supply sector to make a meaningful contribution. Indeed, the regional and local impacts of wind, hot water geothermal, and solar-thermal conversion could be considerable.

R&D on these three particular applications has proceeded to an advanced stage, and it is expected that if momentum can be maintained, their commercial potential will be determined within the next several years. However, it is at this point—the demonstration stage—that funding is most critical. With government emphasis shifting away from commercialization of technologies, there is considerable uncertainty about whether these energy options can make the final all-important step that will bring them firmly into the commercial sphere.

It remains to be seen whether other interested parties—users, manufacturers, or suppliers—will underwrite that portion of the risk necessary to bring geothermal, wind, and solar-thermal applications through the critical demonstration stage. The nation as a whole faces a high risk in failing to follow through on such applications, not only in terms of losing the payoff on a large R&D investment but also in terms of losing the availability of precious resources. The assessments and the initial phases of technology development have been done. These technologies represent the best hope for use of renewable resources in the early 1990s—technologies we need to demonstrate now at commercial scale in anticipation of the energy crisis that is certain to return.

John E. Cummings, Director
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Authors and Articles

Last year the *EPRI Journal* conducted a random-sample survey of its 30,000 subscribers to elicit opinions on the magazine's editorial policy and to gather suggestions for its future. Part of the questionnaire invited readers to supply topics they would like to see covered in upcoming issues. By a large margin, renewable energy sources was the subject most frequently mentioned.

This special issue was created to respond to such widespread interest. The *EPRI Journal* staff, augmented by personnel from EPRI's Public Information Department and Washington Office, put together this update on renewables by drawing on the expertise of the Renewable Resources Department of the Advanced Power Systems Division. Technical contributions were also made by EPRI's Energy Management and Utilization Division.

John Cummings is director of the Renewable Resource Systems Department in EPRI's Advanced Power Systems Division. Before joining EPRI in January 1975, he was director of energy programs for Itek Corp., concentrating on strategies to commercialize solar-thermal and photovoltaic energy conversion processes. Earlier, he undertook resource recovery analyses for the Atomic Energy Commission, including definition of an AEC-sponsored solar program. He holds a BS in engineering from the U.S. Coast Guard Academy and an MS and a PhD in physics, in addition to an MBA, from the University of Arizona.

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Roger Taylor is a project manager in the Solar Power Systems Program. Before joining EPRI in July 1980, he spent two years at the Solar Energy Research Institute, where he was concerned with the integration of solar power technologies and electric utilities. The two years prior to that Taylor spent with the Arizona Public Service Co., where he was involved with solar/utility issues in the research department. He holds a BS in physics from Colorado College and an MS in mechanical engineering from the University of Arizona.


Roberts


Cummings

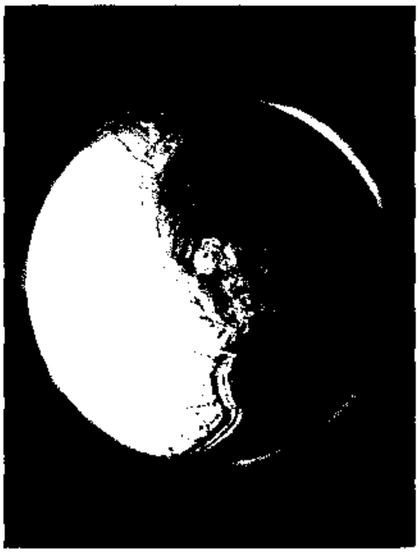

Billman


Lannus Purcell


Bigger DeMeo Goodman Taylor

OVERVIEW

Renewable Resources: Development at the Crossroads



Renewable energy resources are those that draw on the natural energy flows of the earth, such as the wind, the sun, the rise and fall of water, and the venting of the earth's core heat. For millennia they were the predominant energy forms of man's enterprise and survival. They were dispersed as broadly as sunshine and plant life, seemingly inexhaustible, and free for the taking. And then civilization discovered the fossil fuels, those compressed layers and pockets of ancient plant life, and the revolution of industry was on. Energy density was the key.

The new fossil resources and the technologies to exploit them became intimately tied. Coal spurred rapid advances in the steam engine and its nineteenth-century progeny of locomotives, steamboats, and shaft-driven automation. Metallurgically, it transformed iron to steel, opening the door to better boilers, skyscraping structures, and lighter, more resilient machines. And in turn, these new machines, now capable of containing (or internalizing) combustion, stood poised to exploit the newly discovered fluid fuels derived from oil. Cars, planes, tanks, and trucks roared forth into the twentieth century, utterly transforming the societies that created them. And with the exception of hydro power, the diffuse and difficult-to-collect renewable energy sources were left behind like so much dust, seemingly forever.

On a geologic time scale of hundreds of millions of years the fossil fuels are also renewable; but for all practical purposes, which is to say on a contemporary time scale of centuries, they are fixed and finite. It is this simple fact that seemed to strike home with such great urgency in the early 1970s, when domestic oil production peaked and foreign suppliers gathered together to protect their diminishing hoards and to control production and price. The great mistake was realized. The accelerating rush of the industrialized nations into overwhelming dependency on oil could not be sustained. Prices soared, closing the brief era of cheap energy and opening the era of alternatives.

The era opened with some confusion. Alternatives came to mean different things to different people. To some, light water reactor technology was an alternative, at least to fossil fuels, and one whose fuel supply could be stretched indefinitely by breeder technology. To others, alternatives precluded all established forms of energy supply and institutions and concentrated instead on the means of achieving decentralized social structures. Still others thought of alternatives as synonymous with renewable energy resources or limited the term exclusively to solar. In the squabbles that followed, nearly everyone ignored the obvious: that each of the terms is just a handy grab bag for a large number of very dissimilar technologies, each with a different pathway and timetable of development. At a minimum, solar encompasses a half-dozen major technical variations (water heating, space heating, space cooling, solar-thermal electric, photovoltaic, and wind); geothermal includes three (steam, direct flash, binary cycle); and fusion, two (magnetic confinement, inertial confinement). Beyond this there are dozens of important distinctions. Because of the apple-orange dilemma of these collective terms, experts and laymen couldn't agree on the truth of any general statement. Were renewables here and now? Were they economic? Yes and no. Some were, some weren't. Both sides found themselves right—at least upon qualification.

More fundamentally, the era of alternatives also brought about a broad search for technological solutions. Security seemed to lie in the diversity and independence of supply. And American ingenuity was stirred by the competitive opportunities unfolding with each new ratchet in the world price for oil. Energy resources that had previously made no economic sense suddenly looked inviting. Older, discarded technologies, ranging from synfuels to windmills, were reexamined; existing coal and nuclear technologies were assigned higher priorities and a greater role in the national plans; and such new technologies as fusion and photovoltaics were prodded forward with new intensity.

But among all the alternatives that poured forth, serious and whimsical, it was the renewable resources, particularly solar, that fired the American imagination. They seemed to make sense—common sense, if not yet engineering and economic sense. They seemed more understandable and everlasting, free and clean, and somehow more in concert with nature and current philosophical fashion. Besides, they were, almost by definition, the inevitable heirs to those depletable (and dirty) fossil fuels—and if so, why wait, went the dialectic.

Rivalries set in, as advocates for specific technologies emerged. Most overstated their cases, feeding public confusion about the true nature and scale of America's energy problem. Energy options were thus relegated to a popularity contest; and pollsters took the pulse of preference, annually proclaiming solar at the top of the technonogical hit parade. Serious studies by different groups, with widely varying assumptions, contested the renewables' potential contribution to national energy use; estimates of solar alone ranged from 1% to 25% by the year 2000. Those on the low side said it was a question of economics and the pace of technical development and deployment; those on the high side said it was a question of national willpower.

In the public debates over the potential contribution of renewables in general and solar in particular, percentage points were tossed about with casual abandon, reflecting an inability to grasp the full measure of the target, the immensity of the American energy production and consumption system. For the sake of illustration, by the year 2000 annual U.S. energy consumption will be roughly equivalent to the present oil reserves of Alaska's North Slope, and a single percentage point will be roughly equivalent to one quadrillion Btu. In terms of renewables, displacement of a single quadrillion represents the installation of about 20,000 large wind turbines (2.5 MW per machine) or about 400 solar-thermal power tower systems of 100 MW each (15 times the current system near Barstow, California) or about 1000 average hydrothermal sites of 50 MW each. Following the massive CONAES study, Philip Handler, president of the National Academy of Sciences, summed up the problem of perception by saying, "It's very difficult to get your head wrapped around how large it [the U.S. energy supply] is, and until you do, it's easy to accept glib solutions, to think you have an easy solar energy solution, or a geothermal answer, or an idea that we'll just build windmills. What you have to get your head around is what 30 million barrels a day of petroleum really means or what 100 million tons of coal is really like. And until you do, you can't learn to deal with these questions realistically."

Politics and the energy ethic

The only thing that everyone seemed to agree on was that the emerging renewable technologies couldn't stand alone. They would need public support to raise an industry and to compete adequately in the private sector.

Political support for the renewables gathered momentum throughout the 1970s. Federal funding for R&D of solar, geothermal, and fusion climbed several times faster than OPEC oil prices, accelerating from a few million dollars in 1973 to nearly $1.5 billion in fiscal year 1981. Major emphasis was put on bringing new applications of renewable resources into the marketplace. Efforts to assist commercialization ranged from programs to develop large wind turbines and central receiver solar-thermal systems (power towers) to subsidies for residential conservation to tax incentives for the installation of solar or other renewable hardware in the home or business. State governments followed suit with similar tax incentives. Total direct and indirect public support for the renewables was over a billion dollars per year by the end of the decade. And private support was on top of this.

In several respects, the 1970s also became a decade of preparation for the energy transition ahead. A significant industrial R&D capability was established, largely through government financial support and policy emphasis. Nearly 10 years of national preoccupation with energy had slowly led to public awareness and appreciation of the pervasiveness of the energy issue, and a begrudging acceptance of the inability of the nation's technological community to bring about a quick fix. The so-called energy crisis was being seen in a clearer light; the shortage was not a shortage of energy but rather a shortage of cheap oil, nearly half of which was fueling a monstrous fleet of inefficient automobiles. Progressively, people settled in for the long haul, and as energy expense filtered through every fiber of economic life, an energy ethic emerged, one that fostered conservation and improved efficiency. Industry and consumers alike found ways to cut back or substitute or recapture. By the end of the decade conservation efforts appeared to have made a significant dent in oil imports, although the recession fuzzed the claims. After reaching a peak of nearly 9 million barrels a day in 1977 (50% of U.S. oil consumption), imports dropped to about 5 million barrels a day (35% of U.S. oil consumption) by summer 1981.

Exploring the impact

But what of renewables? Where do they stand after a decade of development and evaluation? And what can they ultimately contribute? Enough has been learned through the comparative analytic framework of the R&D process so that the less promising technologies have now been culled from the pack, the seemingly endless stream of conceptual options. Technical feasibility has shaken out some, economics many more. And the pathways and pitfalls to commercial use are now much clearer.

At least for several decades, renewables will probably play only a small, supplementary role in the total U.S. energy system, although they could well become significant contributors on a local or regional level. They are likely to have almost no impact on the large transportation fuels market. Most are pointed at the electric utilities as the predominant, or at least initial, market. Wind, solar-thermal electric, and geothermal, among the most promising of the emerging technologies, are at least a decade away from commercial inroads and are now poised at critical stages in their development. Photovoltaics, with the exception of remote applications, is still further downstream; and fusion, which has just begun the awkward transition from science to engineering, is perhaps 20 to 40 years from commercial demonstration.

As a rough rule of thumb, it now seems that each of these emerging electric generating options—wind, geothermal, solar-thermal electric, and photovoltaics—has the potential for displacing on the order of a quadrillion Btu sometime into the early part of the twenty-first century. With the possible exception of geothermal, none will be competitive with baseload coal- and nuclear-generated electricity. They will be used primarily to displace premium fuels such as oil, and in the case of the intermittent technologies (such as wind and solar), will be given very little credit for displacing new generating capacity. The result is that most of these technologies will end up competing for the same small slice of oil-fired generation as many other emerging technologies, including load management technologies. All this tends to restrict commercial potential.

Overall, the diffuse nature of solar energy and the geographically restricted nature of geothermal energy will probably preclude them from ever becoming the predominant source of U.S. energy supply. Among the technologies treated in this issue, only fusion—with its unlimited supply of fuel—has the potential to radically transform the energy picture in the United States. And among the critical decisions to be made that will affect the fusion development path and its economics are whether the commercial devices will be large or small and whether they will be designed to produce electricity or to breed fuel for an existing fleet of fission reactors. The attempt in this issue is to explore the status and prospects of renewable energy technologies as well as fusion, an inexhaustible if not technically a renewable resource.

Critical juncture

This is a particularly appropriate time to step back and take stock because of the critical juncture that faces renewable energy research. First, energy R&D and energy independence have recently become lost in the fight against inflation and the lull created by a momentary glut of oil. Second, the Reagan administration is philosophically opposed to the role of government in the commercialization process—the progressive development and eventual demonstration of a given technology. It believes that commercialization is more properly the role of the private sector; that government should confine its support to long-term, high-risk research. Third, it appears that DOE may be in the process of being dismantled, its programs dispersed to other departments.

The upshot is that R&D budgets for renewables (excluding fusion) are being slashed to a fraction of their former levels, and major pilot plants and demonstration plants are in jeopardy. And it remains to be seen who will underwrite the risk in the developmental stages for each of these emerging technologies. Some, such as solar heating, are probably far enough along that withdrawal of federal funds for R&D would not in itself significantly affect commercial inroads, although removal of tax incentives would severely retard market development. Other technologies, such as wind and geothermal, which have progressed smoothly and rapidly in development and are now approaching critical demonstration phases, could lose momentum by the sudden withdrawal of federal R&D funds. In the case of wind power, for example, development of the MOD-5 horizontal-axis wind turbine is considered critical to expanding the potential commercial market. Still other technologies, such as ocean-thermal electric conversion and synchronous satellites, which pose enormous technical and economic hurdles, are given much lower priorities and are certain to die without federal R&D support.

Fusion stands in a category by itself, surviving on a stable budget and an extended timetable. Fusion has been cited as a prototype of the kind of high-risk research the new administration believes it should fund.

With the federal government apparently pulling out of many of the renewable energy applications, particularly the solar technologies, industry will be left to select options and carry on development and commercialization. Exactly how this will be done and by whom is unclear. The only thing that is clear is that a serious pruning is about to take place. Some technologies are going to be discarded and others effectively starved to death in a stretch-out of the funds so protracted that inflation eats up construction budgets. Only a few will prosper and those only if the private sector organizes to underwrite the risk of further development.

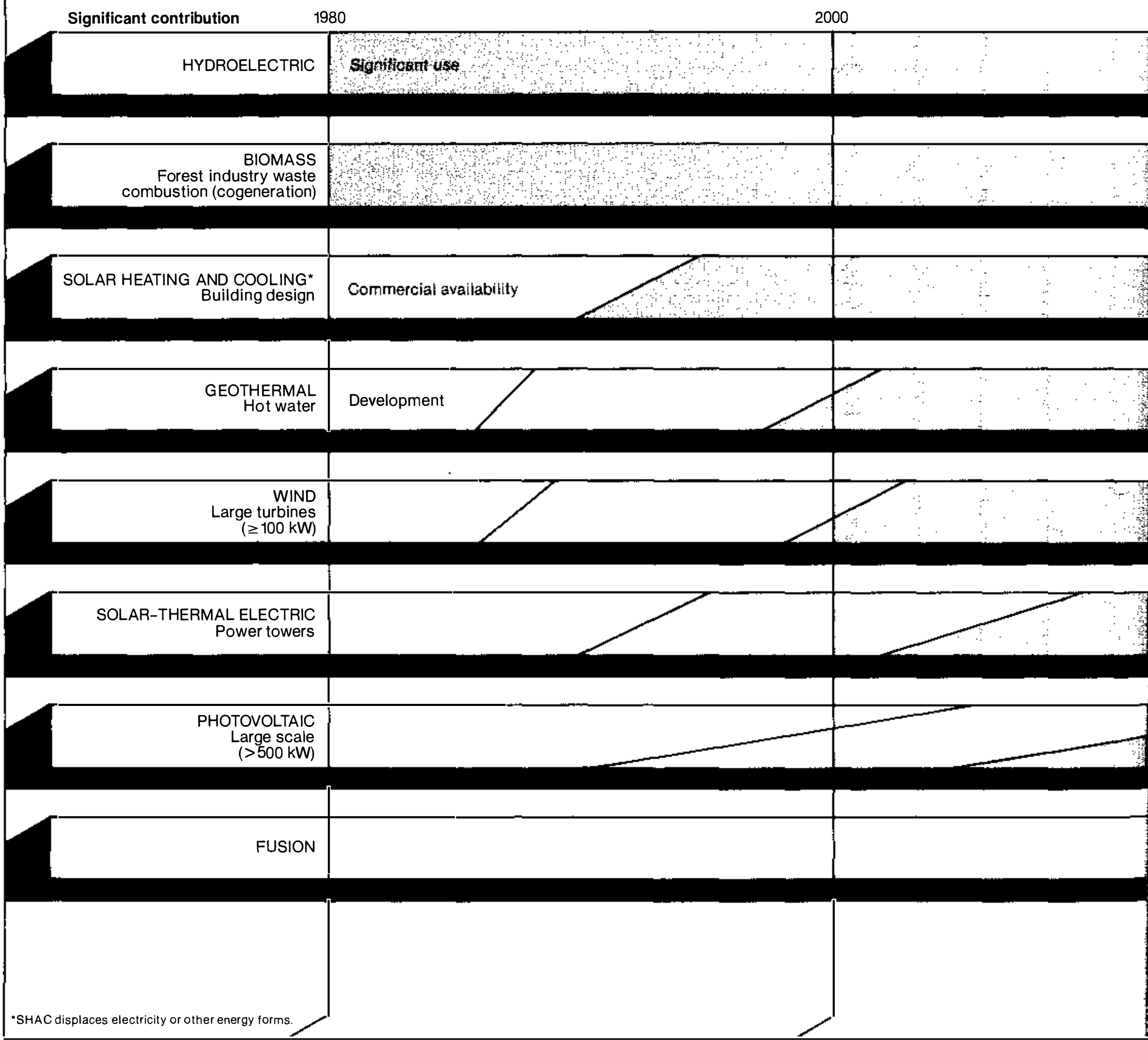
Teams will be required to pull together the expertise and financial resources of utilities, manufacturers, and venture capitalists—in some combination—to carry forward the critical steps to commercialization. Fortunately, the incentives for market development may be there. Many of these new technologies are inherently small and modular in nature, and they can be quite attractive to capital-strained utilities seeking incremental additions to capacity. Without such groups from the private sector to champion specific technologies, the commercial prospects are now in serious question.

At this juncture, somebody has to pick up the ball. No single institution can afford to carry the risk alone, and the larger issue before American industry is how to regroup its talents to exploit its new energy resources—solar and synfuels, fusion and fission, geothermal and shale. As with coal and oil before, technologies will have to evolve in a way that ensures compatibility with the resources at hand. In the end, it must be recognized that innovation, not energy, is the resource of fundamental concern—technical innovation, institutional innovation, and social innovation. For over 200 years, since the great clipper ships stole the seas, Yankee ingenuity has been a point of pride for Americans and, more important, our single greatest resource beyond political and economic freedom.

This article was written by Brent Barker, Editor, *EPRI Journal*. Technical background information was provided by John Cummings, Advanced Power Systems Division.

Timetable of Renewabl

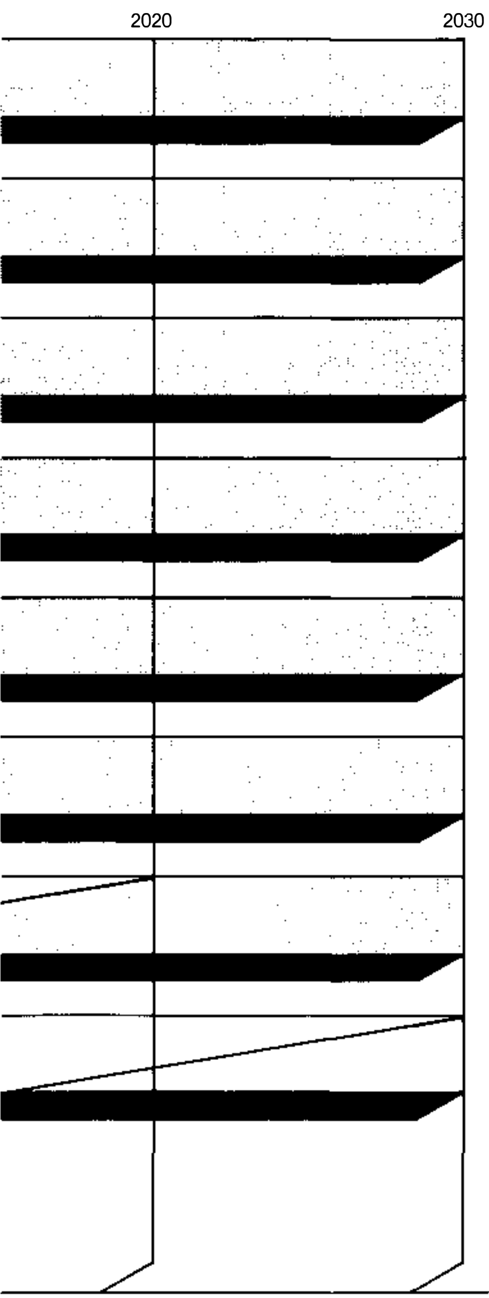
Renewables include a wide variety of technologies, each with its own distinct timetable for engineering development and commercialization. Charted below are those technologies expected to become commercially available and eventually to make a significant contribution, defined here as equal to or greater than the equivalent of 1% of U.S. electricity generation. Listed separately are those technologies expected to make only a limited contribution—less than 1%; this list



*SHAC displaces electricity or other energy forms.

nergy Technologies

includes technologies whose impacts are likely to be felt only on a local or regional level. Also listed are some technologies that are not expected to become commercially available for reasons of economics or technical feasibility. Commercial availability refers to the point in time when a commercial system can be ordered. The pitched lines cover the uncertainty of the time estimates that divide the three phases.



Limited contribution	Contribution unlikely
• Municipal waste combustion • Agricultural product waste combustion • Synthetic fuels from biomass	• Energy plantations
• Solar water heating • Solar space heating	• Solar space cooling
• Geothermal dry steam • Geopressured resources	• Geothermal dry rock
• Small wind turbines (< 100 kW)	
• Distributed receivers	
• Remote photovoltaic systems • Residential photovoltaic systems	
• Solar ponds	• OTEC • Waves, currents, tides • Satellite power systems

SHAC: A Nation Turns to the Sun

One of the first signs that the nation was moving toward renewables was the appearance of solar collectors on roofs across the country, gathering heat for swimming pools, domestic hot water, and interior space. A decade later, experience has confirmed what the experts expected: SHAC doesn't work in every situation, but in some applications it can work very well. The right SHAC system, applied in the right place at the right time, has the potential to lower utility costs and customer electricity bills. Researchers are identifying what those systems are—and where and when they work.

America's response to the increasing scarcity of energy resources began in the home. As the price of energy for residential space heating, hot water heating, and air conditioning went up, individual homeowners responded by conserving energy where they could. Thermostats were lowered, and insulation, weather stripping, and caulking were installed. Sweaters were pulled on, and down comforters purchased. These conservation measures are saving a considerable amount of energy, but only so much insulation and caulk, only so many cardigans and comforters can be applied to the problem; conservation is effective only up to a certain point. Beyond that, many homeowners look for renewable energy sources that have the potential to reduce fuel bills. They don't have to look far: the sun is shining just outside.

Today's applications

Solar energy for heating and cooling (SHAC) has been around for a long time in many forms. Technologies have been developed to use the sun for a range of residential and commercial purposes. With some solar collectors and minimal engineering, the sun can heat swimming pools and, in fact, is being widely used for that purpose throughout such states as California. With a bit more engineering, the sun can be used to heat domestic hot water; such systems are already economical in some areas of the country. Apply more hardware and more engineering, and the sun can heat interior space; this heat can even be stored for later use. Farther down the road, more difficult technical and economic issues might be resolved, and the sun could be used to cool interior space.

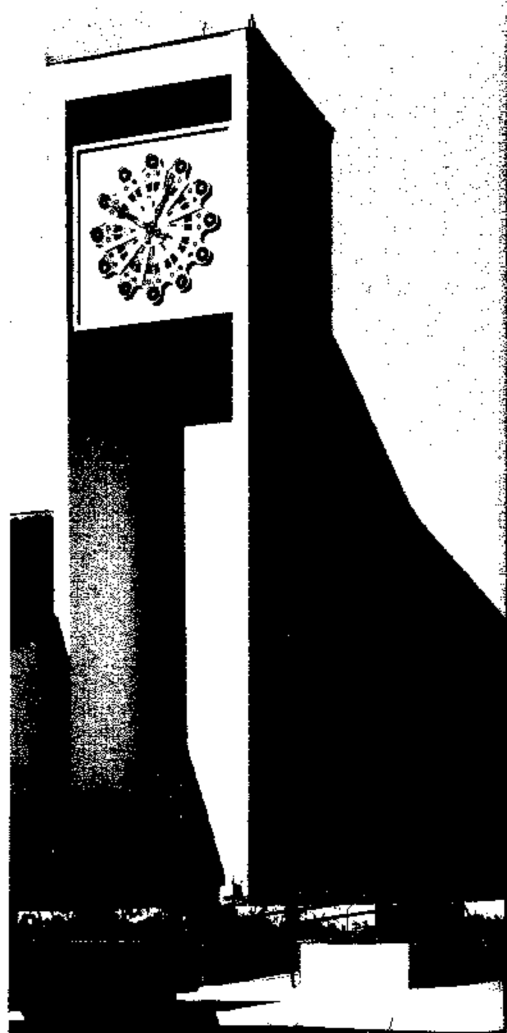
To many homeowners, solar seemed a welcome escape from mounting energy bills, and a large number of pool heaters, water heaters, and space-conditioning systems were enthusiastically installed in private homes. But as many enthusiasts found out, solar was not as free as it appeared at first, even despite the tax credits and other incentives that often came with it. True, solar swimming pool heaters were successful when they replaced costly natural gas heating, and solar domestic hot water heaters have also had a measure of success in certain areas. Yet solar space heating was economical in just a few places, and under certain economic conditions. Solar space cooling still appears to face formidable technical and economic hurdles.

As it turned out, the systems necessary to make the transition from sunlight to usable energy were costly; equipment was often improperly installed; breakdowns were frequent. Furthermore, most solar systems had to resort to backup energy—often electricity—at night or during cloudy days. When solar system owners turn to local utilities for energy, utilities require just as much generating equipment as if there were no solar systems at all. Widespread use of improperly designed solar systems could even result in higher electricity costs because of the expense required to keep generating equipment ready to provide large amounts of power to solar users during those periods of occasional demand.

However, solar still has the potential to lower utility costs and thus customer bills. A solar system equipped with thermal storage could store heat from the sun or from low-cost electricity generated during off-peak hours and use that energy during peak periods. In this way, solar systems could help smooth demand peaks.

Because of this potential for load leveling, SHAC systems are of interest to the utility industry, even though these systems generally belong to individual homeowners. But before full advantage can be taken of solar, specific systems must be defined and developed to meet customer energy needs at the lowest overall cost, including the cost of solar equipment and the cost of backup energy. These so-called preferred systems must take into account available fuels, weather conditions, and local patterns of energy demand. Through demonstration projects and studies, EPRI is trying to find those systems.

EPRI began its research into SHAC in 1975 by first studying active systems, according to EPRI Project Manager Gary Purcell. Active systems use the mechanics of collectors, piping, pumps, and fans to collect, store, and distribute the sun's energy. These systems were closest to commercialization and therefore likely to have the earliest widespread use. Although many active solar homes were being built (frequently as demonstration projects sponsored by individual utilities), they were often without adequate provision for acquiring and interpreting energy-use data. On behalf of the utility industry, EPRI took on the job of data collection and development of analytic methodologies that individual utilities could apply to their own particular situation in order to identify preferred SHAC systems.



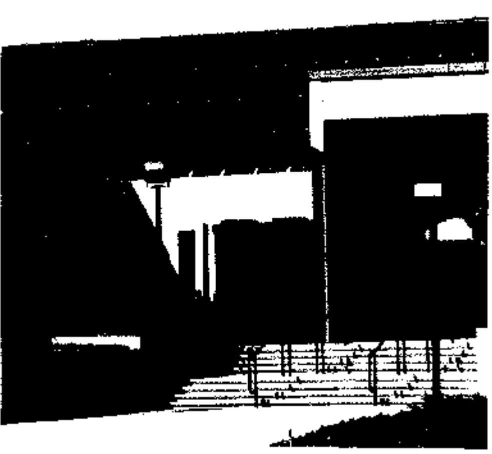
In 1975 EPRI authorized Arthur D. Little, Inc. (ADL) to conduct a project that would help utilities and homeowners find preferred active systems for their service areas. The first phase of the project resulted in the development of an EPRI methodology for preferred solar systems (EMPSS), a computer program that examines residential solar heating and cooling options, analyzes their performance and impact on utility systems, and identifies the lowest-cost configurations, taking into account backup energy requirements.

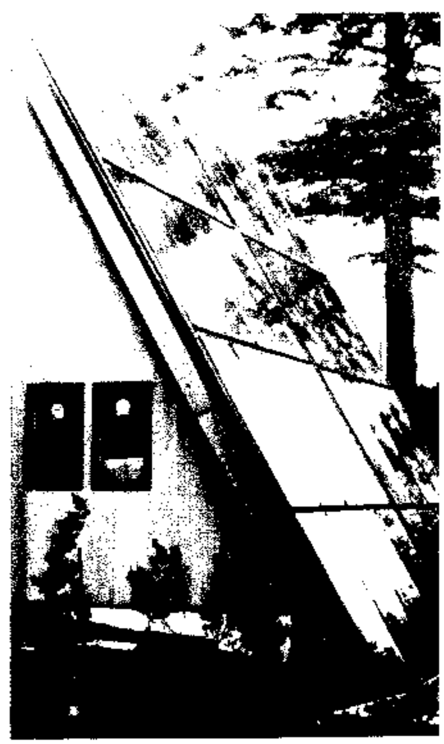
EMPSS was tested with input data from 24 utilities, which included operating costs, electricity demand, fuel costs, and weather conditions in the different utility areas. Also factored into ADL's analysis was information on different residential characteristics, such as type of heating system, number of rooms, and heat transfer through walls. In all, more than 100 combinations of solar heating and cooling systems with electric backup were analyzed.

As the program was being developed, it became evident that there is no single "preferred" SHAC system. The best SHAC options vary considerably from region to region and from utility to utility, and each utility must run its own analyses to find the preferred system for its own region and utility characteristics. For example, application of EMPSS confirmed that demand is a cost factor that is often critical but varies widely. Demand costs reflect capital requirements for generation capacity, transmission and distribution, and other equipment that a utility must have available to meet peak power demands. Even though equipment may not be used often, its capital cost and upkeep add to customer bills, and it should be considered in the question of which, if any, solar systems are the lowest real-cost options for satisfying customer needs.

EMPSS has been available to utilities and in use for three years now. If economic factors change, such as fuel costs, time-of-day rates, or other costs, the model can be altered to accommodate them. Significant improvements in technology can also be factored in.

In the second phase of this SHAC project, 10 experimental houses were constructed—5 in Albuquerque, New Mexico, and 5 in Long Island, New York—to validate EMPSS on active solar heating and cooling system configurations and thus gain first-hand experience on real SHAC systems. The houses were used to provide data on how different SHAC systems performed in these two different parts of the country and how those systems would affect utilities and their customers if they were widely used. The style of the houses was typical of that of





Active SHAC systems use mechanical devices to collect, store, and distribute the sun's energy. The main components of an active system include solar collectors, pipes, pumps, and fans.

other houses in each area. Every home had its own computerized monitoring and data-gathering system, which recorded fluid temperatures and flow rates throughout the system, daily sunshine, equipment performance, and energy use. Each home was tested in a wide variety of modes.

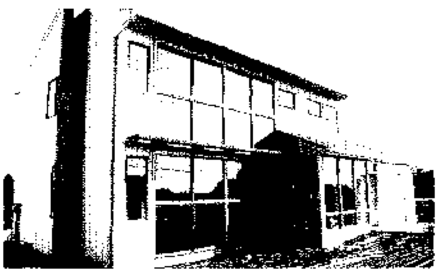
Data collection at the 10 homes concluded early this year. Detailed evaluation of the results is still under way, but some significant conclusions have become evident. For instance, where studies of the solar hot water heating systems in both Albuquerque and Long Island used storage tanks for load leveling, it was found that the tanks' thermal losses were a dominant economic factor when storage was used for load management. This was true whether solar energy or off-peak power was being stored. Single-tank water heaters showed lower standby losses for the same volume than double-tank designs because of the reduced surface area in single-tank heaters. These tests seem to indicate that the effects of conversion, standby, and system losses more than offset the gains from off-peak price differentials. Conversion and storage of solar energy for later use does not currently seem economical when compared with available alternatives.

Other results confirmed that careful system sizing is important. Frequently, when space heating and domestic hot water systems were combined in these experiments, the hot water load tended to use up most of the solar energy, leaving little for space heating. So unless a SHAC system user is willing to carefully manage hot water consumption, more generous sizing or independent hot water and space heating systems might be desirable.

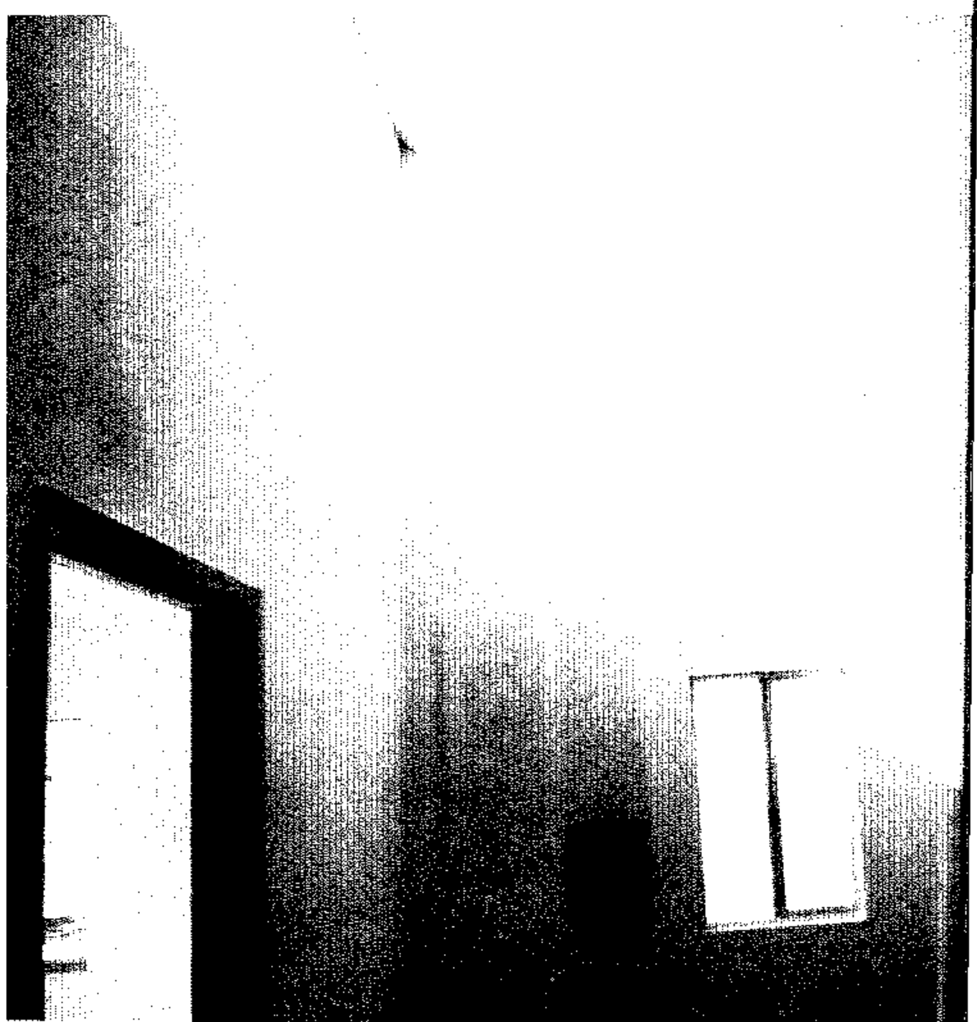
Other interesting results were that SHAC systems equipped with air collectors amassed more thermal energy than systems equipped with liquid collectors of equivalent size. Liquid thermal storage tanks were more efficient at storing energy than rock-bed storage systems. And underground tanks had heat losses virtually identical to those of aboveground tanks. A final report on the project, due early next year, will contain detailed performance comparisons.

EPRI's project on residential SHAC was followed in 1980 by a complementary project on commercial SHAC. The decision to investigate commercial uses of SHAC was made because the economics of commercial solar applications are different from those of residential applications. For example, commercial buildings usually have more lights, appliances, and occupants than residential buildings, and they are occupied at different hours.

ADL is monitoring active SHAC installations at five commercial buildings: a Connecticut delicatessen, an Indiana



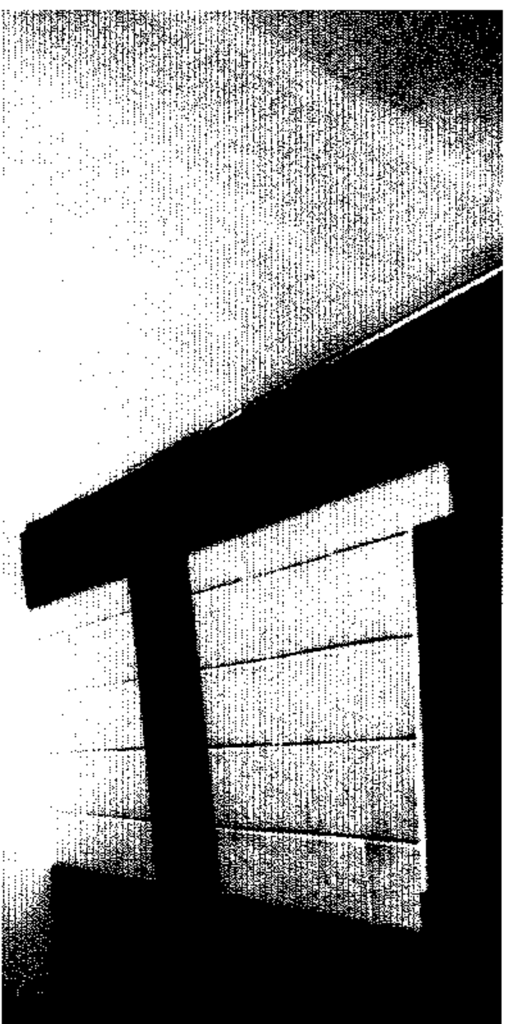
Passive SHAC systems use building design to trap the sun's energy. South-facing windows, double-glazed windows, skylights, movable insulation, and thermal mass are the basic components.



credit union office, an Alabama office building, a Michigan pipefitters' training center, and a Florida utility's service center. Data collection at the five commercial installations began in 1980 and will continue into 1982; EPRI anticipates published results in mid-1982. Early results from these projects are showing the importance of proper control strategies in load leveling. Appropriate strategies can change the electric load shape presented by a commercial building with SHAC from a detrimental utility impact to a shape that actually improves a utility's load factor.

Passive potential

While active SHAC was being investigated, a different type of SHAC—passive—was also getting increased attention. Passive solar heating and cooling is in large part just sound energy-conserving building design. South-facing windows, double-glazed windows, skylights, movable insulation, and thermal mass (a slab floor or special internal concrete or water walls, for example) are incorporated into passive solar buildings to collect, transfer, store, and distribute solar energy for heating. The building can be similarly designed to keep the house cool—for example, by using night air to cool a thermal mass or water tank and recirculating the coolness during daytime.



Passive SHAC has several potential economic advantages that active SHAC lacks. Windows and walls will be required anyway, and careful design may be able to arrange them so that passive SHAC's first cost may not be much more than that of the basic construction. Passive solar uses common building materials and construction techniques, and as there are no complex mechanisms to break down, reliability is enhanced.

Passive solar systems are by no means ideal. For example, passive SHAC is most likely to be used on new housing, and new housing starts have been depressed for some time. Many passive systems have limited potential in the retrofit market. Passive systems are also more difficult to control than active systems: when a massive wall is inadvertently allowed to heat up, for example, it may not cool down for hours. Controls at this time are relatively primitive: the occupant of a passive house must actively adjust blinds, louvers, or shades to control heat transfer. Designers are now developing systems that can control temperatures automatically rather than manually.

Passive SHAC's future technology, economics, and impact are still unclear at this point. As with active solar, passive solar demonstrations and studies are now being conducted by a number of private individuals, utilities, DOE, and other agencies. To complement these activities, EPRI has chosen a research approach of data collection and analysis similar to the one it used to investigate active solar systems. EPRI's major project in this area is an assessment of passive solar's impact.

In the project's first phase, begun one year ago, JBF Scientific Corp. developed a methodology to help utilities identify the preferred passive solar designs for their particular areas and evaluate the impact of those designs on the buildings' electric loads and thus on utilities. As with EPRI's analysis of active solar, these evaluations take into account both the cost of the installed passive SHAC system and the cost of the backup energy the utility must provide. In the second phase this modified EMPSS methodology is being used to analyze the performance of passive solar home designs at seven utilities across the country. The modified program will be available early next year to assist utilities in predicting the effects of passive solar in their service areas.

Solar in perspective

The bustle of SHAC activity over the past decade marks a new era. It signifies a nation willing to save energy, a nation willing to try new engineering approaches. Some approaches are more promising than others, such as the increased use of insulation and the solar swimming pool heaters that replaced costly natural gas heaters in California. Other approaches, such as solar domestic hot water heating and space heating, are viable options in certain areas under specific economic conditions. And some approaches, such as solar cooling, remain beyond commercial application for thermodynamic reasons. The nation uses about 25% of its energy for comfort conditioning. Implementation of SHAC and conservation practices could decrease this by as much as 10%. This reduction is the grass-roots beginning of a national movement toward conservation and the beginning of a renewables era.

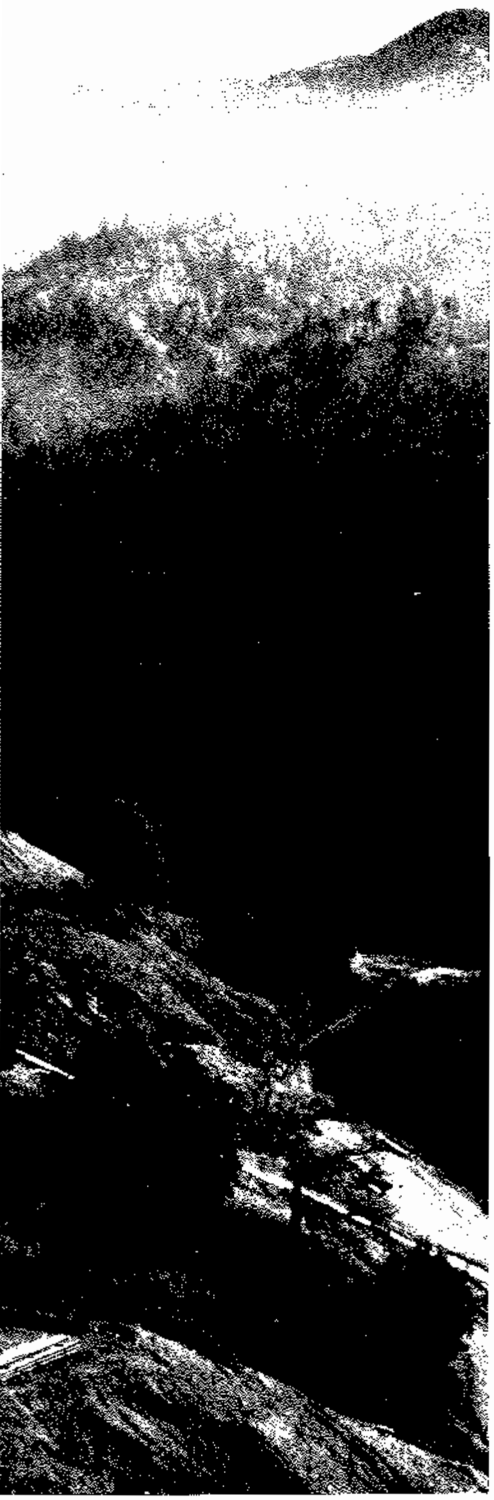
Further reading

Electric Utility Solar Energy Activities: 1980 Survey. Special report, December 1980. AP-1713-SR.

Mazria, Edward. *The Passive Solar Energy Book.* Emmaus, Penn.: Rodale Press, 1979.

Solar Energy. Palo Alto, Calif.: EPRI, February 1981.

This article was written by Nadine Lihach, feature writer. Technical information was provided by Gary Purcell, Energy Management and Utilization Division.



Geothermal: New Potential Underground

The Geysers, 910 MW of natural steam power in northern California, is the culmination of geothermal development in this country over the past 20 years. But that image is changing as the scarcity of steam resources is leading researchers to investigate the much more widely dispersed hot water resources that lie beneath the earth's crust. Geothermal energy is now on the threshold of rapid expansion and several technologies for using hot water resources are to be demonstrated over the next five years. Successful testing could lead to more than 16 GW of installed geothermal capacity by the year 2000.

Over thousands of years, volcanos, lava flows, hot springs, and geysers have been seen as picturesque and awe-inspiring manifestations of the vast heat store that lies beneath the earth's crust. Therapeutic uses of this naturally occurring heat can be traced to pre-Roman times, and limited electricity generation using natural steam was first successfully demonstrated at Lardarello, Italy, in 1904. It was not until fairly recently, however, that people considered capturing this natural heat from the earth—this geothermal energy—for use in space and process heating and in electricity generation on a large scale. Serious consideration of geothermal energy as an important renewable resource started in the 1950s and accelerated in the 1960s with the development of new theories about the nature of the earth's crust and the causes of such phenomena as faulting and volcanic activity.

As with many other renewable energy sources, much of the recent attention given geothermal is a result of the rise in fossil fuel prices over the past 10 years. Today, however, rapid advances in technology and new evidence pointing to substantial new geothermal resources—far more widespread than was once thought—have added impetus to geothermal energy development, both in the United States and abroad. During the past year total world geothermal generating capacity increased from 2.1 GW to 2.5 GW, continuing an established growth rate of about 18% a year. In the United States work by the U.S. Geological Survey indicates that recoverable geothermal resources may underlie most states.

There are three basic types of geothermal energy: hydrothermal, geopressured, and petrothermal. In a hydrothermal system, water becomes heated or is vaporized into steam by contact with hot rock. In geopressured systems, water heated in a similar way occupies an underground reservoir deep within deposits of sand and shale. This hot water is sealed off from the surface by impermeable shale layers, and is subjected to pressure from the overlying rock formations. In addition, the pressurized water is saturated with natural gas thought to have been produced by the decomposition of organic matter. In petrothermal systems, magma lying relatively close to the earth's surface heats overlying rocks to a high temperature. Water or some other fluid could someday be injected into such geologic formations and pumped out again, extracting the thermal energy.

Some2400 quadrillion (2.4×10^{18}) Btu of geothermal resources have been identified in this country. In comparison, U.S. energy consumption last year totaled less than 80 quadrillion Btu. Though only part of this energy store is usable for electricity generation, recent work indicates that more than 220 quadrillion Btu of known resources could be used for that purpose. That translates into a generating capacity of about 24 GW over 30 years in the United States alone. This is equivalent to 14 billion barrels of oil.

Recognizing the potential in geothermal resources, electric utilities, resource companies, DOE, and organizations like EPRI are pushing for a rapid expansion of geothermal energy as an electricity source. U.S. geothermal generating capacity is expected to double from its current level of about 930 MW over the next 5–10 years. If current growth rates continue, as much as 16 GW of electric generating capacity could be operating by the year 2000, mostly in the western states.

Most of the current U.S. capacity, some 910 MW, is in a sprawling power plant in northern California, The Geysers. Operated by Pacific Gas and Electric Co., the plant first began producing electricity in 1960 from an 11-MW unit. Since then, 14 units have been added, raising the plant's capacity to 910 MW. By the year 1990 PG&E plans to have 2000 MW of capacity installed.

The Geysers plant produces electricity by channeling naturally occurring dry steam through turbine generators. The steam forms when rainwater seeps down into rock that has been heated by geologic activity, such as volcanism. Wells tap the steam and send it directly into the turbine, making these systems the easiest and most economical to operate.

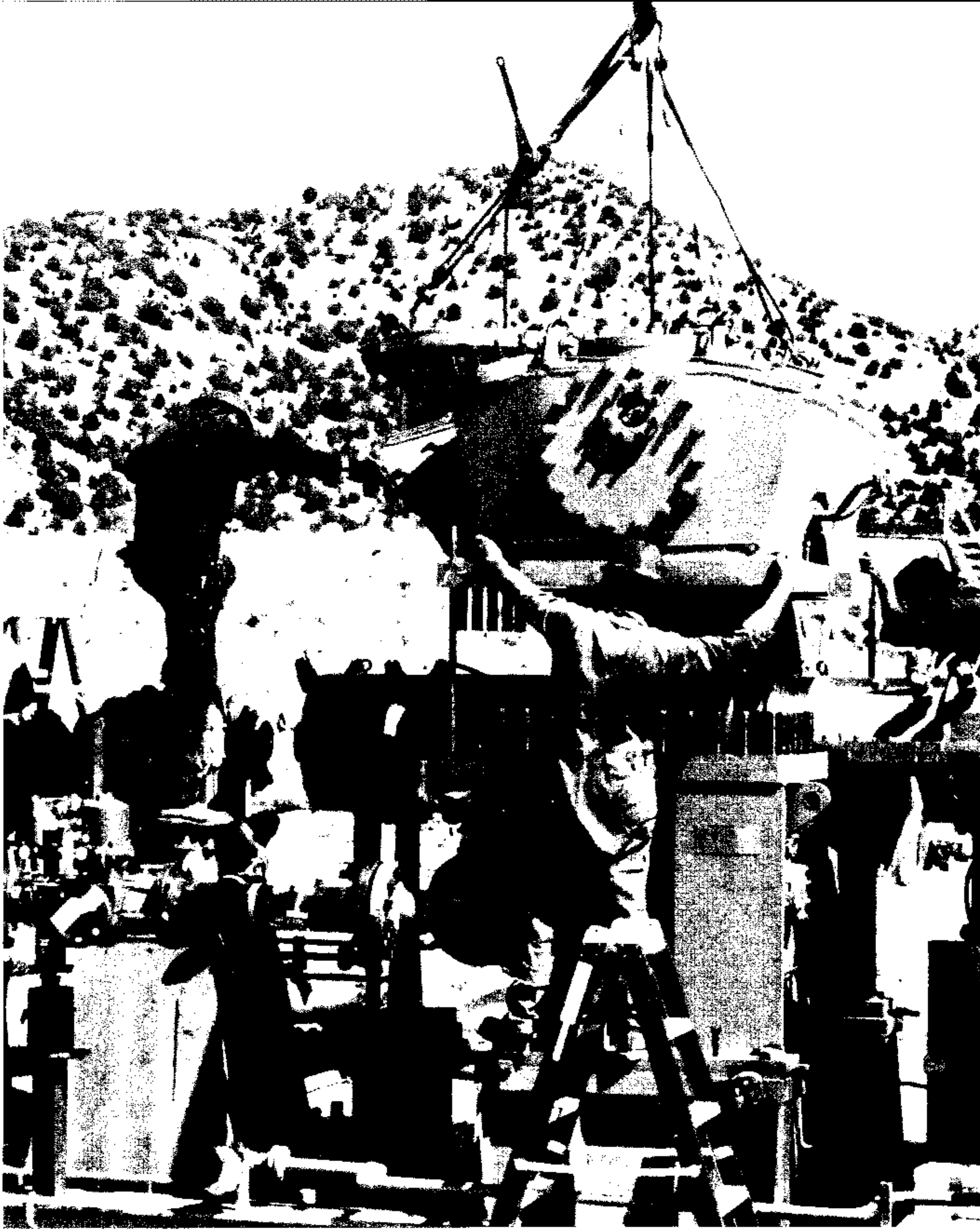
"The Geysers is an amazing resource," says Vasel Roberts, manager of the Geothermal Power Systems Program at EPRI. "Our figures show that there is at least enough steam to produce 2000 MW there for 30 years and perhaps longer. In addition, since most of the heat is in the rock formation, not in the steam, it may be possible to prolong reservoir life and expand capacity by water injection."

A new focus

Unfortunately, dry steam is a rare commodity, accounting for only 0.5% of the U.S. geothermal resource base. Far more common is another hydrothermal resource—hot water. Until recently, hot water received relatively little attention as a potential electricity source, but this form of geothermal energy has now become the focus of geothermal development and much of the geothermal research in the United States. In the past year the first two U.S. facilities to generate electricity with hot water came online. Their combined capacity is only 20 MW, but it has been estimated that by the year 2000, more than 85% of geothermal-derived electricity will come from hot water resources.

The reason is simple, as Roberts explains. "Our present knowledge suggests that if geothermal is going to grow beyond The Geysers in the near term, it must be done with hydrothermal resources. These offer the best potential because we know more about how to recover the energy and use it than about geopressured or petrothermal systems."

For high-temperature (above 210°C) water, direct-flash technology has been employed widely in Japan, New Zealand, Italy, Mexico, and elsewhere. Basically, hot water is drawn from the reservoir and its pressure is dropped, causing some of the water to vaporize (flash boil) to steam. This steam is then run through a turbine the same way natural steam is used at The Geysers.



The 1.6-MW prototype rotary separator–turbine now being tested in Roosevelt Hot Springs, Utah, is expected to increase resource utilization efficiency 15–20% by capturing energy at the wellhead from both the hot water and the steam found in geothermal fluid.

In this country the first pilot plant using a direct-flash steam cycle recently began operation at Brawley, California. The 10-MW unit is operated by Southern California Edison Co. and Union Oil Co. of California. Successful testing at Brawley, plus positive data from other nations, is expected to lead to a rapid growth in direct-flash steam-cycle plants. Several plants, each with a capacity of 20–50 MW, are currently planned, including units in California, Nevada, New Mexico, and Utah.

An improvement in direct-flash technology is being developed to reduce the cost of power from high-temperature hot water resources. The idea is to use energy that would otherwise be lost when flashing the hydrothermal fluid, thereby increasing resource utilization. To accomplish this, a device known as a rotary separator–turbine (RST) has been designed and tested under an EPRI contract.

With an RST coupled to a steam turbine, the system works in this manner. Some flashing occurs in the geothermal well, so the fluid arrives at the wellhead as a two-phase mixture of steam and water. The mixture is then expanded through a nozzle to produce more steam and impart kinetic energy to the water. At this point, the water is captured in a rotating drum where it is separated from the steam by centrifugal acceleration. The steam is drawn off and sent through a normal steam turbine, while the water is sent through a special liquid turbine, which converts its kinetic energy to electricity. The water is then reinjected into the formation. In tests at Roosevelt Hot Springs, Utah, an experimental 20-kW RST unit achieved resource-utilization efficiency that was 15–20% higher than that of single-stage, direct-flash systems, according to Roberts. Testing of a larger prototype is under way, and if the results are favorable, RST units could be commercially available in 1986.

A high priority at EPRI and elsewhere is development of moderate-temperature (150–210°C) hydrothermal resources. "We looked at the thermal quality of our hydrothermal resource base and found that about 50% of the energy is in moderate-temperature resources," Roberts explains. "We felt that the direct-flash technology, which has been used extensively around the world, would be adequate to develop high-temperature, low-salinity resources at competitive prices. So our objective now is to accelerate the development of the moderate-temperature resources."

This effort has concentrated on the binary cycle, a process in which hot geothermal fluid is used to vaporize a secondary fluid that boils at a lower temperature. The process is now being tested on small-scale plants at East Mesa, California, and Raft River, Idaho. The first full-scale demonstration of the binary-cycle concept will be a 45-MW plant at Heber, California, in the Imperial Valley just south of El Centro. That facility, currently being designed, should begin operation in late 1984.

In the binary-cycle system, hot geothermal fluid in a closed loop is brought into close proximity to a second loop carrying the working fluid, likely to be a hydrocarbon with a low boiling point, such as isobutane or isopentane. The heat from the water is transferred to the working fluid through a heat exchanger, and the hydrocarbon boils as a result. That vapor is then sent through a turbine to generate electricity.

For several reasons, EPRI's staff believes this system will be the most efficient, most reliable way to generate power from moderate-temperature resources. First, for a typical resource in this category, a binary system would require only two-thirds the geothermal fluid a direct-flash system needs to generate the same amount of electricity. Although this advantage varies with resource temperature, it is substantial, translating into lower power cost and helping to conserve the resource. Second, the binary cycle can be operated as a closed system, unlike the direct-flash and natural steam systems. This way, after use, all the geothermal fluid can be redeposited into the formation, where it can again come in contact with hot rock and be reheated and reused. This operating mode can be environmentally advantageous in many cases.

The Heber plant, which will cost an estimated $122 million to build and operate through the demonstration period, will give utilities vital information about the design, performance, operation, reliability, and economics of a commercial-size binary-cycle system. The project is being cosponsored by EPRI, DOE, San Diego Gas & Electric Co., the Imperial Irrigation District, the California Department of Water Resources, Southern California Edison Co., and the state of California.

According to Roberts, hydrothermal demonstrations are the most crucial programs to the geothermal industry. For example, at Heber, the results of the demonstration are expected to further future commercial development of binary-cycle systems by removing cost and performance uncertainties that could not be resolved through research at small experimental facilities. In fact, a successful demonstration at Heber could make the binary cycle a commercially available technology by the end of 1986.

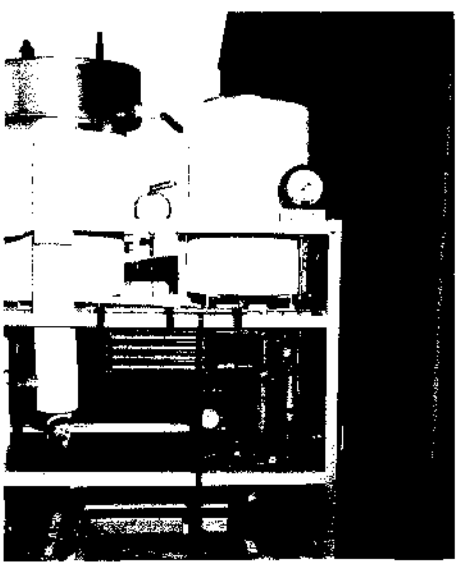
Recent developments at the national level, however, could have an impact on future work. The new national energy policy includes a deemphasis on near-term R&D, and this, coupled with the massive cuts in the federal geothermal program budget, could have long-term effects on geothermal development. Although it appears that federal funding for the Heber project will continue, should federal support be withdrawn, development of binary-cycle system technology is likely to become a very protracted process. According to Roberts, "An absence of federal support could mean that development of half of the known geothermal resources could be delayed indefinitely."

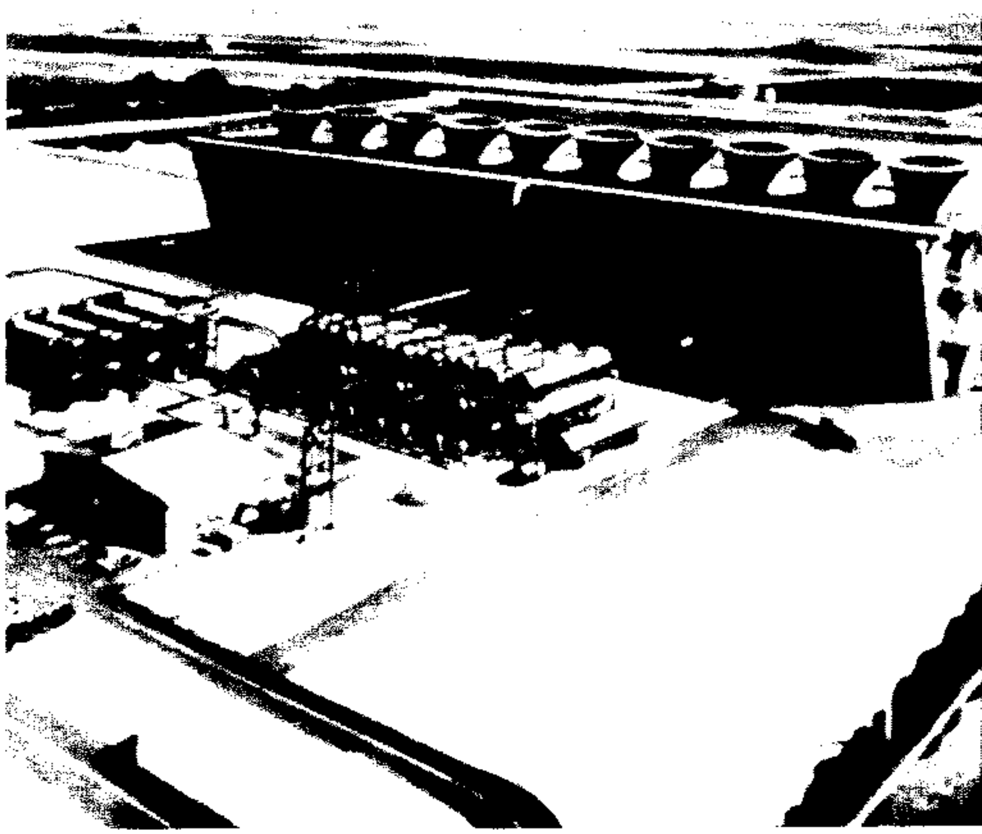
Common problems

Though plant designs for natural steam, direct-flash, and binary-cycle systems are quite different, the plants share certain problems. One of these is scaling. Most hydrothermal fluids contain some quantities of dissolved minerals, and some contain very high concentrations. As the temperature of the brine drops during well flow, flashing, or heat exchange, the minerals can precipitate out and reduce fluid flow and heat exchange.

In response to this problem, EPRI has developed a series of computer programs that will enable engineers to understand more fully the scale problems they are likely to encounter at a given geothermal site. The computer codes simulate scale formation at different points within a geothermal system by using input data on brine chemistry and operating parameters such as temperature, pressure, and fluid flow. The codes allow engineers to analyze the effects of changing certain operating characteristics of a plant, thereby allowing formulation of an optimal design.

To complement the computer codes, EPRI has sponsored a field test program that employs a mobile geothermal fluid chemistry laboratory to help upgrade the data base on the scale-forming components of different geothermal brines and on scale formation rate. In addition, a recent 30-day test by Sierra Pacific Power Co. in Nevada examined the effect of introducing a scale-inhibiting substance into the geothermal fluid to control scaling. Other utilities participating with Sierra Pacific include Portland (Oregon) General Electric Co., the Sacramento Municipal Utilities District, and the Eu-





At Brawley, California, the nation's first direct-flash pilot plant began operation last year (above left). Meanwhile, a key demonstration project that could lead to development of many moderate-temperature resources is being planned for 1984 at Heber, California. Tests at the 45-MW Heber plant are part of a project to examine the feasibility of a binary system at commercial scale.

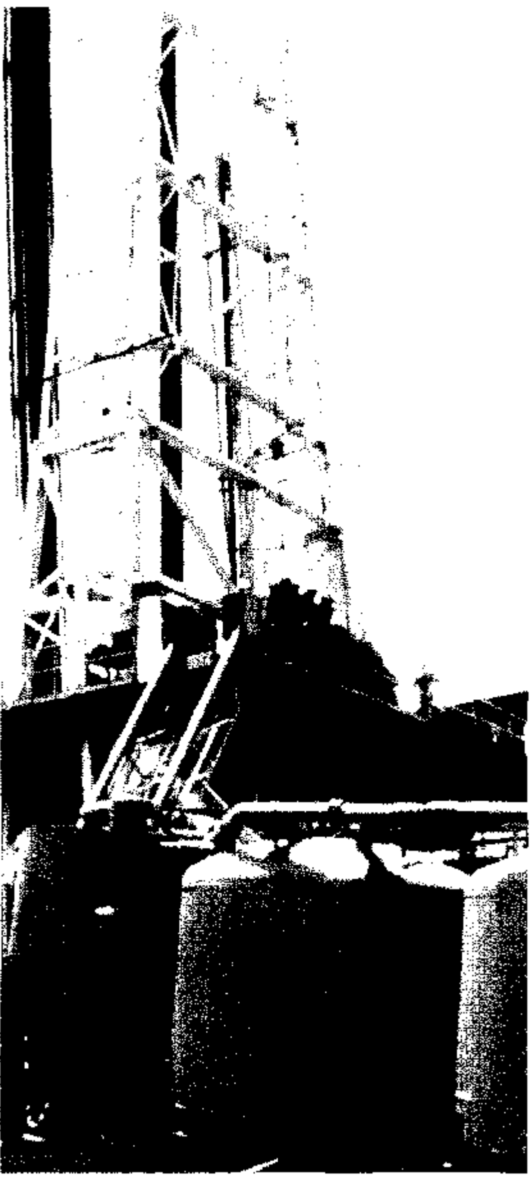
Once a major impediment to geothermal development, scale formation can now be controlled with the help of an advanced fluid sampling system developed under EPRI contract. Housed in a mobile test van, the sampling system can be easily transported to a geothermal well site to analyze the geothermal fluid there. These data, used in conjunction with EPRI-developed computer codes, can help engineers optimize the geothermal system design for the fluid chemistry in their area.

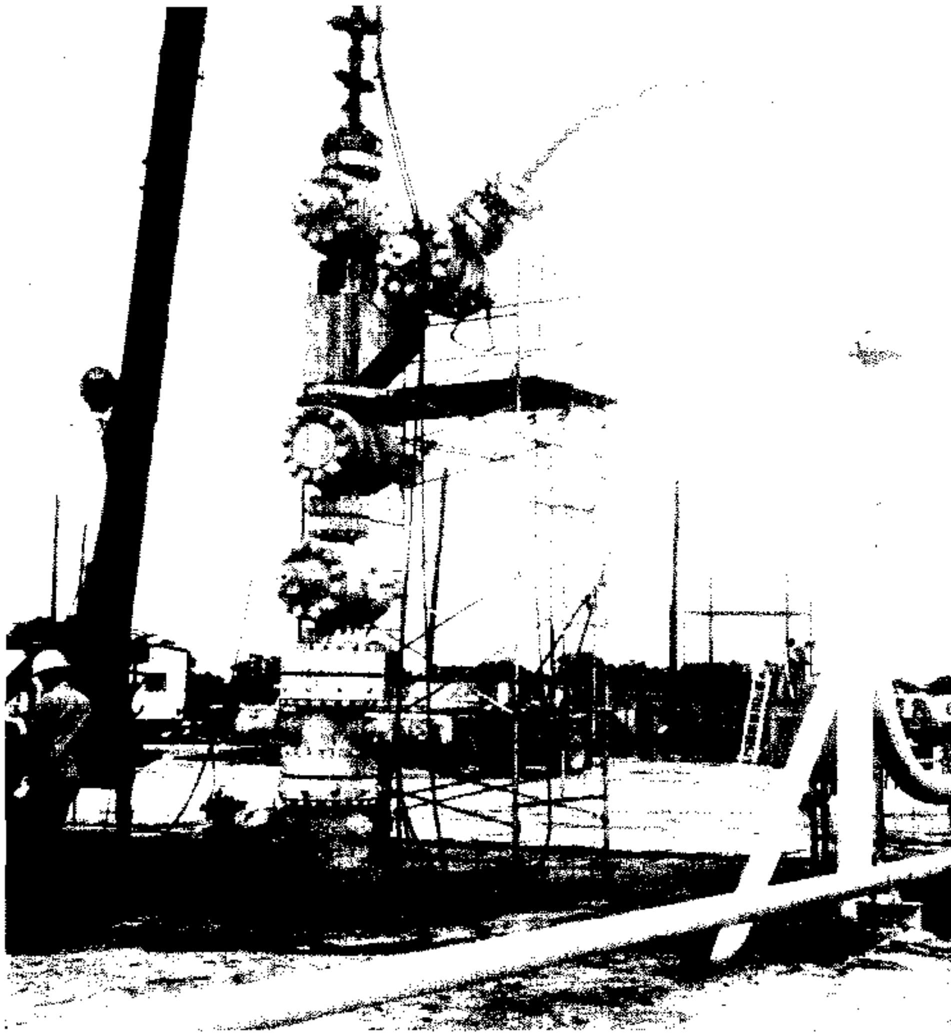
gene (Oregon) Water & Electric Board.

These developments show that the problem of scale formation is yielding to research efforts. "Scale is still a difficult problem, and we have a lot of work to do before we can control it," comments Roberts, "but significant progress has been made. Not long ago, some of the high-salinity brines were written off as unmanageable, even though some were high-temperature fluids. Now these fields are being seriously considered for electricity generation."

Another problem that research is solving involves noncondensable gases found dissolved in many hydrothermal fluids. Because these gases can reduce thermal efficiency, accelerate equipment wear, and cause environmental concerns, removing them has been an EPRI research objective for the past several years. Hydrogen sulfide (H_2S), a noncondensable toxic, noxious gas, is a particular problem at The Geysers, where it is found in the primary steam at concentrations of around 200 ppm. At one time H_2S was a serious impediment to resource development at The Geysers; and even now, although the gas can be controlled to meet environmental standards, the process is not without some negative operational side effects. So it is there that EPRI teamed up with PG&E to test an advanced H_2S abatement system to remove the gas without seriously impairing plant efficiency.

The approach, tested by EPRI contractors on a small scale, has proved technically feasible. In this system, steam from the reservoir is condensed in a vessel, while the H_2S and other undesired gases (which do not condense at the operating





At Pleasant Bayou, Texas, scientists are using this test well (above) to ascertain if the hot water and dissolved methane found in geopressured systems can be used in combination to generate electricity economically. Use of petrothermal resources is a longer-term issue, but an important one, as dry hot rock represents some 85% of the nation's geothermal resource base. Drill rigs like this are being used to create test wells that will provide information on the mechanics and thermodynamics of petrothermal systems.

temperatures used) are removed. The water is then revaporized by heat from incoming steam and sent into the turbine. The unique advantages of this concept are that it is simple and economical to operate, and it removes the noncondensables before the fluid reaches the turbine. The system appears to be efficient, with a net power loss of only a few percent. It removed most of the noncondensable gases, including an average 94% of the H_2S during experiments run at a 1000-lb/h (12.6-kg/s) steam flow.

Plans now are to scale the system up to a 2.5-MW pilot unit that handles 40,000 lb/h (504 kg/s) of steam. The construction of that unit will be complete in 1983. If test results are successful, a further scale-up to commercial size will probably occur.

Energy in solution

In some cases, gases combined with geothermal brines could be sources of additional energy. Such is the case in geopressured systems where methane is found dissolved in the water. In most geopressured wells, the water is not hot enough to justify the cost of drilling a well for the thermal energy alone. Studies have been under way, however, to examine the economic feasibility of generating electricity by combining a combustion system that burns the methane with a binary-cycle system to capture the geothermal heat.

Work to determine the extent and quality of geopressured resources is still in the preliminary stages, involving both studies and the drilling of test wells. Although results of these tests were not as encouraging as had been hoped, a recent examination by Southwest Research Institute for EPRI indicates the energy potential from 20 prospective geopressured sites along the Texas and Louisiana Gulf Coast could total 5.3 GW over 30 years. The study estimates that 1.1 GW of capacity could be on-line within the next 20 years.

Currently, DOE is continuing to fund a program to more fully evaluate the resource potential from geopressured systems, and although no specific plans have yet been made, Roberts believes a pilot plant to test resource recovery will be built in this decade. The future development of geopressured systems is more a question of economic viability than of technologic capability. "Industry knows how to drill the wells; and hydrothermal technology can be adapted to generate electricity if the energy in geopressured resources is sufficiently concentrated," Roberts explains.

This cannot be said of the largely unexplored petrothermal resources, which account for some 85% of the geothermal resource base in the United States. But development of extraction technology is continuing with the support of about $14 million annually from DOE, Japan, and West Germany. At a site near Los Alamos, New Mexico, two sets of test wells have been drilled, and significant progress on the technical issues connected with petrothermal resources has been made. Current experiments involve drilling pairs of wells into beds of dry hot rock. Water injected into the wells causes the rock between them to fracture, creating an underground heat exchanger. The idea is to inject water into one well, let it flow through the hot rock bed, and then extract thermal energy in the form of heated water from the second well.

Even after the technical feasibility of the concept is established, however, significant economic obstacles could remain. These wells must be drilled in hard rock and may need to be deeper than conventional wells, making them considerably more expensive than the relatively shallow wells required to extract hydrothermal resources. In addition, two wells are required for the process, instead of the normal single hole. Because of these factors, petrothermal resource exploitation could be prohibitively expensive unless the rock underground is very hot; far more study of the mechanical and thermodynamic properties of these systems will be necessary before development of dry hot rock beds will be practical.

For now, most of the available R&D resources are being channeled into research on the better-understood geothermal systems. How much money will be available, of course, depends on the outcome of federal budget debates, but it is likely that all the federal energy R&D programs will be affected.

In the area of hydrothermal technology especially, federal cutbacks will have a long-term effect because developers will have to use the limited existing technology for a longer period of time. This could mean the industry will have to concentrate on the highest-quality geothermal resources, which represent only about 25% of the known hydrothermal resource base.

In the present business climate, industry is not expected to expand its R&D efforts to include those areas dropped by the federal government. But some work will continue along a mainstream path that leads directly to more electric power. The incentives to do so are strong, especially with the 24 GW of hydrothermal resources already identified in this country. Geothermal reservoirs are renewable, and the availability of the plants already on-line has exceeded 80% in most cases. These facts, coupled with the need for indigenous sources of energy, are making geothermally generated electricity a more attractive alternative every day.

Further reading

U.S. Department of Energy. *Sourcebook on the Production of Electricity From Geothermal Energy.* DOE/RA/4051-1. Washington, D.C.: Government Printing Office, 1980.

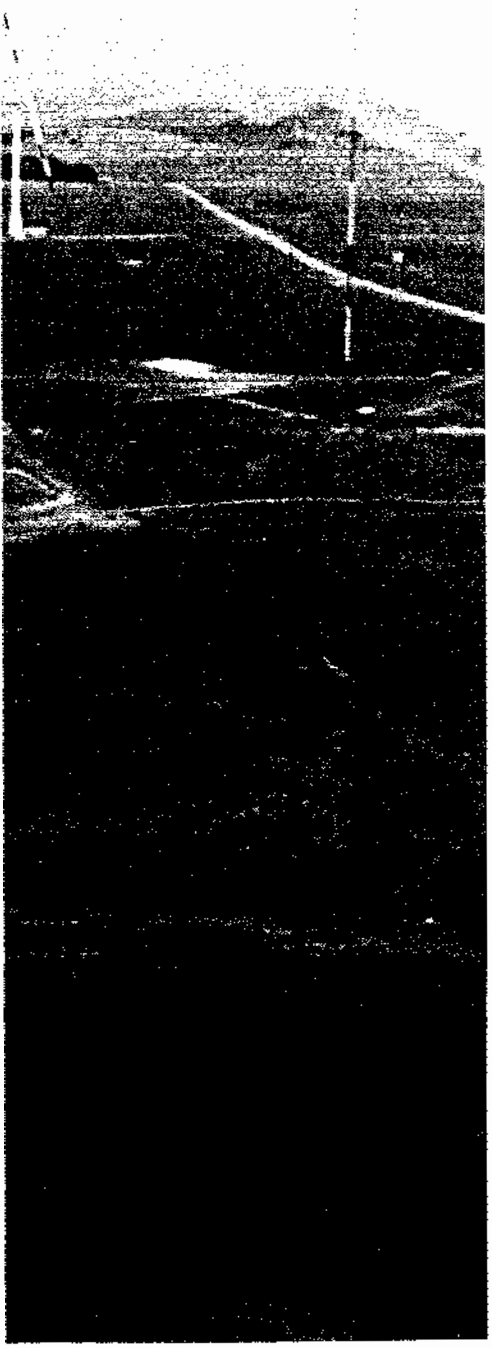
U.S. Department of the Interior. *Assessment of Geothermal Resources of the United States—1978.* Arlington, Va.: U.S. Geological Survey, 1979. Circ. 790.

"Expanding Geothermal Horizons." *EPRI Journal*, Vol. 5, No. 4 (May 1980), pp. 6–15.

Vasel Roberts. "New Career Paths in Engineering—Geothermal Energy." *Mechanical Engineering*, November 1977, pp. 50–54.

Proceedings of the Fifth Annual Geothermal Conference and Workshop. Prepared by Atlas Corp., November 1981 AP-2098.

This article was written by Michael Charlson, communications specialist. Technical background information was provided by Vasel Roberts, Advanced Power Systems Division.



Wind: Prototypes on the Landscape

Wind machines of the future are evolving through a carefully engineered program of wind turbine design. DOE–NASA's second-generation machines (MOD-2) are now up and gathering performance data on the grasslands of southcentral Washington, and third-generation designs—intended to lower costs and improve performance—are on the drawing boards. If research progress can be maintained at the current pace in spite of federal budget cuts, researchers should know in a few years how much of this vast but mercurial resource can be tapped for electricity generation. Clusters of mass-produced multimegawatt machines are the ultimate goal for utilities.

Large wind turbines for utility applications are rapidly emerging as one of the more promising renewable energy options. There are a number of sound reasons for the recent upsurge in wind power development activities. Wind turbine development programs are beginning to yield promising results. Wind machines may provide a way to reduce oil and gas consumption with a technology that has a relatively low cost of entry for utilities. Because wind power systems can be developed in small increments over a period of several years, the potential risk is relatively low. Moreover, wind energy is widely available throughout the world, although some regions have a much better wind resource than others, and the resource can vary within a small area.

DOE and other agencies of the federal government have been supporting a wide range of wind power R&D. The rapid advances in technology during the past few years are a triumph of the R&D process, but the job is not yet complete. Significant cost reductions and improvements in operating performance are still needed and are feasible, but the requisite advanced systems are still on the drawing boards. It is generally believed that these systems, incorporating additional advances in technology, must be designed, built, and tested to make wind power competitive in widespread applications. Because of anticipated budget cuts in the federal wind energy program, there is considerable uncertainty as to how and when needed cost and performance improvements will be demonstrated.

There is little doubt that utility participation is essential if wind is to make a significant contribution to the U.S. energy supply. Economies of scale, distances between good wind sites and population centers, space requirements, and maintenance demands make utilities the logical primary market, and probably the only significant market for large wind turbines.

Wind power's potential value is essentially in the displacement of fuel consumption rather than in the displacement of planned generating capacity. Fuel displacement means the saving of a specific type of fuel, such as oil, coal, or nuclear, by substitution of another energy source—in this case, wind. Under normal operating circumstances, a utility would preserve its most expensive fuels, typically oil or gas, during windy periods; practical limitations on generating unit cycling rates usually make it uneconomical to back off large baseload generating plants, such as coal and nuclear, for intermittent periods of wind availability. Thus, utilities that have a high dependence on oil and gas and are situated in or near windy areas appear to be promising markets for large wind turbines.

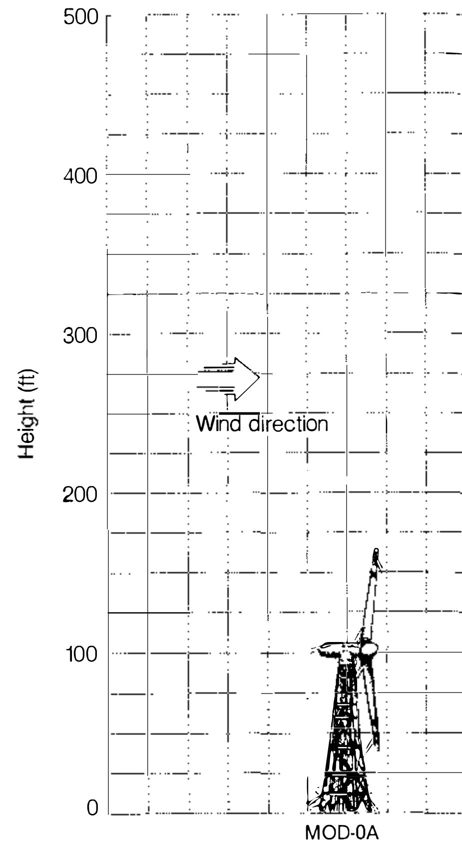
As wind is intermittent, few or no credits for capacity displacement are likely to be realized from wind power in most applications. However, if wind turbines become inexpensive enough, they may be economically attractive for their fuel displacement value alone.

Technology development

Currently, the most advanced technology being developed by major industrial sources for harnessing wind power is the large, horizontal-axis wind turbine with propeller-type rotor blades. With horizontal machines, the axis of rotation is parallel to the ground; large machines are nominally considered to be those with rated power outputs over 100 kW. The National Aeronautics and Space Administration (NASA) is the manager of horizontal-axis system development and field test programs for DOE and the U.S. Bureau of Reclamation.

The first generation of these machines included the 100-kW MOD-0 machine that was first tested in September 1975 at NASA's Plumbrook station near Sandusky, Ohio; four 200-kW MOD-0A machines (Clayton, New Mexico; Culebra Island, Puerto Rico; Block Island, Rhode Island; and Oahu, Hawaii); and one 2-MW MOD-1 machine in Boone, North Carolina.

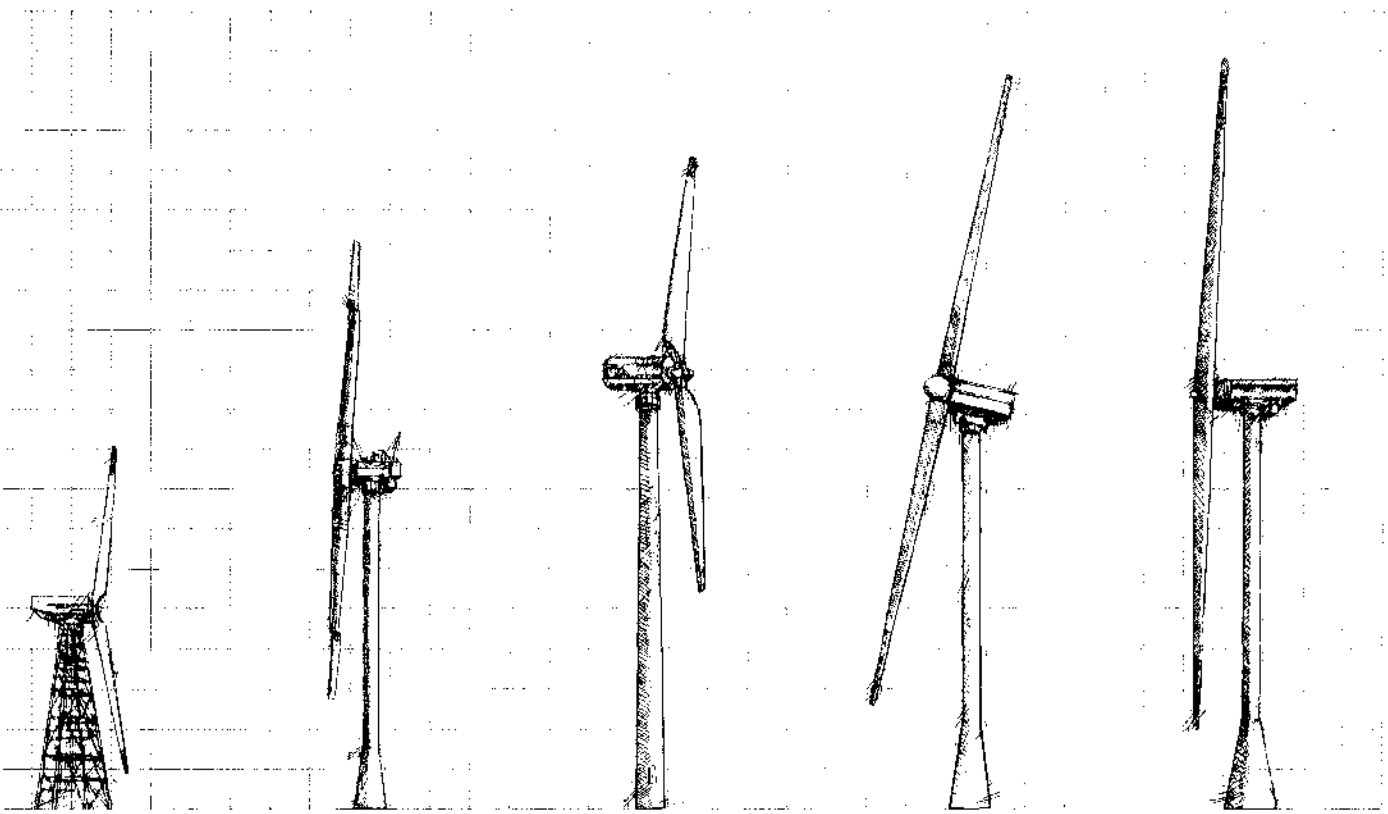
The MOD-0A sited in Hawaii incor-



	First Generation
Height of blade axis (ft)	100
Rotor diameter (ft)	125
Rated power (kW)	200
Rated wind speed at 30 ft (mph)	18.3
Cut-in/Cut out speed at 30 ft (mph)	6.9/34.2
Weight on foundation (tons)	45
Weight/Rated power (lb/kW)	447
Annual electric output at 12 mph (GWh)*	0.64
Annual electric output at 16 mph (GWh)*	0.98
Prime contractor	Westinghouse Electric C
Location (year of first rotation)	Clayton, New Mexico (1977); Culebra Island, Puerto Rico (1978); Bloc Island, Rhode Island (19 Oahu, Hawaii (1980)

*Assumptions: 90% machine availability; wind speed averaged at 30

LARGE HORIZONTAL-AXIS WIND TURBINES



MOD-1	MOD-2	WTS-4	MOD-5A	MOD-5B
	Second Generation		*Third Generation*	
140	200	262	250	262
200	300	256	400	420
2000	2500	4000	6200	7200
25.5	20.0	26.4	20.4	20.5
11.0/35.0	9.0/36.0	9.7/49.7	7.0/49.3	4.3/46.3
325	310	389	600	630
325	247	194	193	175
2.4	7.0	7.0	16.7	18.9
5.1	11.3	13.0	27.1	29.9
General Electric Co.	Boeing Engineering & Construction	Hamilton Standard Div., United Technologies Corp.	General Electric Co.	Boeing Engineering & Construction
Boone, North Carolina (1979)	Goldendale, Washington (3 units: 1980, 1981, 1981) Medicine Bow, Wyoming (1981) Solano County, California (1982)	Medicine Bow, Wyoming (1982)	To be determined	To be determined

vel; Weibull wind speed distribution. The relative performance of specific designs is dependent on site wind characteristics.

porated improvements over the three earlier MOD-0As in its drive train, yaw-drive system (which keeps the turbine aligned with wind direction), and rotor construction. These improvements, together with the excellent wind resource in Hawaii, resulted in a very high rate of energy production. Between the start of operation in July 1980 and mid-November 1981, the machine has produced over 1.14 GWh of energy, and its capacity factor has been approximately 0.45. (Capacity factor is the ratio of actual energy produced over a given time period to energy that would have been produced if the unit operated at full rating over the same time period.)

These early machines were intended to be research prototypes for field experiments to verify and assess structural and aerodynamic performance and to obtain operating experience. Data gathered from these prototypes have resulted in considerable improvements in second-generation designs. Additional useful operating experience is being obtained from the early machines in ongoing test programs.

The most advanced design developed by NASA to date is the MOD-2, and it represents the second generation of large wind turbines. This machine has a two-bladed rotor situated upwind on a cylindrical tower that is 200 ft (61 m) in height. The rotor span is 300 ft (91 m), the length of a football field, and it is configured as a continuous structure with no hub. The tips of the rotor can be pitched for speed control. The machine starts to generate power in a 14-mi/h (6.3 m/s) wind (measured at the top of the tower) and achieves its rated power of 2.5 MW when wind speed reaches 27.5 mi/h (12.3 m/s). It shuts down automatically in winds over 45 mi/h (20.1 m/s) to prevent structural damage. Last May three MOD-2 machines were dedicated at Goodnoe Hills, near Goldendale, Washington.

The third-generation large wind turbine, the MOD-5, is now on the drawing boards. The goal of the MOD-5 wind turbine project is to design and fabricate advanced multimegawatt wind turbines that will reduce the cost of energy to approximately 30% below design goals for the second generation. The two MOD-5 conceptual designs have rated power outputs of 6.2 and 7.2 MW. They would be larger than the MOD-2, with blade spans of 400 and 420 ft (122 and 128 m), respectively. In addition, the MOD-5 may employ such new features as two-speed or variable-speed operation, induction generators, and the use of laminated wood rotor blades.

Concurrently, DOE is supporting other turbine designs that may offer technical and economic advantages in the future. One type, the vertical-axis (Darrieus) rotor, may eventually be cost-competitive with the horizontal-axis systems in some applications. Invented by G. J. M. Darrieus of France in the 1920s, it has egg-beater-shaped blades. Sandia Laboratories in Albuquerque is managing the development of the Darrieus design for DOE. Other more innovative, but less developed, designs are also under study by DOE.

Aided by federal and industrial support, a number of large machine developers have evolved. Among these are Aluminum Co. of America; Bendix Wind Products Co.; Boeing Engineering & Construction; General Electric Co.; Hamilton Standard Division of United Technologies Corp.; Merkham Energy Development Co.; Westinghouse Electric Corp.; and WTG Energy Systems, Inc. The widespread activity by a variety of developers is the foundation from which a competitive large wind turbine could emerge in the next several years.

Experts in the field believe that it is desirable to develop the largest feasible multimegawatt machines for most utility applications (especially for sites with large open land areas and uniform wind flow). However, some specialized situations are also expected in which unusual site topography or some other siting constraint would make submegawatt large wind turbines best suited. For example, the terrain could be so rough that it is not possible to transport and construct a multimegawatt machine. Further, in the case of some small utilities, only a relatively small amount of wind power may be required. Thus, there is justification for developing large wind turbines in both multimegawatt and submegawatt sizes. At this time it is not clear which size range of turbines will be most economical in mass-produced quantities.

A larger wind turbine rotor collects more energy by virtue of its larger blade sweep area. Also, for most terrain, winds are generally stronger at higher altitudes, and the larger machines (such as the MOD-5) are taller and therefore able to make use of the stronger winds. The larger machines have a higher power rating for each individual unit, so when a group of machines is clustered on the same site, fewer units are required to achieve the same aggregate rating than if smaller units are used. Fewer units would also simplify the cluster layout and interconnection problems and potentially reduce operating and maintenance demands.

Collectively, these facts provide the rationale for the MOD-5 program thrust. As Ronald Thomas, manager of the Wind Energy Projects Office at NASA's Lewis Research Center, puts it, "I believe these technological improvements will be readily attainable if the MOD-5 program is carried to completion. The third-generation machines would enable us to make better use of the good wind turbine sites."

"Wind has been a surprise to many people," comments Daniel Ancona, chief of DOE's Large Wind Technology Branch. "I think many saw it as a whim back in the early 1970s. But today, people have discovered that the resource is better than they thought and the hardware to harvest it has come a long way." Frank Goodman, who is responsible for managing wind power activities at EPRI, adds, "Wind power is promising, and there are reasons to be enthusiastic about it. If current R&D programs are completed and their objectives are attained, wind

The Land Use Question

Requirements for land have often been cited as a major drawback to the development of renewable resource technologies for generating electricity. It is now becoming clear that this concern may not be as critical as was once thought. Although some renewables will require more land than conventional power technologies because of the diffuse nature of their resources (wind and sunlight, for example), it is not so much the amount of land itself or even the cost of the land that is the obstacle. A more important land concern, common to several of the renewable resource technologies, is the problem of siting.

As has always been the case with hydro plants, the first consideration must be finding a location that offers an energy resource in sufficient quantity to allow its economic use. Geothermal power plants can only be built where a geothermal energy source can be tapped, as with The Geysers in California. The choice of sites for wind turbines is limited to areas with high, relatively steady winds. Direct solar conversion plants, such as solar-thermal central receiver and large-array photovoltaic power plants, will require areas with abundant sunshine, such as those found in the Southwest.

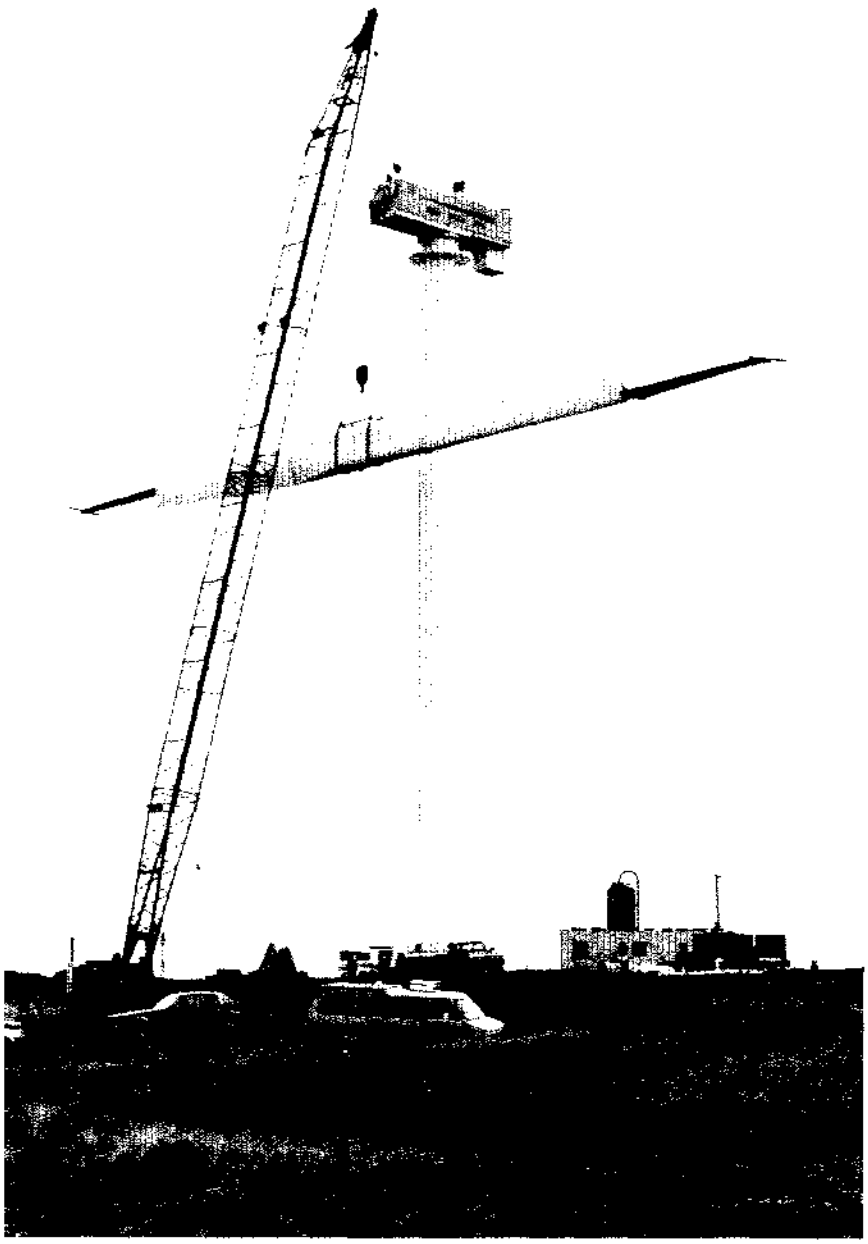
The cost of land for power plant sites is related to the land area needed, as well as to the type of terrain. Geothermal plants require roughly the same size site as a coal-fired plant of the same capacity, exclusive of the land associated with coal mining activities. A direct solar plant, on the other hand, will require about one square mile of land per 100 MW of capacity. This is comparable to the land needed for a coal plant fired with surface-mined coal, including the land from which the coal is mined. Although this represents a need for significantly more land for direct solar options than for geothermal, desirable sites are likely to be found in arid areas where the cost of land is low. (The land cost is expected to be on the order of 1% of total plant cost, which will not be an economic barrier.)

Wind turbine clusters may require four or five times as much land area as direct solar plants of similar capacity to avoid interference between adjacent wind turbines. However, because of this wide spacing between machines, only a small fraction of this land need be dedicated entirely to the wind turbines themselves; much will still be available for other purposes.

For biomass, the land use issue is of greater concern. Far more land is necessary with this technology because almost all the energy conversion is performed by vegetation through the photosynthetic process, which has a low conversion efficiency. At best, 1% of the incident solar energy eventually appears as electricity, which is about one-tenth the conversion rate for most other solar options. In addition, unlike the deserts suitable for the direct solar options, land for biomass must be of good quality to ensure productive growth of the plants and trees to be used for combustion or conversion. Such high-quality land is relatively expensive and sought after for other uses, such as for food or feed crops.

So the land question is not simply How much? Except for biomass, this is a secondary consideration. More to the point is whether sites can be identified that are optimally suited to the application of new technologies for the development of renewable resources. □

could begin making a significant contribution to our overall energy needs before the end of the century."



The most advanced wind turbine design developed by NASA to date is the 2.5-MW MOD-2. The rotor is 300 ft (91 m) long and is mounted on a 200-ft (61-m) cylindrical tower. The boxcar-shaped nacelle on the tower houses the generator and drive train. The rotor weighs approximately 90 t.

Utility involvement

The foundation for that significant contribution is already taking shape on several utility systems around the country. In addition to hosting the improved DOE–NASA MOD-0A turbine mentioned earlier, Hawaiian Electric Co., Inc., has plans to purchase energy from a private developer who hopes to install an 80-MW cluster of wind turbines on Oahu by 1985.

Southern California Edison Co. is testing several wind turbine designs at its San Gorgonio Pass site near Palm Springs, California. By the turn of the century, SCE hopes to have wind contributing up to 3% of its energy requirements.

Pacific Gas and Electric Co. has contracted to purchase a 2.5-MW MOD-2 wind turbine, modified to operate in winds up to 60 mi/h (26.8 m/s). This unit is scheduled for operation in the spring of 1982. PG&E also has entered into an agreement in principle to buy energy from a 350-MW cluster proposed for installation by a private developer. It is hoped that this cluster will be fully operational by 1989. A contract has been signed to purchase energy from another cluster development, which may have a rating as high as 30 MW. Both SCE and PG&E are negotiating with several cluster developers at this time.

The U.S. Bureau of Reclamation has purchased two second-generation machines to be evaluated at its site near Medicine Bow, Wyoming. One is a 2.5-MW MOD-2 and the other is a 4-MW WTS-4. Ultimately, the bureau hopes to install approximately 150 MW of wind machines in the Medicine Bow region.

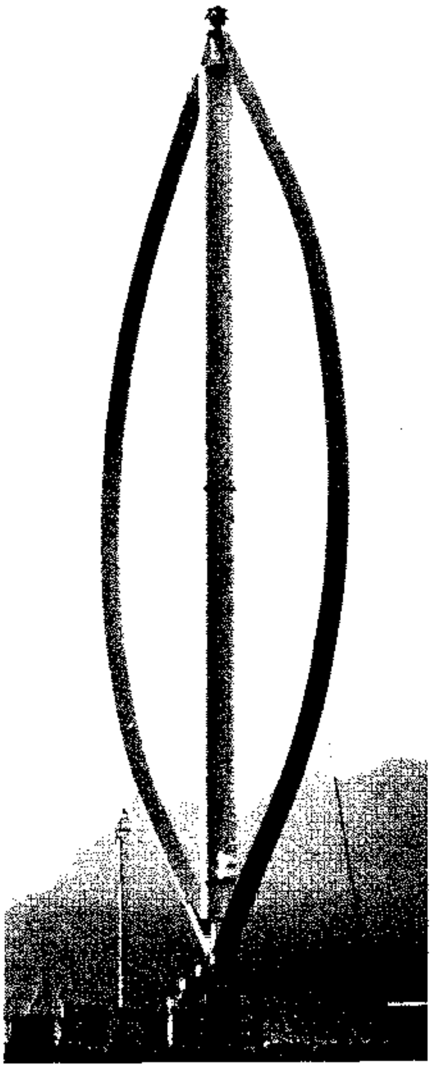
Several other utilities are involved in large wind turbine field experiments, negotiation of energy purchase agreements with independent developers of wind turbine clusters, and in some cases, both. Additionally, many utilities have begun siting work and long-range planning studies for use of wind power. This high level of activity in the utility industry has been motivated by the recognition that large wind turbines would provide an energy source with a relatively low capital risk, if the technology development is carried to maturity.

The primary objectives of EPRI's wind power activities are the transfer of technical information and the development of planning tools to help the utility industry prepare for using wind power. EPRI's efforts complement federal and private wind power research.

EPRI gathers, evaluates, and transfers data from wind turbine field tests to the utility industry on a regular basis. Three reports (AP-1317, AP-1641, and AP-1959) are available that document significant results of large wind turbine development and field tests. New reports in this series are expected semiannually.

Other EPRI projects in the wind area are directed toward developing methodology for wind turbine siting; evaluating utility experiences with wind power, including planning, siting, hardware procurement, project costs, and operation; developing market penetration estimates for wind power systems; and assessing wind turbine dynamic impacts on utility system operation. Initial results from these projects are expected to become available during 1982.

Sandia Laboratories and the Aluminum Co. of America are sponsoring development of the vertical-axis Darrieus wind machine. Invented by G. J. M. Darrieus of France in the 1920s, this machine may eventually be directly cost-competitive with horizontal-axis systems in some applications.



A NASA MOD-0A machine at Kahuku Point on Oahu has been operating routinely for more than a year, and so far, the machine has produced over 1140 MWh of energy. Long-term operating experience such as is being acquired with this machine is essential for successful future technology development.

Wind resources and turbine siting

Two important, related areas of study are wind resource assessment and wind turbine siting. Complementary DOE and EPRI programs have evolved in these areas. DOE's role in wind resource assessment is being managed by Battelle, Pacific Northwest Laboratories (PNL) in Richland, Washington. The research goals are to begin detailed documentation of wind resources and to develop techniques to predict wind speed, direction, and profile that can be used to select the best areas for siting wind turbines.

Researchers gather information from weather station reports, analyses of relief maps and surface pressure maps, observation of wind-deformed vegetation and landforms, and direct measurement. In this manner, average wind power density at various locations has been charted on a seasonal and annual basis, and graphs have been prepared showing annual, monthly, and daily variations of wind speed and power, as well as curves of frequency and duration. Under DOE sponsorship, PNL has published a 12-volume atlas giving preliminary estimates of national wind resources.

To complement the DOE-sponsored resource studies, EPRI has initiated work to develop siting methods through a contract with PNL. A systematic procedure is being developed for selecting wind turbine sites by addressing relevant siting criteria, such as the amount of available wind energy, accessibility of roads, proximity of sites to existing transmission rights-of-way, influence of terrain features, environmental impact, meteorological hazards, compatibility with legal concerns, and land availability and alternative uses.

The availability and ownership of the land at and around a potential site are significant because a large cluster of machines must be spread over a considerable area. It is important to keep in mind, however, that the land supporting wind turbine clusters can be used simultaneously for other purposes, such as grazing, farming, and recreation, to the extent that such activities can be coordinated while maintaining adequate safety.

The future for wind

During the next few years, the results from wind turbine development and test programs should establish whether wind power will have a significant impact on the electric utility industry.

"In talking about wind's potential," EPRI's Goodman stresses, "it's critical to recognize that today's machines are experimental models; accumulated performance information on these machines is needed before they are committed to mass production. The R&D process cannot be short-circuited. To get from where we are now to the point where we have widespread use of wind power will require the continuation of a well-paced program with logical, achievable milestones. It's a matter of not promising too much too soon, of not rushing the technology so fast that a serious failure occurs that gives the program a black eye."

Earlier this year, two mishaps did occur. At SCE's San Gorgonio Pass site, a 500-kW vertical-axis machine experienced a braking malfunction caused by a programming error during a simultaneous wind gust and system voltage drop, and an overspeed resulted. Detection of the overspeed caused a second application of one braking system, which wore out its brake shoes. A rotor blade eventually pulled loose at the bottom, swung outward, and hit a guy wire. The guy wire failed and the machine collapsed.

Last summer one of the three MOD-2 wind turbines at Goodnoe Hills experienced a 60% overspeed because of a control system malfunction during a test of the emergency shutdown system. This resulted in damage to the generator and drive train. The unit is being repaired and should be back in operation in early 1982. All three of the Goodnoe Hills units have been modified to protect against recurrence of this problem. "All this is part of the R&D process," says Goodman. "It's to be expected, and the fact that specific mishaps have not recurred is a success in itself."

Despite the rapid momentum that wind power development has enjoyed in recent years, there is good reason for concern that this pace may not be sustained. The federal wind energy program is faced with substantial budget cuts. These cuts come at a time when the utility industry is on the threshold of obtaining performance information from several key wind turbine experiments, including data from the three MOD-2s at Goodnoe Hills. In addition, the MOD-5 wind turbine program has just reached the point of having two conceptual designs completed. It now appears that DOE may be forced to restructure its program, shifting away from new system development and performance testing.

In view of these changing circumstances, it appears the development process, at best, will be protracted unless increased support comes from other program sponsors to maintain the momentum that had been established in the past by the federal program. The utility industry will need performance information for several alternative wind turbine designs in order to fully understand the technology's prospects. Further, advanced wind turbines, such as the MOD-5, and a competitive wind turbine industry will be needed to enable the utility industry to derive maximum future benefit from wind power.

What will be the source of the support needed to keep wind power development on track? No one has a definite answer, but there are several options and possibilities, including restoration of DOE's wind power budget, continued and/or increased R&D by the fledgling wind turbine industry, greater utility-sponsored R&D, infusion of capital from interested private investors, and programs being carried out in other countries. The answer may emerge as a combination of some or all these sources, with the various sectors interested in wind energy working cooperatively to bring the technology to maturity.

EPRI's Goodman says, "I don't believe wind is going to be the singular answer to problems of future energy supply. But I do believe it's one of a blend of technologies that could help solve the energy problems the nation faces. Large wind turbine R&D in recent years has served as an excellent example of this country's vast technological capability. The challenge before us at this time is to make increased use of this capability in developing promising renewable energy options, such as wind power." ▪

Further reading

Requirements Assessment of Wind Power Plants in Electric Utility Systems. Final report for RP740 prepared by General Electric Co. (3 vols.), January 1979. ER-978.

"Going With the Wind." *EPRI Journal,* Vol. 5, No. 2 (March 1980), pp. 6–17.

Wind Power Generation Dynamic Impacts on Electric Utility Systems. Final report for TPS79-775 prepared by Zaininger Engineering Co., November 1980. AP-1614.

Large Wind Turbine Generator Performance Assessment: Technology Status Report No. 1. Technical report for RP1348-1 prepared by Arthur D. Little, Inc., January 1980. AP-1317.

Large Wind Turbine Generator Performance Assessment: Technology Status Report No. 2. Interim report for RP1348-1 prepared by Arthur D. Little, Inc., December 1980. AP-1641.

Large Wind Turbine Generator Performance Assessment: Technology Status Report No. 3. Interim report for RP1348-1 prepared by Arthur D. Little, Inc., July 1981. AP-1959.

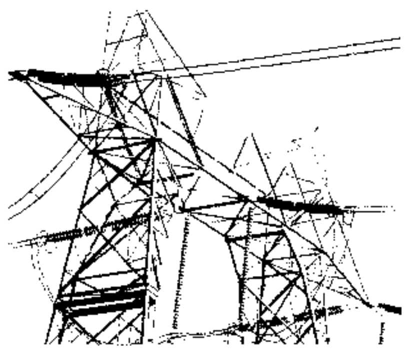
This article was written by Marcie Lynn Smith, utility communications coordinator. Technical background information was provided by F. R. Goodman, Advanced Power Systems Division.

Integrating Renewables Into Utility Networks

Technologies for generating power from renewable energy sources offer a diversity of engineering challenges, but one particular challenge is common to all: how to integrate these new technologies into existing utility systems. The conventional modes of utility power generation—coal, oil, gas, and nuclear—fit conveniently into utility systems because they can be turned on as demand requires. Conventional modes of generation also deliver the smooth, 60-Hz ac power that the nation's electricity network was designed for.

But many of the renewables (solar and wind, for example) cannot be turned on at utility convenience. As utilities contemplate the construction of wind, solar-thermal, and photovoltaic power plants, they must also consider how these intermittent energy sources will fit into existing generation schemes to the greatest advantage. To integrate power from renewables in the most economic way, engineers must know not only how much fuel energy but also how much generation capacity the renewables can be counted on to displace.

Renewables do not always displace conventional fuel or generating capacity. For example, when extra power is required at periods of peak demand, solar or wind installations—by their intermittent nature—may not be producing energy, and utilities might still

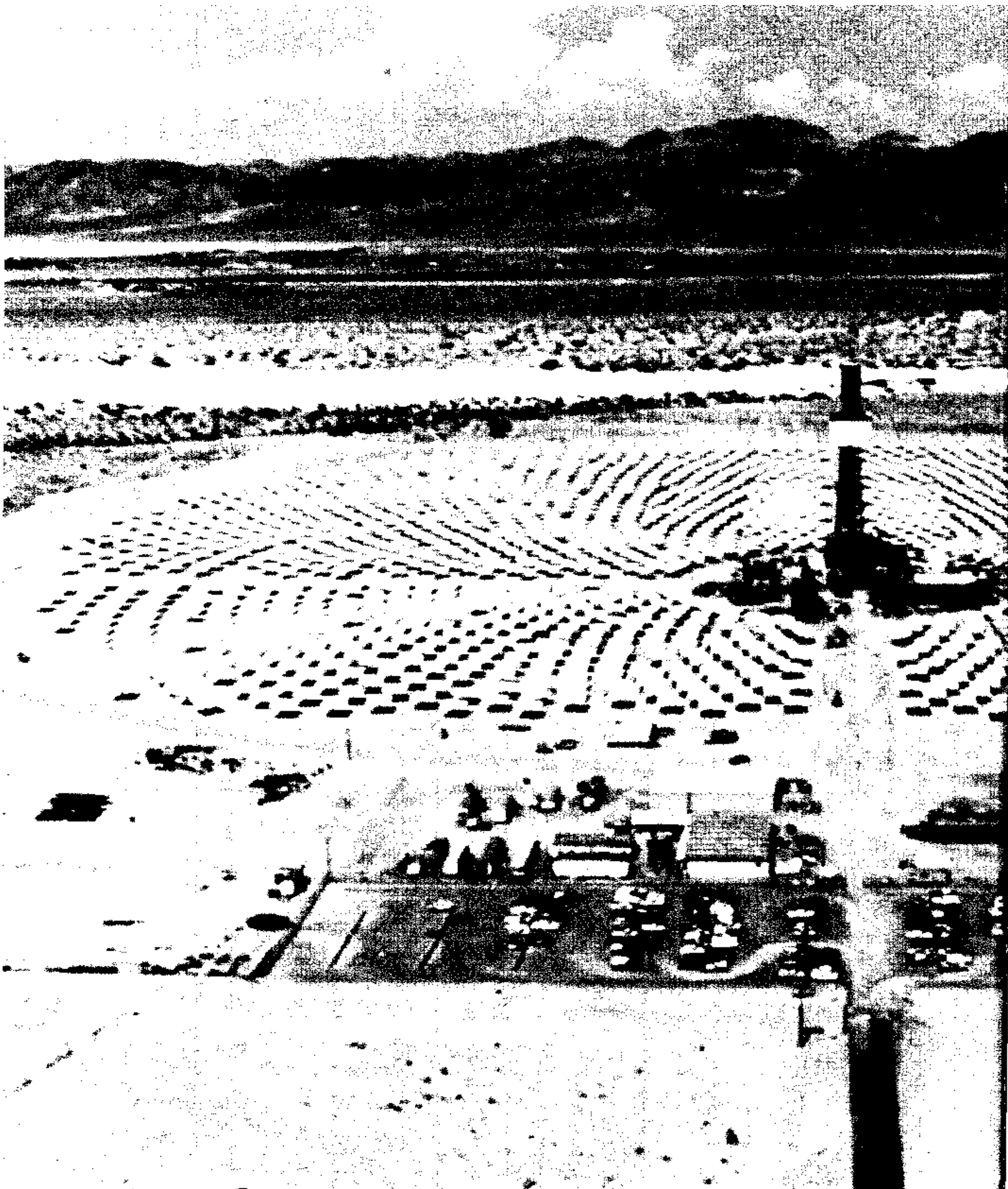


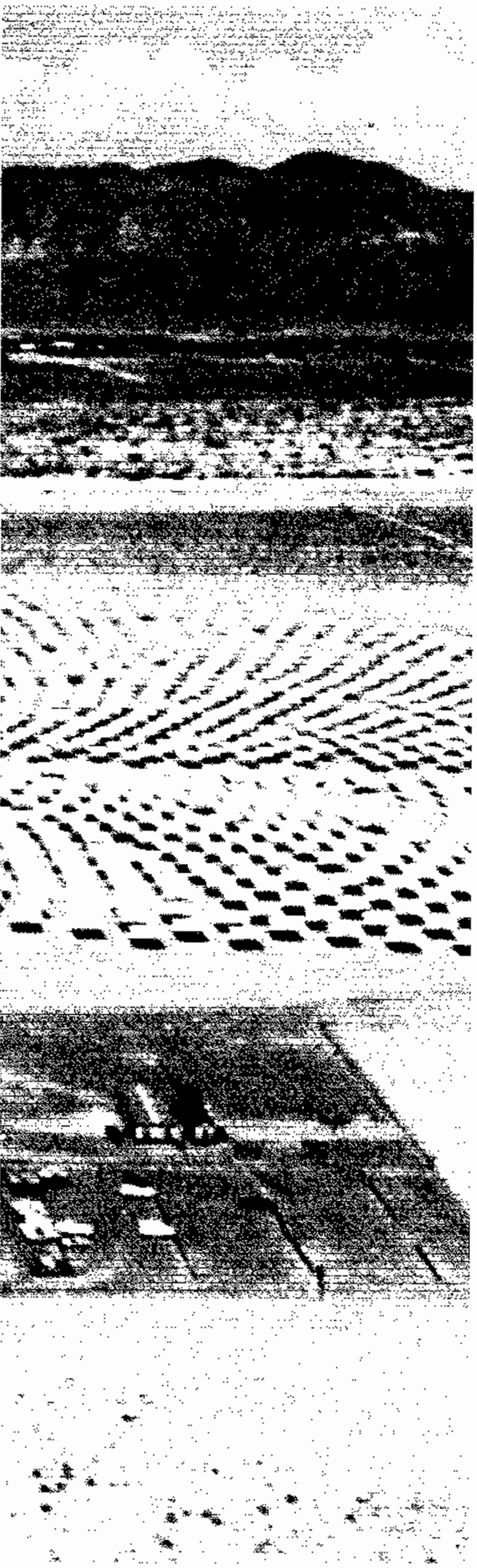
require costly oil fuel (as well as oil-fired capacity) to meet the peaks, despite renewables installations. Conversely, a solar or wind installation may produce energy at times when coal or nuclear baseload plants—a utility's most efficient power producers—are already delivering sufficient energy to meet demand. As a result, the fuel displacement value solar or wind might provide during these baseload periods might not justify the installation of solar or wind capacity.

As renewable technologies near the utility market, engineers are directing closer attention to the effect of these technologies on fuel and generation planning. For instance, EPRI's Advanced Power Systems Division has recently developed methods that utilities can use to determine the future value and role of wind, solar-thermal, and photovoltaics on their own systems. These methods use utility planning techniques currently available to the industry.

After a utility has decided that a renewable technology can be an advantageous addition to its total generation system, the new technology must be electrically integrated with the existing system. Renewables, such as solar and wind, may produce uneven bursts of dc or ac electricity rather than the 60-Hz ac power that conventional plants provide. Uncorrected surges of power from, say, a gust of strong wind might trip utility protection system components or instigate unstable network behavior. Inconstant power can cause efficiency losses and may damage utility and customer equipment. Power-conditioning systems that can tame variable electric output into regular ac form are essential to integrate new sources into utility systems. EPRI's Energy Management and Utilization Division has undertaken preliminary work in this area by developing a 10-MW power-conditioning system for batteries and fuel cells. Many of the technological approaches used for this system are also applicable to photovoltaics and wind.

Planning for the integration of emerging renewable energy technologies is just beginning. "But as use of these new technologies won't become widespread overnight, there's time to work out the interconnection problems," says APS Division's Edgar DeMeo confidently. "The industry can do a lot of engineering in 10 years." □





Solar-Thermal Electric: Focal Point for the Desert Sun

Power towers are now being raised in several countries, but the Solar One project in the California desert is perhaps the most critical milestone on the path to commercialization. Information flowing from this 10-MW working laboratory will assist in modifying future designs and provide sound data for evaluating performance and cost. With the benefits of mass production, it now appears that these systems for converting concentrated sunlight to electricity could become competitive with oil- and gas-fired plants in the American Southwest. If research momentum can be sustained, demonstration plants could be on-line by the end of the decade.

Bank upon bank of mirrors move slowly under the southern California sky, tracking the sun and concentrating its radiation on the receiver of a power tower nearby. Jutting 310 ft (94.5 m) above the desert floor, the tower looks a little like a rocket awaiting liftoff.

In a sense, the Solar One pilot plant, a joint DOE-utility project located in the Mojave Desert near Barstow, California, is a launchpad, but not for extraterrestrial travel. As the first U.S. 10-MW (e) solar-thermal pilot plant, it might well become the critical milestone for a joint industry-government commitment to the solar-thermal central receiver concept.

As Gerald Braun, director of DOE's Solar-Thermal Technology Division, has noted, the planned turbine roll at Solar One early in 1982, the first test of its electric output, represents a major event in efforts to advance this new technology to the point of commercial development.

Robert Hughey, director of DOE's Solar Energy Division office in San Francisco, adds that of all the solar-thermal conversion concepts, central receiver plants hold the greatest potential for electric utility applications. DOE and EPRI studies show that if carried through the test and demonstration cycles, solar-thermal central receiver power plants may be competitive in the Southwest with gas- and oil-fired plants.

"Of all the direct solar options under consideration by electric utilities today," says John Bigger, EPRI's solar-thermal project manager, "the prospects for solar-thermal conversion look the best." He adds that the most recent EPRI survey indicates that U.S. electric utility interest in solar-thermal energy is greater today than ever before, with utility support and participation in 68 solar-thermal projects this year.

What are the vital steps that remain to be taken for solar-thermal conversion to move from a promising prospect to an operating, commercial reality? Bigger sees two key steps: performance demonstrations and corporate commitments. "Pilot plants, like the Solar One project and five other central receiver tests starting up in Western Europe and Japan this year and next, are expected to contribute performance information and operating experience to encourage supply industries and electric utilities to make commitments to this emerging technology," says Bigger. This information and experience is needed to confirm the estimates of cost and performance made in earlier studies. Corporate commitments are needed to foster mass production, and hence economies of scale, in the construction of key components, such as heliostats (the mechanical tracking mirrors that reflect and concentrate solar energy).

A working laboratory

Deserts make ideal locations for solar-thermal conversion plants not only because the sunshine is abundant, which is critical, but also because land is relatively inexpensive and available. The Solar One site comprises 130 acres at Daggett, California, about 12 miles southeast of Barstow, California. It is owned by Southern California Edison Co., a sponsor of the project with DOE and the Los Angeles Department of Water & Power, the nation's largest municipal utility. The California Energy Commission is also a participant. In addition to providing the site, SCE joined LADWP in designing and building the steam turbine generator and other conventional components of the plant at a cost of about $21.5 million. McDonnell Douglas Corp. and Martin Marietta Corp. are the major contractors.

Solar One's start of operation is planned for mid-1982. The first two years of operation will include experimental testing of the major subsystems and evaluation of the operation and maintenance costs and requirements. This period will be followed by power production tests, which are designed to obtain longer-term operating, maintenance, and reliability data. The intent is to make more accurate estimates of commercial solar-thermal plant costs and performance.

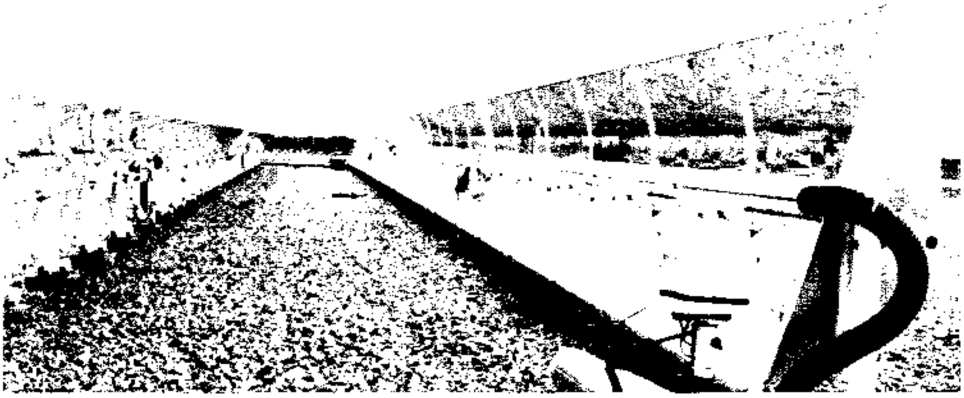
When operating, the plant will use 1818 heliostats, each containing 12 separate mirror facets. Preprogrammed coordinates will be used to allow the heliostats to automatically track the position of the sun across the sky. The concentrated beam of solar energy reflected from the heliostats will be aimed at the central receiver on top of the structural steel tower. The energy focused on the central receiver will convert water to steam to operate a conventional turbine generator, producing up to 10 MW of electricity, the amount of power needed to supply a community of 7000–10,000. At night or during periods of high winds, the heliostats will be moved to the stow position horizontal to the ground, with the reflecting surfaces facing downward.

Solar One will serve as a laboratory, providing information on which many future decisions will be based. Information on equipment reliability and failure, for example, will be coupled with system performance data. These data will be vital to the decision makers planning and designing the next solar central receiver installations, perhaps in the 30–100-MW (e) range. In addition, the Solar One test will provide electric utility personnel with first-hand experience, both in the operation and in the maintenance of the new technology. Utilities will monitor the information, experience, and performance data that develop from operation of the Solar One plant.

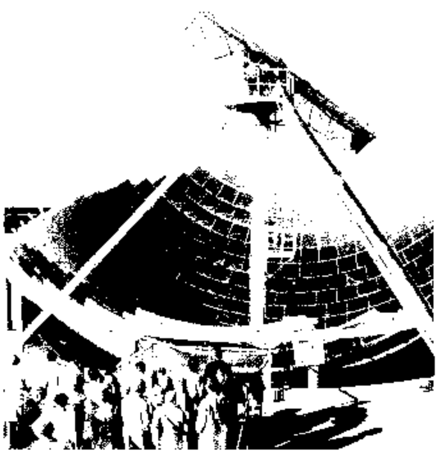
Next step: repowering

EPRI's Bigger believes information learned at Solar One, together with data from other ongoing experiments and central receiver pilot plants outside the United States, will pave the way for the next major step toward commercialization of solar-thermal conversion technology: implementation of a larger, precommercial project, probably a repowering plant. *Repowering* is a term applied to the concept of adding a solar-thermal conversion front end to an existing conventional fossil fuel power plant. Based on seven conceptual design studies recently completed (six were funded by DOE), the prospect exists that selected power plants

Flat plate collectors, like the rooftop unit providing energy for an air conditioning system at a Florida Power & Light Co. facility, are used to collect solar energy for water heating and the space heating and cooling of buildings.

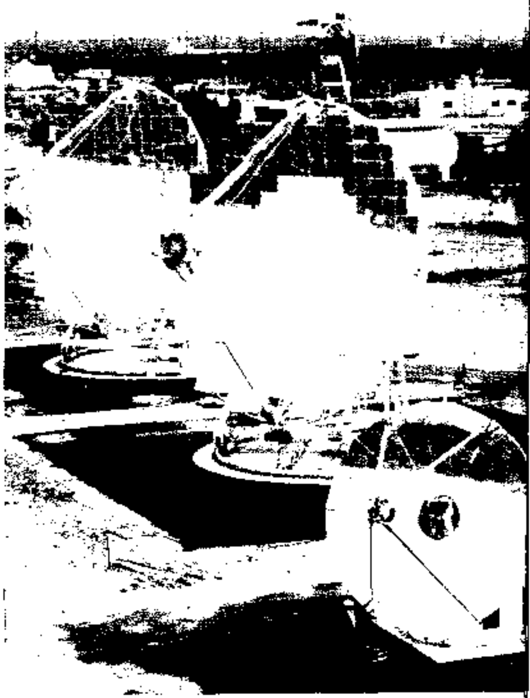


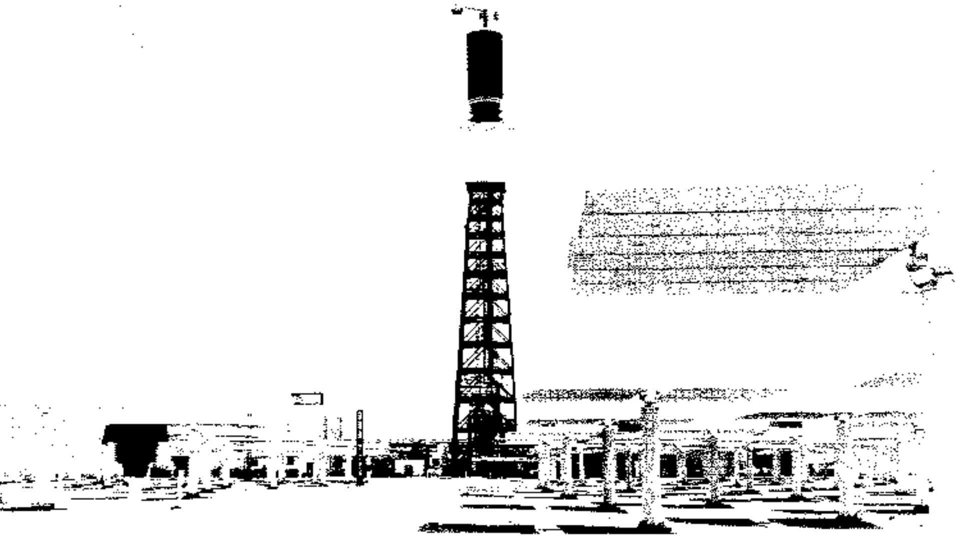
Line focus troughs reflect solar energy onto heat transfer fluid moving through a focal line. Such systems are demonstrating their capabilities in providing thermal energy for a wide range of industrial and agricultural processes.



Line focus bowls being tested under DOE sponsorship use a large number of mirror segments attached to a spherical structure to concentrate solar energy on the fluid moving along a line. This concept differs from the others in that the heat receiver moves rather than the reflectors. Heat collected in a number of bowls may be used for heating or cooling buildings, steam production, or small-scale electricity generation. (left)

Point focus dishes, like these DOE-funded test units, achieve high temperatures by using a number of mirrored reflectors attached to a single parabolic structure to focus intense solar heat on a receiver located at the focal point. Heat collected in this manner may be used to generate electricity, to provide energy for heating and cooling buildings, or to provide energy for many industrial and chemical processes. (right)





Central receivers, like this one near Barstow, California, achieve the high temperatures required for large-scale electricity generation by reflecting the energy received by hundreds of mirrored surfaces onto a single point, or receiver. The high temperatures achieved by central receiver units may also prove economic for many fuel and chemical production processes.

could be repowered and energy from the sun might replace as much as 20% of the expensive oil and gas now being burned. Future projects would demonstrate the concept of solar-thermal conversion in a conventional operating environment, and if the 20% savings in fossil fuels could be achieved at acceptable cost, such plants might be attractive.

Still, the cost of such systems remains a critical question. While the rising cost of fossil fuels is an obvious economic plus in the solar-thermal equation, it is also clear the cost of building the solar power plants is a major stumbling block. Estimates of the cost to modify and build solar repowering plants runs from $1500 to $4000/kW (in 1980 dollars), assuming a heliostat cost of about $250/m^2. EPRI analyses indicate that heliostats must be available for about half that cost if commercial solar-thermal plants are to compete with those now burning gas and oil for electricity generation. Even greater cost reductions would be needed to compete with coal-fired generating plants. Much of the development work supported by DOE's Solar-Thermal Program and under way in private industry is aimed at reducing costs by designing more efficient components and systems. Results of DOE's Second-Generation Heliostat Program were announced recently. This work covered a two-year test and development program with four potential heliostat suppliers. The results indicate the price of these new heliostats, if ordered in sufficient quantities, could approach the $110/m^2–$150/m^2 range.

DOE has also examined a number of advanced central receiver concepts; the performance of each is considered to be better than the first-generation water-steam system now being installed at the Solar One pilot plant. These concepts include advanced water-steam systems, liquid-metal and molten-salt systems, and a combined-cycle concept. With DOE support, Martin Marietta has developed a 5-MW (th) molten-salt receiver, which was designed, built, and successfully tested at DOE's central receiver test facility (CRTF) at Sandia Laboratories in Albuquerque, New Mexico. A smaller-size liquid-metal (sodium) receiver panel was designed and built with private industry funds; it will undergo solar testing in the late-1981 through early-1982 time period.

Developing hybrid plants

The cost of developing solar-thermal energy is affected by an inherent handicap shared by all the emerging solar electric options: reliance on an intermittent source. How does a utility compensate for the lack of energy at night or on overcast days? To circumvent this problem, EPRI studies have concentrated on the Brayton-cycle gas-cooled solar-thermal system in a hybrid mode. Such hybrid power plants would use solar energy when the sun is shining, then burn oil or gas to generate electricity on cloudy days or at night. In contrast, the federal program is emphasizing thermal storage as part of the solar power plant. (The Solar One facility at Barstow was designed to have a thermal storage system capable of producing 7 MW (e) for four hours, using an oil and rock mixture inside a 60-ft-diameter tank storage vessel.)

Unlike the Rankine-cycle water-steam systems (such as is installed at Solar One), Brayton-cycle systems use air, helium, or other gas mixtures as the heat transfer fluid in the solar receiver (*EPRI Journal*, June 1979, pp. 18–21). Such systems, under development by EPRI and DOE, have been successfully tested at DOE's CRTF and at other solar-thermal test facilities at the Georgia Institute of Technology and the U.S. Army's White Sands Proving Ground.

Whereas Rankine-cycle systems operate in the temperature range of about 1000–1100°F (538–593°C), with pressures in the 1000–2000-psi (6.9–13.8-MPa) range, solar Brayton-cycle receivers have been successfully tested with air at temperatures in the 1500–2400°F (815–1315°C) range. These higher operating temperatures have the advantage of offering potentially higher efficiencies; they have the disadvantage of encountering material problems, usually at about 1500°F (816°C). To address these material problems, EPRI and DOE have sponsored studies aimed at developing and using high-temperature metallic alloy and ceramic components in Brayton-cycle receivers.

EPRI full-system experiment

The next step in the EPRI Solar Program is an experiment involving a complete Brayton-cycle solar-fossil hybrid system to generate electricity. Called the solar-fossil hybrid full-system experiment, the system is now being designed and will use the 1-MW (th) receiver previously tested at CRTF from October 1978 to March 1979, which was developed for EPRI by Boeing Engineering & Construction.

The commercial gas turbine to be used in the full-system experiment will be equipped with a parallel trim combustor, which allows fossil fuels to supplement the sun in a solar-fossil mode of operation and increases the system's operating flexibility and reliability. The parallel trim combustor concept was developed under a separate EPRI contract with Solar Turbines, Inc., which is bringing this experience to the full-system experiment as a subcontractor to Boeing.

In accordance with EPRI's goal of providing a link between research, development, and commercial implementation by the electric utilities, Public Service Co. of New Mexico is coordinating activities of the recently formed Utility Test and Operations Group, whose members represent about a dozen utilities, most of them located in the Southwest. This group will provide technical assistance to Boeing and will conduct the experiment during the solar operating phase. The experiment will give electric utility operating and engineering personnel firsthand exposure to a complete solar-fossil hybrid generating system.

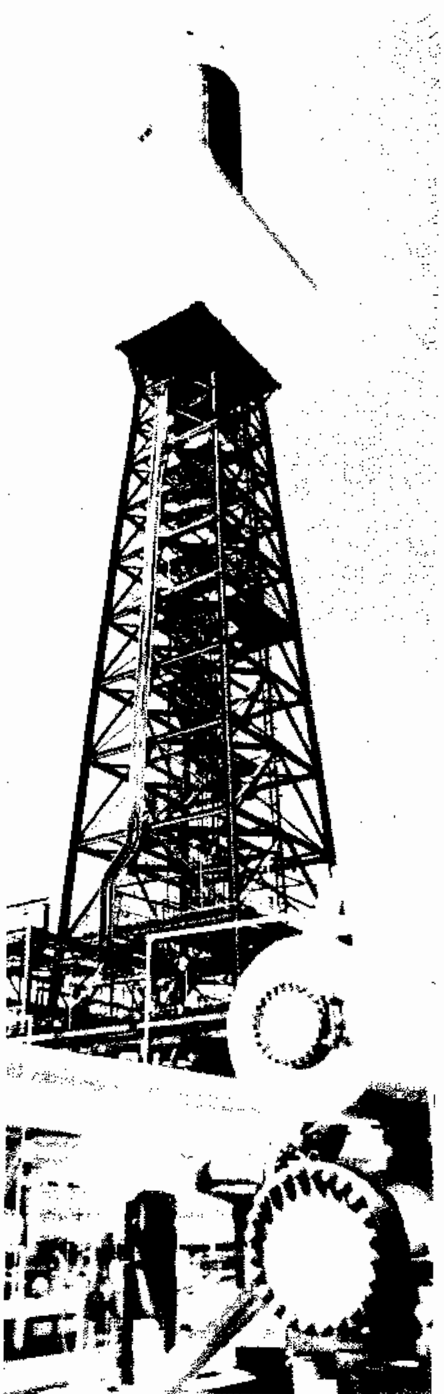
Several of the southwestern utility companies participating in this experiment have also been taking part in DOE's repowering projects, and they can be expected to play a lead role in the development of solar-thermal conversion.

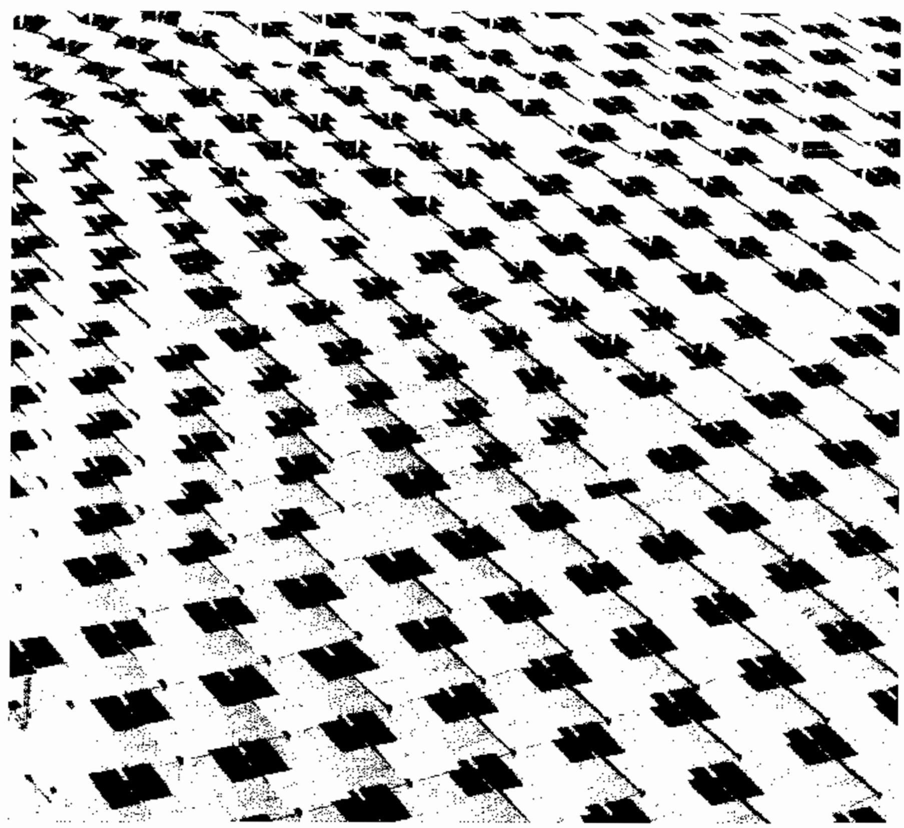
Information garnered from the full-system experiment and Solar One will be combined with data from other central receiver projects coming on-line throughout the world to advance solar-thermal central receiver technology and understanding.

Dishes, troughs, and bowls

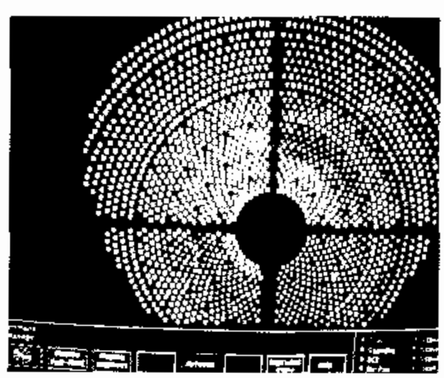
In addition to the central receiver, or power tower, approach to solar-thermal energy conversion, considerable interest has also developed in various forms of dispersed, or distributed, solar-thermal systems. Such systems fall into two broad categories: point focus and line focus systems.

Point focus systems are similar to the power tower concept to the extent that the solar energy is focused on a central location. Rather than hundreds of heliostats focusing a solar beam at a distant receiver on top of a tower, however, a single mirrored tracking device in the shape of a parabolic dish captures the solar energy and focuses it on a receiver mounted a few feet above the dish. A special facility for testing dish systems and components is located at Edwards Air Force Base in California and is operated by Jet Propulsion Laboratory. Also, at Shenandoah, Georgia, DOE is currently building an array of parabolic dish concentrators to be used for electricity





Photos by Ken Sloan



Solar One, a 10-MW installation located near Barstow, California, is the nation's first solar-thermal central receiver electric generating station. A field of 1818 heliostats, controlled by computer, tracks the sun throughout the day and reflects its energy onto the receiver, where steam is produced. The steam is then sent either through heat exchangers for thermal storage and later use or to a conventional steam turbine that generates electricity. EPRI researchers believe information coming from the Solar One central receiver station will help advance this emerging technology and can lead to additional industry and utility commitments to continue its development.

SOLAR-THERMAL RESEARCH IN OTHER COUNTRIES

Interest in solar-thermal energy systems is not confined to the United States but is being actively pursued in a number of industrialized nations. Some of the major work currently under way includes the central receiver pilot projects described below.

Almeria, Spain: The International Energy Agency has funded the construction of a 500-kW (e) small solar power system that uses liquid metal (sodium) as the heat transfer and thermal storage fluid. A cavity receiver located on top of a 140-ft (43-m) central receiver heats the sodium to 975°F (525°C). The 93 heliostats in the field provide 430 ft² (40 m²) of surface area and were supplied by the Martin Marietta Corp. The project is funded by several European countries and the United States; startup was in September 1981. This IEA installation also includes a (nominal) 500-kW (e) line focus system for a direct comparison of performance with the adjacent central receiver.

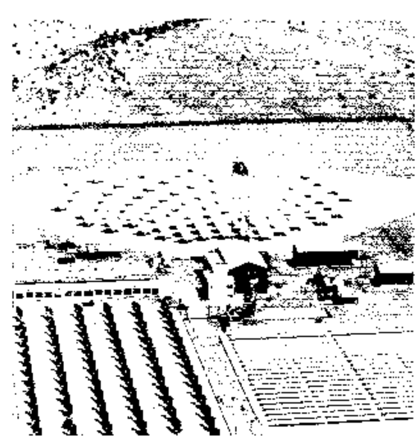
Almeria, Spain: A 1.2-MW (e) central receiver system is under construction and scheduled for completion in late 1982. Called CESA-1, the unit uses a cavity receiver to produce 975°F (525°C) steam. A German and a French firm each supplied 150 heliostats with 430 ft² (40 m²) of surface area. The unit has a thermal storage capacity of 3 MWh (th) and uses Hytec as the storage fluid. Funding is being provided by the Spanish Joint Committee for Scientific and Technological Cooperation and the United States.

Adrano (Sicily), Italy: Eurelios, a 1-MW (e) central receiver solar power plant, began operation in May 1981. The cavity receiver sits on top of a 180-ft (55-m) tower and produces steam at 950°F (510°C). A 30-minute thermal storage subsystem is used to even out cloud transients, and Hytec is the storage fluid. The project was developed by a consortium from Italy, Germany, and France.

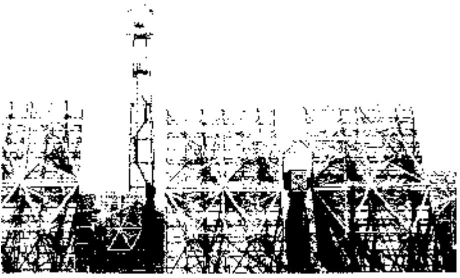
France: In the Thémis project, a 2-MW (e) central receiver solar power plant will use molten salt as the transfer fluid, heated to 975°F (525°C) by solar energy reflected by 200 heliostats, each with a surface area of 560 ft² (52 m²) aimed at the cavity receiver. The storage system has 4 MWh (th) of capacity and uses Hytec as the storage medium. The project is scheduled to begin operation early next year.

Nio Town (Nagawa Prefecture), Japan: A 1-MW (th) water-steam central receiver power plant went into operation earlier this year. The field consists of 807 heliostats, each providing 172 ft² (16 m²) of surface area; it reflects the sun's rays into a semicavity located on top of a 197-ft (60-m) tower and produces saturated steam at 480°F (250°C). Pressurized water is used as the thermal storage medium for 3 MWh (th) of heat storage. The project is completely funded by the Japanese Agency of Industrial Science and Technology and the Ministry of International Trade and Industry. □

CESA-1, Spain

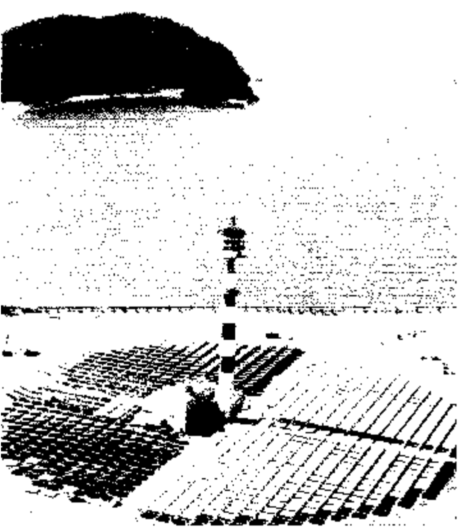


IEA, Spain



Eurelios, Italy

Thémis, France



Project Sunshine, Japan

generation, heating and cooling, and low-temperature steam production for a nearby knitwear plant.

Line focus, or trough, systems consist of a series of specially designed cylindrical or parabolic troughs lined with mirrors to collect and concentrate the sun's radiation. Under federal sponsorship, a number of the line focus systems have been installed at industrial and research sites. These systems usually operate in the lower temperature ranges, 200–600°F (93–316°C), adequate for providing industrial process heat, for operating small turbine generators, or for some specific commercial or industrial applications. Such uses might include irrigation pumping, for example, or steam injection for secondary oil recovery. Recent EPRI analyses indicate that line focus systems, because of temperature limitations, do not look favorable for large-scale electricity production.

Outlook

After an investment of many hundreds of millions of dollars in solar-thermal conversion technology since the early 1970s, where are we now and where do we go from here? Of all the solar-thermal technologies, only one is in commercial use: flat-plate collectors for water and space heating. The others are in various stages of development.

Of those solar-thermal technologies in development, the line focus systems have the most experience in field installations. This experience has been gathered in industrial and commercial process heat applications, where the temperature requirements are lower than those of utility power generation needs.

The point focus systems are the least developed of the solar-thermal technologies, but with further development they may have the capability for utility applications because they can achieve temperatures high enough for efficient electricity generation. Because the point focus systems are modular, they hold the potential for serving a wide range of electric requirements and may lend themselves to incremental installation.

Considerable resources have been expended on the development of central receiver systems, both in the United States and abroad. The technology holds significant promise for electric utilities as stand-alone plants that contain thermal storage systems; as solarrepowering units tied to existing oil- and gas-fired units; and as new solar-fossil hybrid plants. It is also significant that a number of electric utilities have become directly involved in the studies and projects conducted by both DOE and EPRI.

With the level of federal solar program support sharply decreasing and future federal involvement increasingly cloudy, the corporate commitment of funds from suppliers and utilities needed for continued development will be determined in large measure by the analysis of results of solar-thermal conversion projects in the field today. These include not only the U.S. projects but also those experiments under way abroad, whose results will now become even more crucial. As these important data are collected, the next critical step in the development of solar-thermal power will be to ensure the broad and accurate dissemination of this information. ■

Further reading

Penetration Analysis and Margin Requirements Associated With Large-Scale Utilization of Solar Power Plants. Final report for TPS75-611 prepared by Aerospace Corp., August 1976. ER-198.

Closed-Cycle, High-Temperature Central Receiver Concept for Solar Electric Power. Final report for RP377-1 prepared by Boeing Engineering & Construction, January 1978. ER-629.

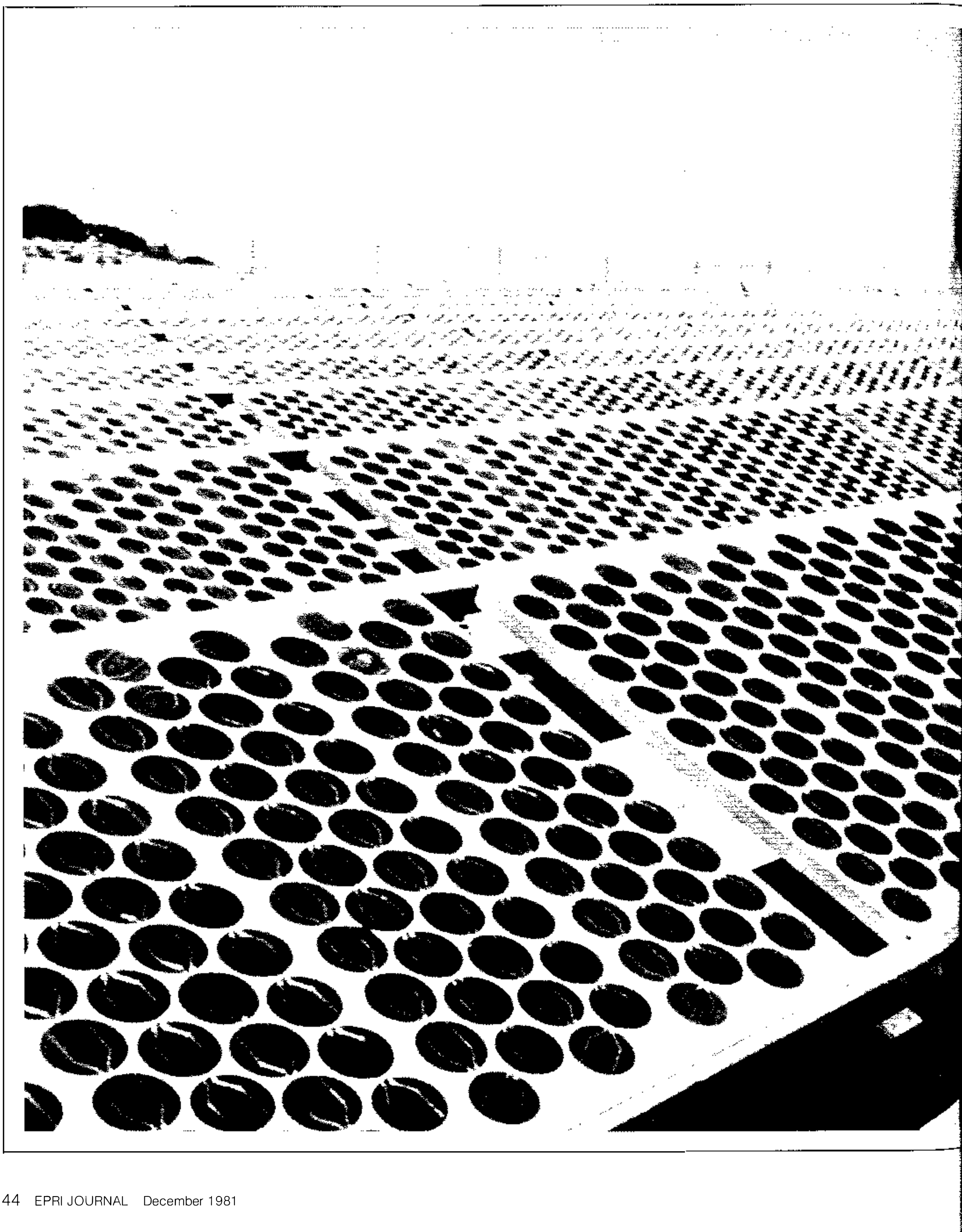
A Methodology for Solar-Thermal Power Plant Evaluation. Final report for RP648 prepared by Westinghouse Electric Corp., August 1978. ER-869.

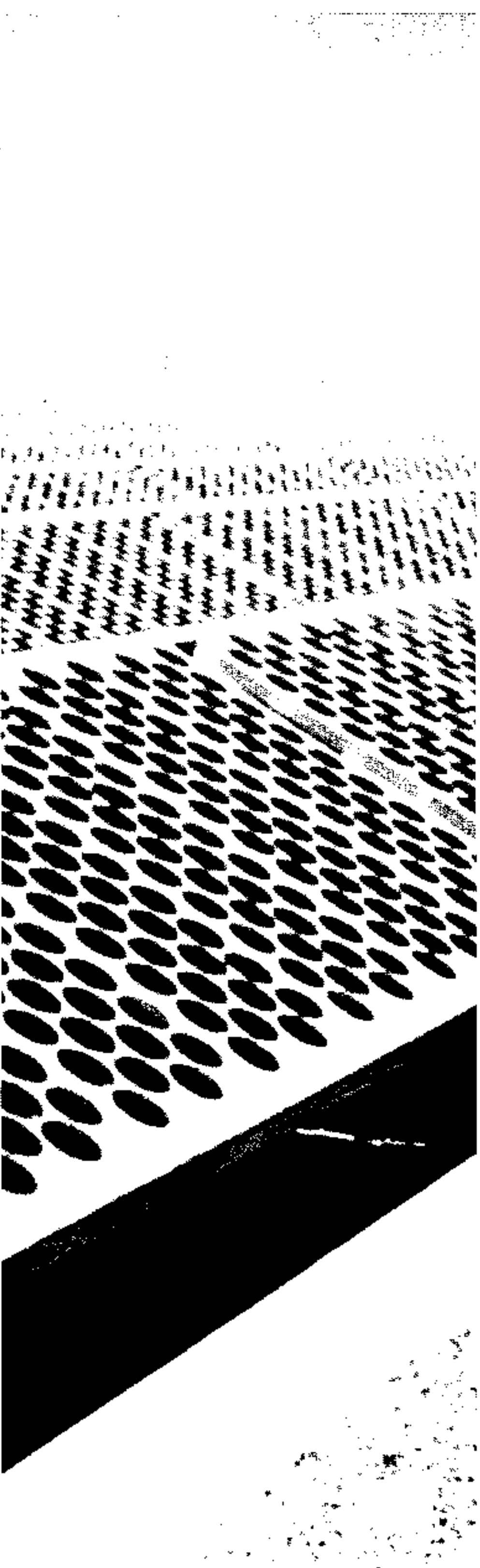
Design and Fabrication of a 1-MW (t) Bench Model Solar Receiver. Interim summary report for RP377-2 prepared by Boeing Engineering & Construction, August 1979. ER-1101-SY.

A Description and Assessment of Large Solar Power Systems Technology. Livermore, Calif.: Sandia National Laboratories, August 1979. SAND79-8015.

Solar-Thermal Conversion to Electricity, Utilizing a Central Receiver, Open-Cycle Gas Turbine Design. Final report for RP475-1 prepared by Black & Veatch Consulting Engineers, March 1978. ER-652.

This article was written by Dan Van Atta, manager, Public Information. Technical information was provided by John Bigger, Advanced Power Systems Division.





Photovoltaics: A Question of Efficiency

Solar photovoltaic cells make economic sense today in areas remote from central station networks where the need is critical and the power requirements are relatively small. But where there is access to conventional power generation, photovoltaic arrays are not yet competitive because of low efficiency and high cost, including the cost of support structures and power conditioning apparatus. The key R&D need is to double typically available energy conversion efficiencies for photovoltaic materials. Should efficiency be improved, solar cells will become economic first for those users—electric utilities among them—who can spread the costs of large systems over a long service life.

Photovoltaic energy conversion is considered a promising technology because it produces electricity directly from sunlight without intermediate gas, steam, or mechanical cycle. It therefore appears efficient and benign. Moreover, photovoltaic electricity systems are modular—arrays of identical modules can be assembled to meet almost any power need, so it seems possible to use them even on individual house rooftops.

These attributes have fostered an image that commercial use of photovoltaic electricity is just around the corner. Manufacturers and venturers see a business opportunity. Utilities see a new way to generate power. Futurists see an inexhaustible energy resource. And reformers see modular systems that encourage decentralization and a lessening of control by corporate giants.

A small, specialized photovoltaics market does exist. Remote needs for electricity account for the annual manufacture and sale of solar cells that total some 4 MW of new generating capability. The major application is in telecommunications, for which solar cells and batteries convert and store energy to operate isolated microwave relay stations. Similar systems provide the energy for railway controls in the desert, navigation aids ashore and afloat, and communications gear on offshore oil drilling and production platforms. Power has a very high value in these remote applications, and solar cells generate it more cheaply than any other means.

But the growth of this one market is unlikely to fulfill the expectations of today's solar cell producers. There is increasing evidence that the cost of photovoltaic systems will not soon be low enough to capture the high-volume rooftop market of small consumers. If costs do become more favorable, photovoltaic systems at utility scale (at least several hundred kilowatts) are likely to be the first widespread application in which photovoltaic electricity is feasible on its own, free of tax credits or other incentives. To see why and how this is so, it is necessary to take some note of the last 10 years.

The push for lower costs

Photovoltaic energy conversion was first exploited meaningfully in 1958, when solar cells powered a radio transmitter on the Vanguard space satellite. The technology has been highly successful in space since then. It was seriously considered for power on earth when fossil fuel limits began to be seen and when the embargo of 1973 severely reduced the availability of oil from the Middle East. Federal R&D support began under auspices of the National Science Foundation in 1972 and by the 1981 fiscal year was at a level of $135 million in annual DOE expenditures for research, technology development, and field testing.

A major intention of the national effort in photovoltaics, as evidenced in project selection and funding, was to encourage an early market based on small rooftop installations. (This objective was a matter of emphasis; it would not preclude the emergence of other markets.) Although research in photovoltaic phenomena, materials, and devices was part of the program, priority was given to technology development, that is, optimizing the efficiency, reliability, and economy of solar cells made from what is called single-crystal silicon. Costs were expected to fall mainly because of the economies of mass production.

Federal planners estimated that the annual production and sale of 500 MW of photovoltaic electricity generation capacity would constitute a true commercial foothold. A unit cost target was also set: $0.70 per peak watt (in 1980 dollars) at the level of a modular package containing many interconnected cells. These volume and cost targets were seen to be interdependent and achievable by 1986.

The government push in photovoltaics R&D has been paralleled in the private sector, where funding is thought to have reached comparable levels: $100–$150 million annually. Most corporate research budgets and achievements are guarded for proprietary reasons, but much industrial activity remains evident. For example, Atlantic Richfield Co. has invested in one of the largest single-crystal silicon cell production facilities. United States and foreign oil interests are funding R&D and production facilities for cells that use thin films of cadmium and copper sulfide. Energy Conversion Devices, Inc., is working with amorphous (noncrystalline) silicon technology. In separate and differently structured transactions, the company has drawn investments from Atlantic Richfield and Standard Oil Co. of Ohio that may total $110 million. Amorphous silicon is also the subject of recent heavy R&D commitments in Japan.

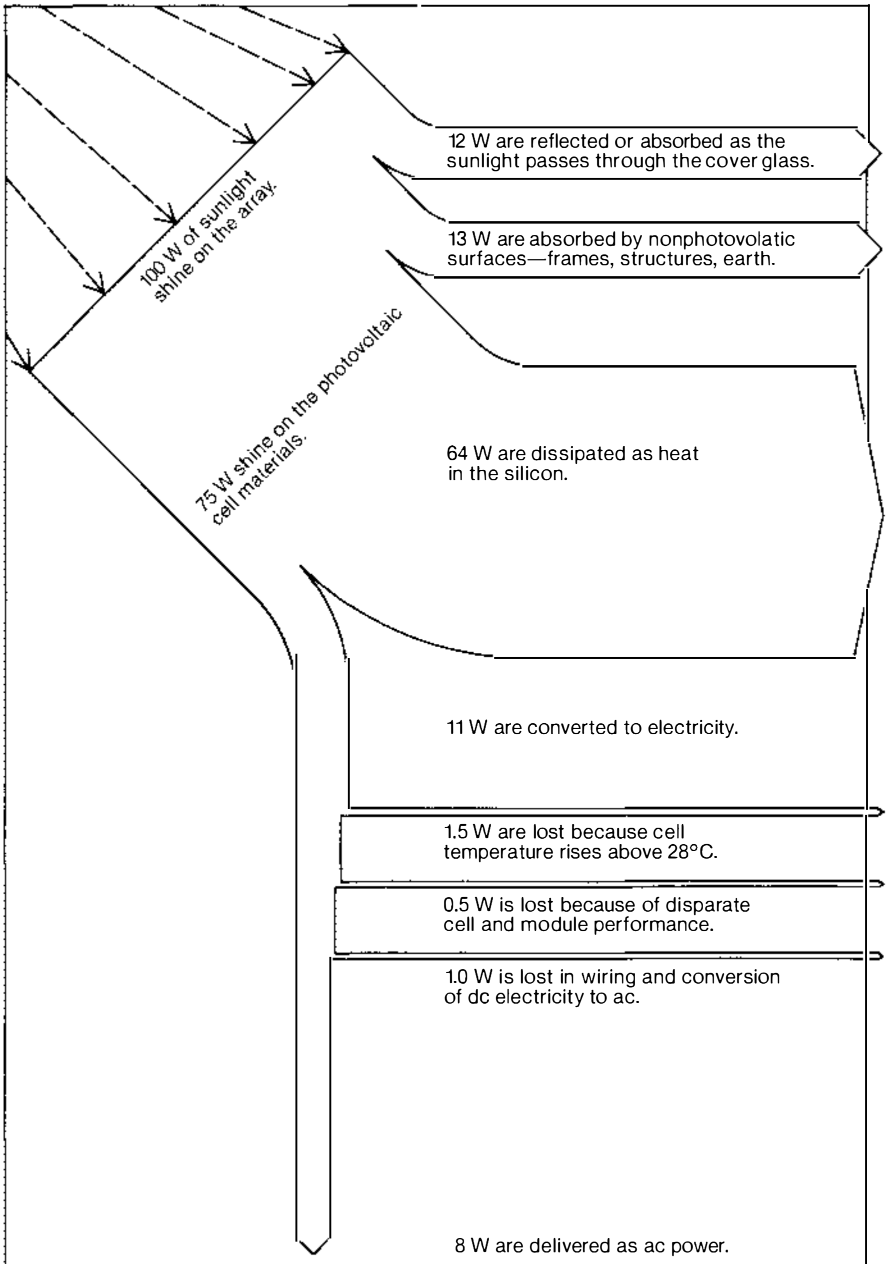
The results of development to date include good news and bad news. The unit costs have indeed come down—from the $200 per peak watt of satellite photovoltaic modules in 1959 to $22 by 1976 and to about $10 today. As a result, the specialty market for high-value remote systems is truly economic on its own.

However, the 1986 goal of $0.70 per peak watt is unlikely to be reached. Some observers feel that there are too few years in which to build annual markets and production volume from 4 MW to 500 MW. Other observers assert that the costs of silicon and its processing will always be too high for overall module costs to fall to $0.70 per peak watt. Faced with diminishing returns in cost reduction for single-crystal silicon, the photovoltaics community is looking more intently at R&D prospects in other materials and techniques.

Performance in the real world

Photovoltaic behavior is the generation of voltage (electric potential) in a material when it absorbs light. Because the energy content of solar radiation varies with its wavelength, R&D is being performed to find which photovoltaic materials are most sensitive to the wavelengths that carry most of the sun's energy.

The most common solar cell (like the most common semiconductor) begins as



Losses in six main categories reduce the overall efficiency of photovoltaic energy conversion. The figures shown here are representative of today's nonconcentrating silicon system performance.

In general, the largest loss categories offer the most room for improvement, so they are the major topics of R&D. Cell loss is deceptive, however. For the 75 W entering the silicon, the 64-W loss (and 11-W output) results from a 15% conversion efficiency. Even silicon's maximum theoretical efficiency of 22% would entail a loss of 58 W. To do better requires photovoltaic materials and configurations that react more effectively to a greater range of the solar energy wavelengths.

highly refined silicon, solidified as a single-crystal ingot by slow withdrawal of a "seed" from molten silicon. Thin wafers are then cut and polished (with the loss of nearly half the material), and a pattern of one or more chemical elements is introduced into the wafers, each of which becomes an individual photovoltaic cell. When a cell absorbs light, electrons are freed, and the chemically defined regions in the silicon channel their flow. An electric current is produced when the flow of electrons is conducted into an external circuit.

A single such cell—some 3 in (7.6 cm) across and 300 μm thick—may represent 0.5 V and generate about 1 W. Cells are connected in series to build up the voltage or in parallel to build up the current. A module combines many cells into a package about 4 ft (1.2 m) square. Modules and panels (made up of several modules) are the customary design units for assembling photovoltaic arrays that will meet specific power or energy requirements.

Efficiency is a useful way to compare different kinds of cells and to compare cells with modules, with arrays, and with entire systems. Efficiency is the ratio of the electric power output of a solar cell, module, or array to the power content of the sunlight over its entire surface area. Outputs are measured and efficiencies are compared under standard (peak-watt) conditions: a solar intensity of 1000 W/m^2 and a cell temperature of 28°C.

Using this yardstick and under these rather idealized conditions, today's best single-crystal cells yield efficiencies of 16–17%. Modules of typical mass-produced cells seldom exceed 10%, according to Roger Taylor, project manager for photovoltaics in EPRI's Solar Power Systems Program. And he adds that well-designed systems are getting only 5 to 8%. Taylor goes on to explain why efficiency falls when components are successively connected and put to use.

"One reason is the mismatch loss. This results from the inability to make all cells truly identical. There's one least-efficient cell in any string, and it limits the value for the whole string. There are mismatch losses within modules and between modules as they're hooked up in arrays.

"Another source of loss," says Taylor, "is the packing factor. Many cells are circular, so there are spaces between them—as well as the surface of exposed framing—that get sunshine but don't produce any electricity. Rectangular cells in advanced modules minimize this loss, of course. There are also electrical losses through the system wiring and in the equipment that converts dc electricity to ac.

"One major loss has nothing to do with how cells and modules are connected," Taylor concludes. "It really is a derating caused by higher temperature. The standard lab measurement of efficiency is at 28°C, but in the real world, cells are more likely to operate at 50–60°C, and this cuts one or two percentage points off any cell efficiency."

R&D directions

The Solar Energy Research Institute and DOE's national laboratories conduct and sponsor R&D in photovoltaics, with the principal program management in technology development furnished by Jet Propulsion Laboratory, California Institute of Technology. A few examples represent current R&D avenues, both in silicon technology and in new photovoltaic device research.

Solidifying single-crystal silicon in sheets avoids the material waste that occurs when wafers are sawn from ingots. The technique may be economical if sheets can be made wide enough to achieve production rate goals for total cell area. An alternative would be faster withdrawal rates from the molten silicon, but this tends to cause thermal stress and cracking because the sheets cool quickly.

Silicon with many crystals is another candidate for making low-cost sheets, but the grain boundaries reduce voltage and impede current flow. One remedy being investigated is a hydrogen plasma treatment that makes the boundaries electrically invisible.

Thin film devices (as little as 2 μm thick) are one advanced R&D approach. The base is a cheap substrate, and there is only enough active material for the photovoltaic response to occur. Thin-film R&D is investigating a wide range of chemical compounds in various combinations, among them indium phosphide, cadmium sulfide, copper indium selenide, gallium arsenide, and amorphous silicon.

Grain boundaries also tend to reduce the performance of thin-film cells, but precisely controlled melting and resolidification of the surface material may significantly improve its electrical properties by increasing the size of individual grains. This technique is called laser recrystallization, and EPRI is funding Poly Solar, Inc., to test it on several thin-film materials.

Unlike other thin films, amorphous silicon has no crystalline structure, but its random atomic arrangement limits current flow even more than do grain boundaries. Here, as with crystalline silicon, hydrogen treatment shows promise for overcoming the limitation.

Photovoltaic cells for use in concentrated sunlight are the other major area of advanced R&D. Concentration brings obvious advantages. With more power input and output at each cell, fewer cells are needed and higher cell costs become affordable. In addition, cell efficiency tends to improve with concentration, further reducing the number of cells. Higher efficiency also permits a smaller array of the mechanized optical elements used to track the sun.

But there are countering losses and costs. Concentrators are effective only with direct solar radiation. The optical elements exact a toll of as much as 15% of available solar energy. And high power concentrations in solar cells are accompanied by electrical losses related to the elevated currents and temperatures involved. Concentrating mechanisms cost more than do the supporting structures for equivalent flat-plate photovoltaic arrays. If concentrating systems are to be economic, their cell conversion efficiencies must considerably exceed those in flat-plate systems.

EPRI is funding Stanford University research on silicon cells for use at a concentration of about 500 suns. Models of performance indicate that cell efficiencies of about 25% could be achievable. This work stems from earlier funded development of a thermophotovoltaic system, in which even more highly concentrated sunlight is absorbed by a refractory element that gets very hot and reradiates the transmitted energy at wavelengths more efficiently converted to electricity by silicon cells. It now appears that a system with the new concentrating cells—using sunlight directly—can attain efficiencies sufficiently close to those projected for the thermophotovoltaic system, but without the materials problems associated with its 1900°C temperatures.

Conversion efficiencies even higher than 25% may be possible in multijunction (or cascade) devices, where different portions of the solar spectrum are converted to electricity in different regions of the device, each operating at its most efficient point. Such cells are the subject of both government and private sector research.

Analyzing value and cost

For seven of the past nine years of intensified nationwide work in photovoltaics, EPRI has selected research projects that complement the federal effort. The Institute has become closely involved with the scientific community in photovoltaics, thereby gaining a solid basis for assessing the state of the art.

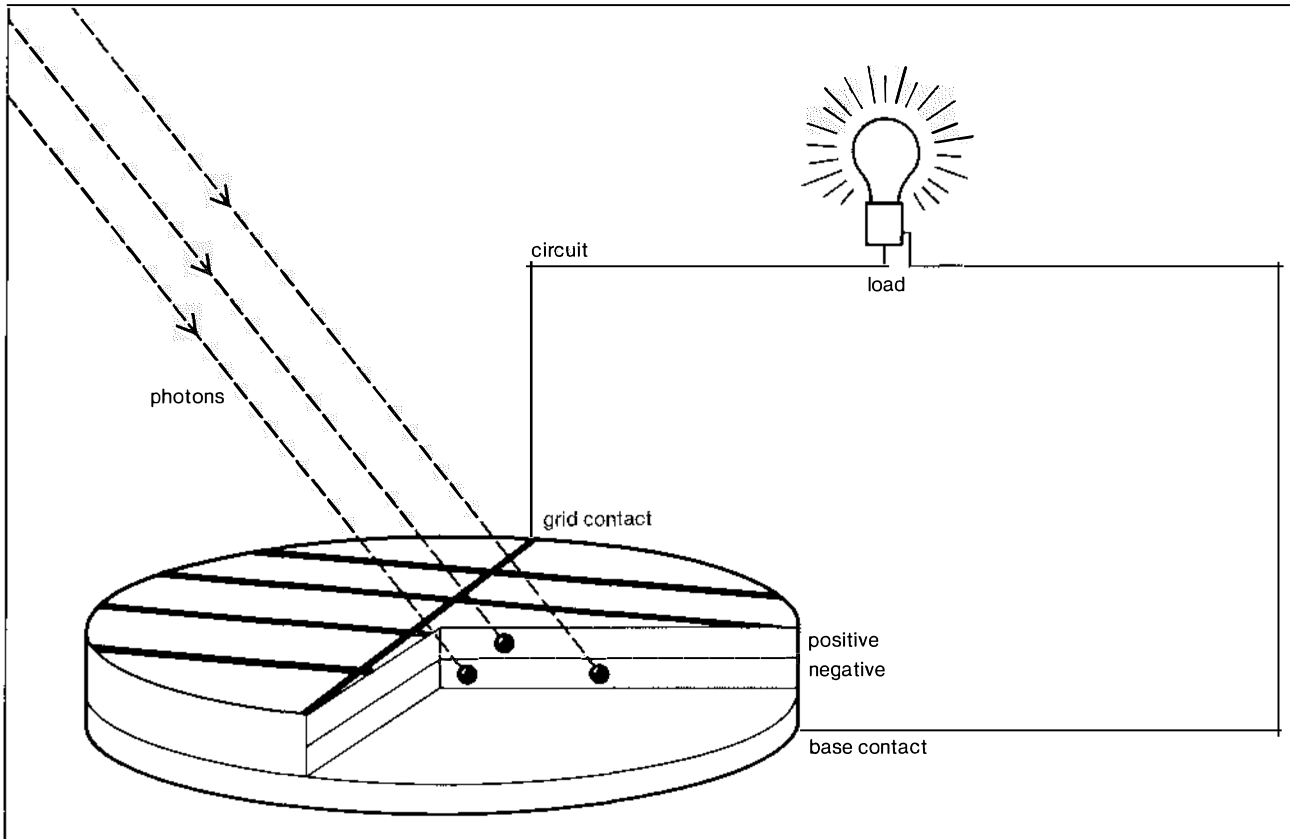
Most important to the utility industry are EPRI's economic feasibility studies of photovoltaic energy conversion that flow from such assessments. For example, higher efficiency is the mark of technical progress in components. It is also a meaningful index of economic feasibility because of how it reduces the area-dependent costs of a system. The question therefore arises: What efficiency is possible?

The theoretical maximum in single-junction devices (without concentration) is about 22% for silicon and as much as 27% for some other materials. Both values are nearly twice what is being produced today, leading Taylor to observe, "This is one reason people are interested—there's so much room for improvement."

The question of possible efficiency necessarily begins at the level of a cell and proceeds to the level of a system. It is perhaps more relevant to ask: What efficiency is required? The first answers are found at the level of an entire system, in terms of its value to an electric utility.

Value analysis is the way a utility determines the most economic way to handle system load growth. The daily pattern of forecast load is considered, and for that pattern the costs are estimated for electricity produced by existing and by new generating units that might be operated in various combinations. Each kind of unit has its own characteristic reliability, yielding a frequency and cost of outage time and consequent requirement for replacement power from yet another generator (with its own attendant costs).

By these analyses, it is possible for a utility to rank prospective generating op-



Photovoltaic energy conversion begins with photons, the increments of energy that are carried in all wavelengths of light. Photovoltaic conversion is completed when current flows in a circuit connected to the opposite sides of a solar cell.

The essence of a cell—whether treated silicon or molecular films of selected materials—is its two regions, one electrically positive and one electrically negative. Solar photons dislodge electrons from their chemical bonds in the cell materials. The positive and negative regions encourage electron flow, and contacts on the cell surfaces channel this flow into a circuit.

Photons in the longer wavelengths of sunlight are too weak to dislodge electrons. Photons in the shorter wavelengths dislodge electrons and have energy left over. This unexploited photon energy limits the efficiency of photovoltaic energy conversion.

Photo courtesy Arco Solar, Inc.

Photo courtesy Solavolt International.

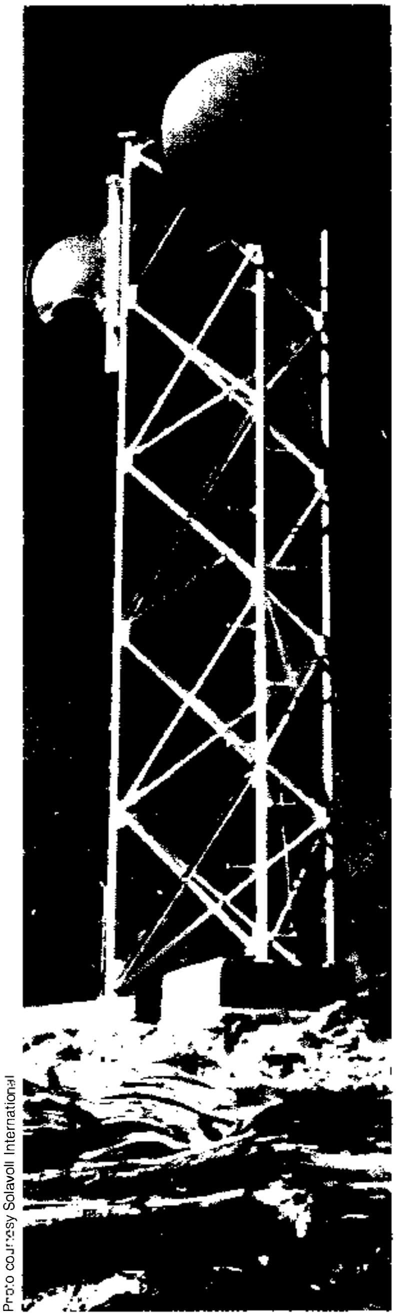


Photo courtesy Solavolt International

Photo courtesy Solarex Corp.

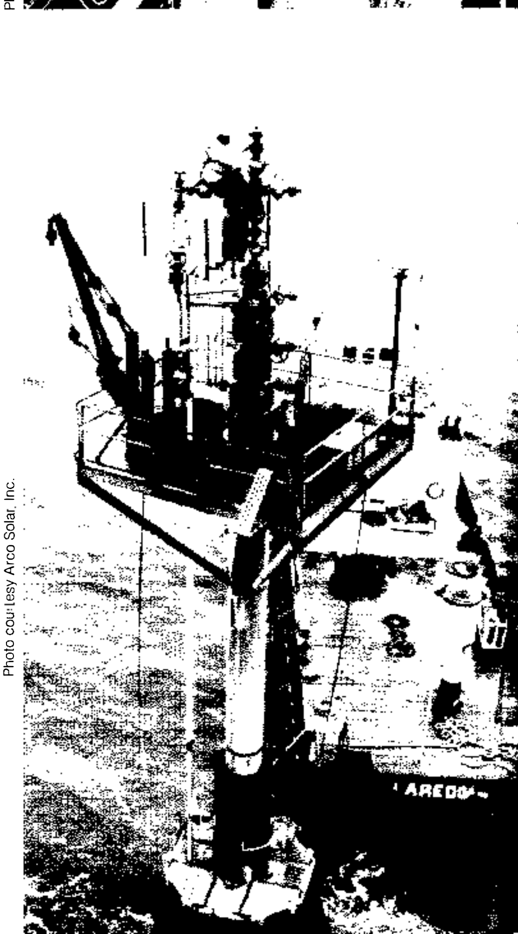


Photo courtesy Arco Solar, Inc.

Electricity from solar photovoltaic arrays is finding application in remote corners of the world—from land-based communication relay stations to sea-based platforms—wherever access to conventional power networks is impractical and power requirements are relatively small.

tions by the economic benefits they produce. Within the electric utility context, peak-period electricity generated by oil-fired power units is the most expensive energy today. It is therefore the market target of all new solar power technologies.

Balance-of-system costs must be subtracted from system value to arrive at permissible costs for the photovoltaic components alone. Today's photovoltaic systems of intermediate size (1–500 kW) cost about $30,000/kW. Two-thirds of this, about $20,000/kW, represents costs for nonphotovoltaic apparatus. Even in systems of the future, it is expected that half the cost will be for the balance of the system. Photovoltaic array area increases directly with power level, so there is little economy of scale for components that are area-dependent, such as foundations, structures, and wiring. Their cost per unit of area, or of power output, will not change much in systems beyond several hundred kilowatts. Other components are not area-dependent. They are related only to power level, and their costs per unit of power output fall as system size increases. Examples are the equipment for dc-to-ac power conditioning and connection to a utility grid.

During the next several years, balance-of-system items and their costs will be a major focus of R&D under EPRI's Solar Power Systems Program. The objective is twofold: to find out how (and how much) these costs can be reduced and to better understand their influence on the requirements for photovoltaic devices.

Efficiency as a cost cutter

When the lowest unit costs have been achieved for balance-of-system items, the only remaining way to reduce their effect on system cost is to cut the system area. This means higher photovoltaic efficiency is needed. Efficiency figures for modules are most useful as goals and in comparisons of performance because the module is the basic component assembled and sold. Individual cells may vary, and the performance of a module shows how they average out. But system photovoltaic efficiency figures are most useful in overall economic analyses.

Efficiency requirements may be established for utility components accordingly. But other reasoning explains why photovoltaics will become attractive to utilities sooner than to any other sizable market. A given level of technology sophistication, with its associate system efficiency and cost, will first become saleable for the manufacturer when applied to large (utility scale) systems. It is mainly a matter of large-lot factory-direct pricing compared with single-unit retail pricing. Markups are minimized because some product distribution steps (and their costs) are avoided.

Also, the 25–30-year time spans of utility planning and costing practice contrast sharply with the 3–5 years into which other users must shoehorn their recovery of photovoltaic system costs. Together with economies of scale and of large factory-direct purchases, life-cycle costing suggests that utility photovoltaic applications will be attractive sooner than a rooftop retail market.

Current technology does not yet permit a utility market to take shape. Costs are still too high. If relief is to be found, it must be in higher device and system efficiencies, that is, in further research.

Thus, the foreseen large (and early) end-use market for photovoltaics is not emerging. Instead, photovoltaic systems at a scale of interest to electric utilities are likely to be the first significant volume sold. Those systems probably will not be based on the technology of flat-plate single-crystal silicon modules. Their economic viability will depend—among other things—on improved efficiencies and lower costs that have yet to flow from the R&D laboratory.

Will this progress in photovoltaics R&D actually be made, or will cuts in the federal program be fatal, not just by their own severity but by discouraging private sector research as well? EPRI's outlook is guardedly positive. Of all the renewable energy resource technologies, photovoltaics may have the best chance for success with only limited government R&D funding. This is true during the research (as opposed to development) phase because the principal need is for laboratory experimentation with photovoltaic materials and device configurations. Also, semiconductor and computer industry research involves extensive investigation of similar materials and surface physics, as well as of production technologies. It is reasonable to anticipate relevant advances from that quarter. Photovoltaics R&D thus seems to have its own momentum.

Moreover, the modular nature of photovoltaic systems suggests that there never need be large demonstration plants and the funding to match. Performance, reliability, and economic prospects can be authenticated at the scale of a few megawatts. On these bases, photovoltaic energy conversion continues to have potential as a commercial producer of bulk electricity. Just around the corner, perhaps, but it looks like a long walk to the end of the block.

Further reading

"DOE Explores Solar Photovoltaics." *EPRI Journal*, Vol. 5, No. 7 (September 1980), pp. 27–28.

Perspectives on Utility Central Station Photovoltaic Applications. Special report, January 1978. EPRI ER-589-SR.

"Photovoltaics." *Science*, Vol. 212, No. 4502 (June 26, 1981), pp. 1472–1478.

Proceedings of 15th IEEE Photovoltaic Specialists Conference. New York: IEEE Publishing Services, 1981.

"The Promise of Photovoltaics." *SERI Journal*, Spring 1981, pp. 5–13.

Requirements Assessment of Photovoltaic Power Plants in Electric Utility Systems. Summary report, June 1978. EPRI ER-685-SY.

"Solar Photovoltaic Conversion." Advanced Power Systems Division Report, *EPRI Journal*, Vol. 5, No. 7 (September 1980), pp. 32–33.

"The Sun on a Semiconductor." *EPRI Journal*, Vol. 3, No. 2 (March 1978), pp. 20–25.

Sunworld. Journal of the International Solar Energy Society, Vol. 4, No. 1. Elmsford, New York: Pergamon Press, 1980. (Entire issue is devoted to photovoltaics.)

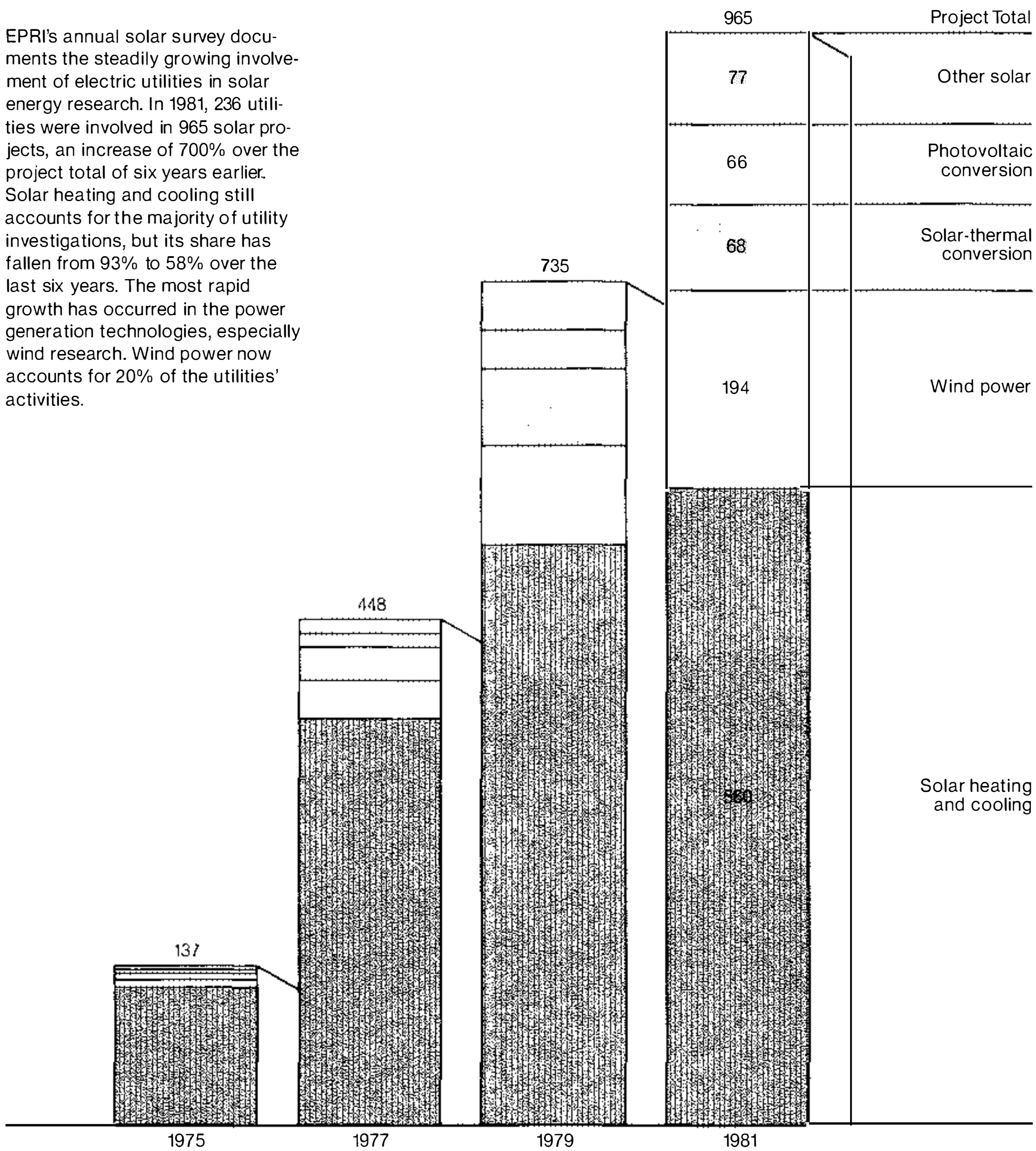
D. Costello and P. Rappaport. "The Technological and Economic Development of Photovoltaics." *Annual Review of Energy*, 1980, 5:335–356.

"TPV: Management Approach to High-Risk Research." *EPRI Journal*, Vol. 4, No. 3 (April 1979), pp. 19–22.

This article was written by Ralph Whitaker, feature editor. Technical background information was provided by Roger Taylor, Advanced Power Systems Division.

Utility Solar Survey

EPRI's annual solar survey documents the steadily growing involvement of electric utilities in solar energy research. In 1981, 236 utilities were involved in 965 solar projects, an increase of 700% over the project total of six years earlier. Solar heating and cooling still accounts for the majority of utility investigations, but its share has fallen from 93% to 58% over the last six years. The most rapid growth has occurred in the power generation technologies, especially wind research. Wind power now accounts for 20% of the utilities' activities.



Squeezing More From Hydroelectric Power

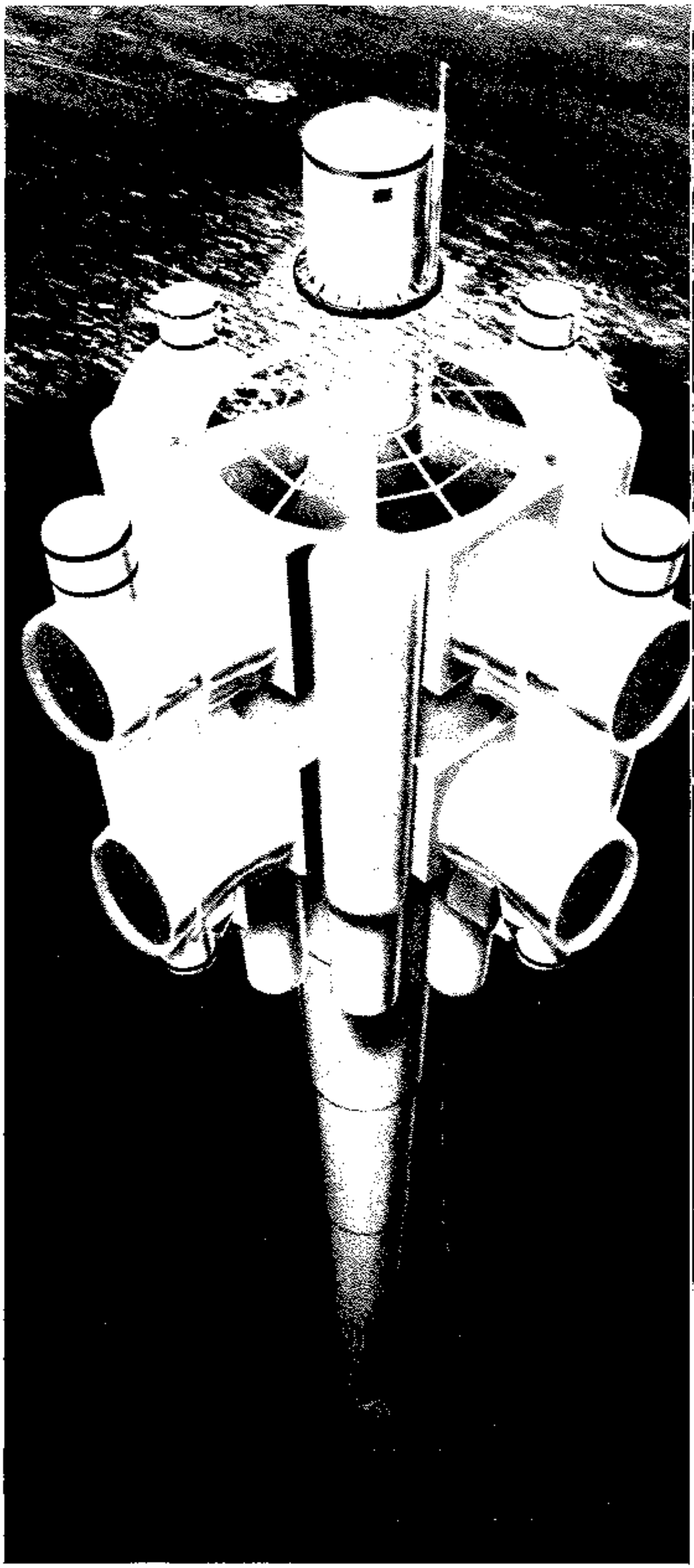
One renewable energy resource—hydroelectric power—was developed decades ago; it is the nation's third-largest source of electric energy, and it is expected to expand in the immediate future as its relatively inflation-proof economics become increasingly attractive. In 1980 hydro produced 12% of the nation's electric energy, right after coal (50%) and natural gas (17%), but just ahead of nuclear (11%) and oil (10%) and far outdistancing solar, wind, and geothermal.

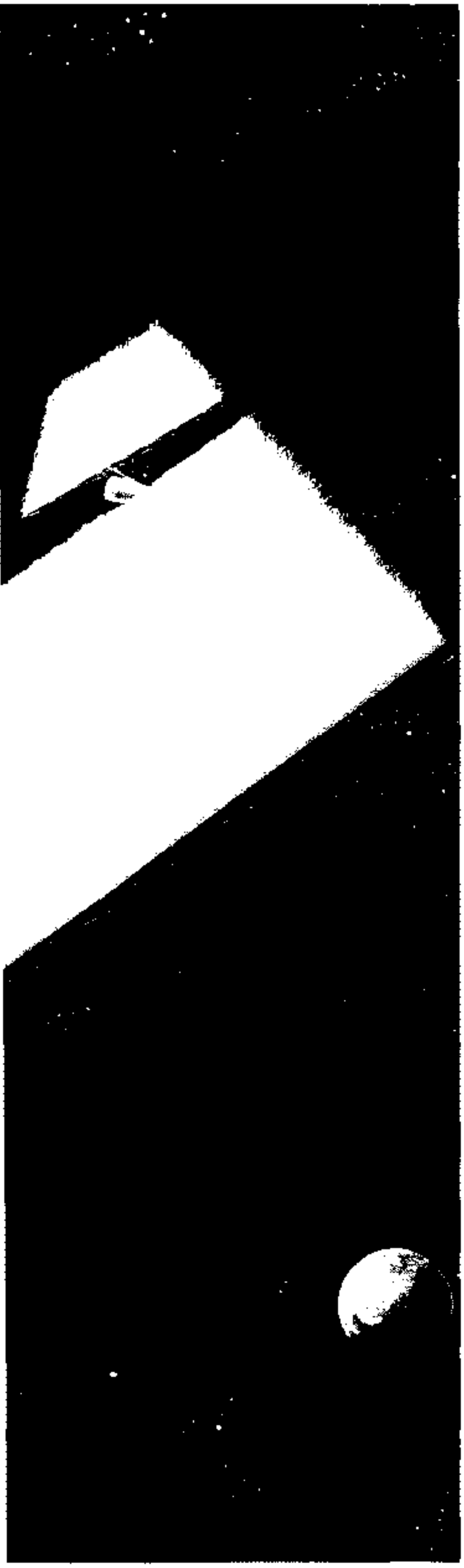
Hydro was first used to generate electricity in the 1880s, but by the 1940s large central plants fired by fossil fuels produced lower-priced power, and interest in small hydro receded. In the 1970s increases in the price of power from oil and other conventional fuels prompted electric utilities and others to reassess hydro.

Of course, the choicest hydro sites have already been taken, and many other potential sites have long since been claimed by dams built for other purposes or have been set aside for preservation of the natural environment. But existing dams and powerhouses can be redeveloped to yield more generating capacity, and nongenerating dams used for water management can be retrofitted to produce electricity as they continue to carry out their original functions. Redevelopment spares the costly construction of new dams and powerhouses. New engineering techniques and ways of minimizing environmental effects will also permit carefully designed hydro plants to be built at sites once considered unfeasible, such as smaller sites.

Many groups, including EPRI's Energy Management and Utilization Division, are now investigating the potential of both large and small hydro installations (*EPRI Journal*, December 1980). Hydro's biggest booster has perhaps been the National Hydroelectric Power Study, authorized by Congress as part of the Water Resources Development Act of 1976. The U.S. Army Corps of Engineers was to inventory existing and potential hydro sites, estimate hydro demand and potential, and identify the economic, environmental, and institutional obstacles to its development. Initially, the study identified over 60,000 potential hydro sites, including existing dams and undeveloped sites. Subsequent screening reduced the final inventory to approximately 2100 potentially feasible sites, which could add up to 57 GW of capacity to hydro's current 73 GW and add an annual energy potential of 149,000 GWh to the current contribution of roughly 280,000 GWh. About 40% of the additional capacity would be at existing dams. Bearing out the renewed interest in hydro, the Federal Energy Regulatory Commission's permit applications for exclusive preliminary evaluation of hydro sites increased from 25 in 1978 to over 1200 (for nearly 20 GW) in 1981.

EPRI's recently instituted hydro research is taking a number of approaches to hydro development and is trying to improve plant availability, plant output, and the economics of small hydro. To assist utilities in determining the economic viability of numerous potential hydro sites, EPRI has prepared a simple, inexpensive method for preliminary site screening that will permit users to inventory possible sites, analyze their potential, rank them in order of feasibility, and determine those that merit further investigation. As the price of power from oil, gas, coal, and uranium rises, more and more utilities may discover hydro's new potential. □





Sea, Soil, Sky: Testing Solar's Limits

Gigantic heat exchangers for ocean-thermal energy conversion, vast plantations harvested for fuel, and massive arrays of photovoltaic cells in geocentric orbit have captured conceptual fancy in recent years. But the facts emerging from engineering assessments and the limitation of federal support point to lower priority among the R&D options. For the foreseeable future, greater emphasis will be placed on less grandiose schemes, such as forest and agricultural waste combustion and municipal refuse, which may have significant local impacts.

Biofuel processes, ocean-thermal energy conversion (OTEC), and satellite power systems are electricity generation technologies that could be feasible sometime in the twenty-first century. Apart from wood combustion, which is already a familiar biofuel system, these types of solar technologies are still in the early stages of development and affect most utilities little at present. Nevertheless, utilities need to be aware of the status of these concepts in planning long-term R&D for potential generating options.

Biofuel applications that make sense, such as wood waste combustion, have been in use for decades. But they require a guaranteed feedstock supply and, if a multiparty operation, call for mutually beneficial business arrangements.

OTEC and satellite power systems are intriguing technologies in theory, but in light of the magnitude of development problems, the size of required systems, and limitations in market penetration, the question arises of whether electric utilities should share in underwriting the risks associated with the development of these technologies.

Biofuels

The burning of wastes and residues to produce electricity or process steam is already a well-established practice in the forest products industry, which satisfies about 50% of its own energy needs by burning mill wastes. This currently represents about 1.5 quadrillion (1.5×10^{15}) Btu, which is about 2% of the total annual U.S. primary energy supply of 80 quadrillion Btu.

Several electric utilities, too, have taken advantage of local supplies of wood waste. For instance, Northern States Power Co. fuels its 25-MW peaking plant at Red Wing, Minnesota, with lumber mill wastes. Two boilers, originally fired on coal only, are fed a fuel blend of 80% coal and 20% (by weight) sawdust, wood chips, and bark. The utility has made no significant changes in equipment to accommodate biomass, and in two years it has experienced no operational problems, deposits, emissions, or corrosion beyond those typical of firing coal. The only additional processing required is blending the coal with the biomass, and this higher cost of handling is offset by the lower price of locally available wood waste: $0.5–$0.6/million Btu, as opposed to $1.5/million Btu for coal delivered to the site.

Some other utilities that have found it financially beneficial to burn wood wastes are Burlington Electric Dept. (Vermont), Eugene Water & Electric Board (Oregon), Grand Haven Board of Light & Power (Michigan), and Lake Superior District Power Co. (Wisconsin).

The two major requirements for making wood combustion an economic option are guaranteed supply and minimal transportation costs. Regarding supply, long-term supply contracts, such as those that utilities establish with coal and oil companies, are difficult to obtain because of seasonal and market variations. Also, biomass supplies can easily be affected by bad weather or plant disease. With regard to transportation, if the wood has to be collected and trucked from several distant locations, the fuel may not be worth the cost of transportation. The energy content per unit weight of wood is half or less that of good-quality coal because moisture content is higher and the density of material is lower. Hence, the transportation cost for wood per unit of energy may be double that for coal. For these and other reasons, commercial wood-burning power plants tend to be limited in size to 10–50 MW.

These two factors—guaranteed supply and transportation—are crucial to the feasibility of other types of biomass as well, such as wheat straw, oil-seed crops, and fast-growing trees like eucalyptus and alder that could be cultivated in the future on energy farms.

The question remains of whether it will be socially acceptable to use land, water, and fertilizer to produce crops for fuel rather than for food, feed, or fiber. Two potential solutions might be to limit biofuel production to plants like the creosote bush that will grow in arid conditions and poor soil and/or to select plants like sunflowers that can be used as food and feed as well as fuel.

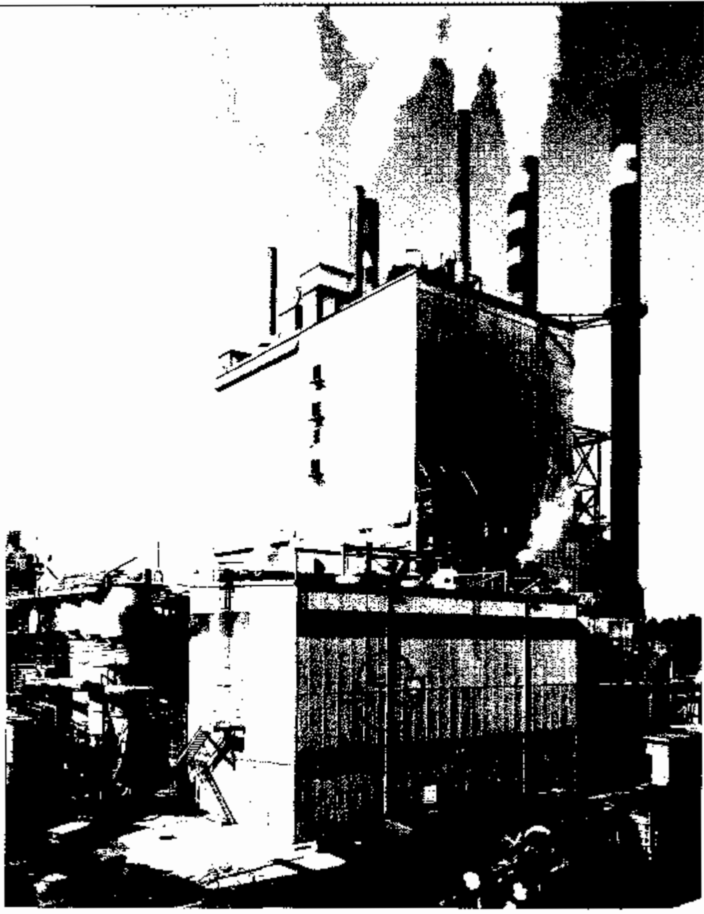
Finding plants suitable for cultivation as electric utility fuel will take years of research. One EPRI contractor, the University of California at Davis, experimentally determined that *Euphorbia lathyris*—a desert plant—produced an inadequate harvest in the arid conditions it was thought to enjoy. A long-term solution to problems of this sort may arise from basic research on genetic engineering, in which test-tube plants are developed specifically to enhance the characteristics most important for their effectiveness as a fuel. However, it is unlikely that the efficiency of photosynthesis can be increased considerably, so the energy contribution from biofuels is unlikely ever to exceed a few percent of national needs.

Another possibility for the future is the development of other processes for using biomass, namely, conversion to combustible liquids, gases, and other solids (e.g., charcoal). Two categories of processing are being tried: thermochemical and biochemical.

The thermochemical processes—pyrolysis and gasification—involve heating the biomass. Pyrolysis, heating in the absence of air, is generally a lower-temperature process that forms gases, liquids, and solids; gasification, a higher-temperature operation that takes place in the presence of an oxidant (e.g., air), principally produces gaseous fuels.

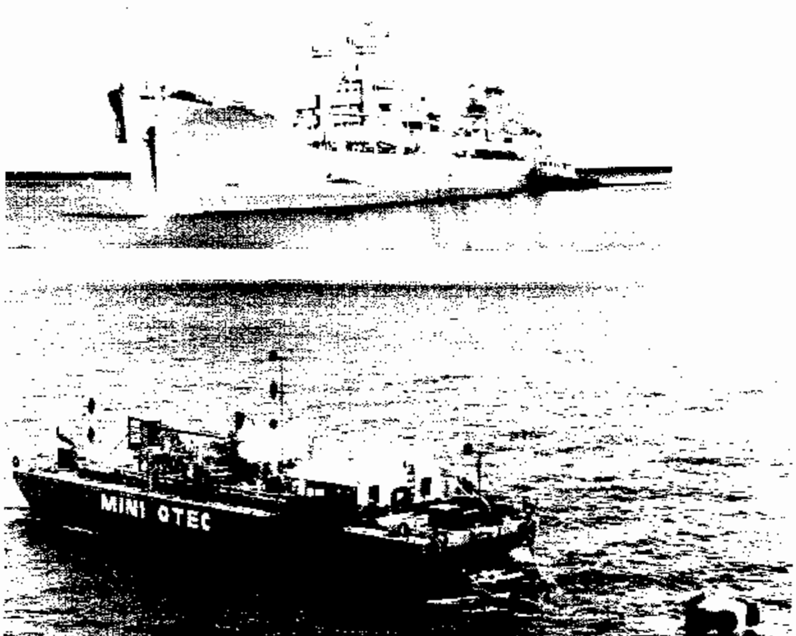
The biochemical processes are all fermentations, that is, microbial transformations of organic feed materials that take place without oxygen and produce alcohols and organic chemicals, such as methane, ethanol, acetic acid, and acetone.

Before biomass can be processed thermochemically or biochemically, it must be prepared, whether reduced to small chips, dried, compressed, or treated with enzymes or acids. Such pretreatment increases the cost of the end product.



Wood wastes from Weyerhaeuser Co.'s pulp and paper factory (rear) are burned to produce steam. In this cogeneration facility, the steam is first routed to drive the turbine generators for Eugene Water & Electric Board (foreground) and is then directed back to Weyerhaeuser's manufacturing process.

OTEC takes advantage of the temperature difference between surface and deep waters to drive turbine generators. The government test facility, OTEC-1, was built by TRW, Inc., and Global Marine Development. Mini-OTEC was backed by the state of Hawaii, Lockheed Missiles & Space Co., Inc., Alfa-Laval Thermal, Inc., and the Dillingham Corp.



Production of fuels by these processes also raises the question of market competition: If a fuel derived from biomass is clean-burning and produced in a liquid or gaseous form, will it not be preferentially drawn into the transportation market rather than the utility market?

In addition to plant-derived biofuels, manure, sewage, and municipal solid waste could become sources of energy for electricity generation. However, the amount of the resource is small from an electric utility standpoint, and institutional barriers may exist. For example, several independent parties may be involved: the electric utility itself, the city government, the sanitation company, recycling organizations, farmers, and individual homeowners. Historically, it has been difficult to define program objectives that meet the needs of all parties involved.

The applications that are emerging for biomass, manure, sewage, and municipal solid waste are basically regional ones. Although these resources may never contribute more than a few percent to the U.S. primary energy supply, local or regional situations may exist where it makes economic and technical sense for these resources to provide a portion of a utility's fuel needs. EPRI will continue to monitor technological advances in these fields to permit utilities to apply these concepts to their local situations when feasible.

Ocean-thermal energy conversion (OTEC)

The concept of generating electricity with OTEC systems takes advantage of the approximately 40°F (22°C) temperature difference between the surface and the depths of tropical, subtropical, and equatorial ocean waters. Because the United States has a limited warm water resource and because the ratio of coastal area to inland area is small, relatively few U.S. electric utilities have shown an interest in this technology.

However, two basic designs have been investigated: closed cycle and open cycle.

In the closed cycle, warm surface water is drawn into the system to heat a working fluid, such as ammonia. The liquid ammonia vaporizes when its temperature reaches about 60°F (16°C) and expands to turn a turbine generator; after it has passed through the turbine, it is condensed back to liquid form by cold water drawn from the ocean depths through a huge vertical pipe.

The open cycle requires no working fluid or heat exchangers. Instead, surface water is flashed to steam in a partial vacuum. The steam drives a turbine generator and is then condensed by cold water from the depths. With minor modifications to this system, the open-cycle design can provide fresh water as a by-product.

A characteristic of both open- and closed-cycle systems is that they are extremely inefficient in terms of energy conversion because the temperature difference on which their operation is based is very small. For this reason, OTEC systems must be built to enormous proportions if they are to generate enough electricity to be economically worthwhile. Comments David Jopling, coordinator of research and development for Florida Power & Light Co., "To my knowledge, there is no electric utility, no architect-engineer, no equipment manufacturer, and no vendor presently in the electric power business that has any direct experience with the design, construction, operation, and maintenance of facilities of the magnitude of size that OTEC is proposing to operate." He adds, "I'm not saying it can't be done; I'm just saying it hasn't been done."

Before any commercial-sized system can be contemplated, heat exchangers larger than any that now exist must be designed. Pumps capable of moving a vast amount of water will be needed; for example, a 100-MW OTEC plant would have a water flow comparable to that of Boulder Dam. Cold water pipes measuring 3000 ft (900 m) long and 100 ft (30 m) across must be designed, fabricated, and installed in the ocean environment. Such pipes are far larger than any yet made.

Solar salt ponds operate on a principle similar to that of OTEC. The sun's heat passes through the top, freshwater layer of the pond and concentrates in the lower, salty layer. Ormat Turbines of Israel has operated test ponds for several years.

Near St. Malo in Brittany, France, a 240-MW tidal power plant spans the River Rance. Because tides do not give a constant water flow, the plant can produce power only about 25% of the time.

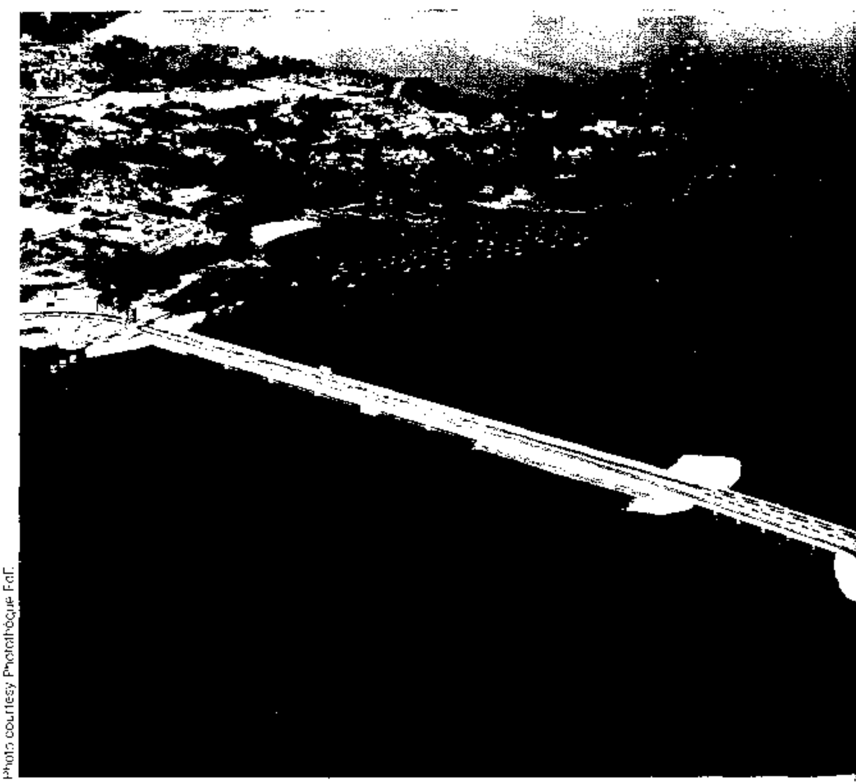


Photo courtesy Photothèque FdF

The entire system, whether shaped like a ship, a sphere, or an oil rig, must be moored or otherwise kept in position in depths at which no vessel has ever before been stationed.

In addition, no turbines of 10 MW or larger are available that operate at the low pressures OTEC systems demand. Moreover, the design, manufacture, and deployment of the cable required to carry electricity to shore must be better understood. For example, the portion of cable leading directly from the OTEC plant to the ocean floor would be subject to severe stresses from sea currents and eddies in addition to those caused by its own weight.

In fact, the entire OTEC system would have to be able to withstand severe storms over many years, corrosion by salt, erosion by the constant movement of fluids, and biofouling caused by growth of algae and encrustation of barnacles and other marine life.

An alternative to the stationary system concept is the OTEC plant ship, which avoids the complexities of cabling electricity to shore and also enables the OTEC system to move seasonally to locations of warmest surface water. In the plant ship, the electricity generated would power equipment for processes to produce such chemicals as ammonia.

The grazing plant ship (so named for its probable speed of 0.5 knots) could also be designed for on-board processing of energy-intensive products like aluminum, magnesium, nickel, various alloys, or semiconductor materials. Or the ships might even serve as mining platforms for extraction of manganese, copper, cobalt, and nickel from the seabed.

As yet, only the stationary system has been tried—stationary in name only, as both demonstrations (one a DOE effort and the other a private-industry system) are cradled in converted ships.

The federal OTEC program was born in the early 1970s, when ocean energy systems were selected as one of a group of six options for investigation in terms of their potential for reducing the nation's dependence on imported oil. The DOE test facility, OTEC-1, was built by TRW, Inc., and Global Marine Development and installed on a 26,000-ton converted tanker, which was first moored 18 miles (29 km) off Kawaihae Harbor, Hawaii, in July 1980.

The research aims were to prove heat exchanger performance and thermal efficiency and to assess levels of corrosion and biofouling. The system was a closed-cycle operation incorporating a 1-MW titanium tube-and-shell heat exchanger, which could simulate 10 MW of capacity. It had three cold water pipes, each 2800 ft (853 m) long and 4 ft (1.2 m) in diameter, and the deepest ocean moor in the world (4000 ft; 1219 m). The system did not include a turbine, however, and therefore could not generate electricity. It has now been retired, and federal funding for overall OTEC R&D in FY82 is uncertain.

"The next step would have been a totally integrated system," says Carmen Castellano, DOE project officer in the Division of Ocean Energy Systems. "A pilot plant in the mid-1980s that would be the real baseline to which utilities could look and say,'Yes, it's real,' or 'No, we don't believe it.'"

Island markets, where the OTEC resource base is comparatively large in relation to energy needs and where the population is mainly if not wholly dependent on oil-generated electric energy, represented DOE's first target: Hawaii, Puerto Rico, the Virgin Islands, Guam, American Samoa, and others.

The second OTEC demonstration, Mini-OTEC, was cooperatively supported by the state of Hawaii; Lockheed Missiles & Space Co., Inc.; Alfa-Laval Thermal, Inc.; and the Dillingham Corp. at a cost of about $3 million. The demonstration took place between August and November of 1979 off Keahole Point, Hawaii, and produced between 12 and 15 kW of net power (50 kW gross). A converted U.S. Navy scow housed the equipment, which included a titanium-plate heat exchanger and a cold water pipe 2170 ft (661 m) long and 2 ft (0.6 m) in diameter. This project provided a working test of the concept and was believed to be technically successful in that the performance was comparable to predictions.

Despite these results, it is a fact that the only areas in the United States that have the appropriate differential in water temperatures, in addition to being close enough to land for transmission purposes, are the upper Gulf of Mexico and the lower eastern coast of Florida. Because of this limitation in suitable geographic locations, a relatively small number of U.S. electric utilities could benefit from OTEC generation in terms of the baseload capacity increment on their systems.

In addition to the United States, a number of nations have been active in OTEC research: Japan, France, Sweden, the Federal Republic of Germany, and the Netherlands. The island nation of Nauru near the equator in the central Pacific has entered into an agreement with the Japanese to build a 100-kW land-based system. With a larger OTEC system, the island might eventually become an attractive site for energy-intensive industries.

Solar ponds, waves, and tides

Solar ponds work on a principle similar to that of OTEC, but here the temperature difference that makes electricity generation possible exists between a layer of highly concentrated salt water and a layer of fresh water that floats on its surface. The sun's heat passes through the freshwater layer, which does not warm up significantly, and is trapped in the salty layer, which can reach about 200°F (93°C). Heat exchangers, pumps, and turbine generators are used in much the same way as in an OTEC system.

Southern California Edison Co. and Ormat Turbines of Israel are studying the feasibility of building a 5-MW demonstration plant at the Salton Sea, California, and eventually developing a 600-MW commercial generating facility. Ormat has operated test ponds in Israel for several years and is currently constructing a 5-MW facility there.

The Tennessee Valley Authority is also constructing a solar pond for research purposes near Chattanooga, Tennessee. TVA hopes to demonstrate that the pond, which should be fully operational by summer 1982, can provide heat at a sufficiently high temperature to permit electric power generation.

Although ponds may have appeal in special applications where appropriate conditions already exist, such as a supply of brackish water and a sunny climate, their requirements for land area and the availability of water and salt make them unlikely to contribute in large measure to the national energy supply. Because of the low energy density of solar radiation, an extensive collecting area is necessary. For example, assuming solar radiation at the world average, about 2800 ft^2 (260 m^2) of water are required in order to replace one barrel of oil a day—if the collector is 100% efficient. Efficiencies are in fact very much lower; therefore, far larger areas of water are needed. In addition, about one-third of a ton of salt must be added to every square meter of pond. In building a solar pond, provisions must be made to prevent leakage, both of the solution from the bottom of the pond and of heat into the ground.

Although these types of losses present a real challenge for the development of solar ponds, such problems seem minor when compared with the potential loss of entire generating systems that depend on waves and tides. The unforgiving ocean environment is extremely hard on machinery and could actually destroy generating equipment.

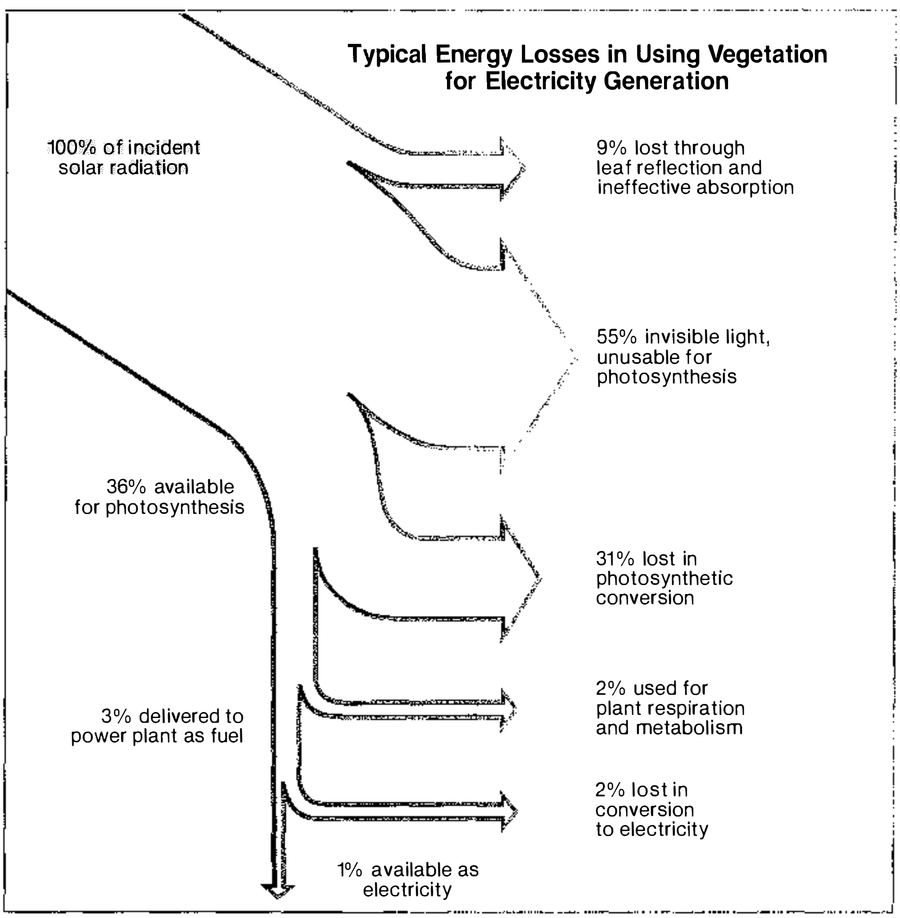
Coastal and deep-ocean wave power has been studied, particularly in Great Britain. Wave power along our North Atlantic coast, which may have the highest annual energy potential of all U.S. wave resources, is estimated to average about 10 MW per mile of shoreline. If a fifth of all this energy could be converted to electricity, the effective supply would be 2 MW per coastal mile. Considering that 500 miles of coastline equipment would be needed to generate enough power for a million households, this would not seem a practical concept.

Deep-ocean wave energy may be 5–10 times greater than at the coastline. However, as with OTEC, collecting wave energy in the deep oceans presents extremely harsh conditions for a plant, its mooring mechanism, its transmission line, and its operating crew. Nevertheless, several countries have built devices to harness wave power. Japan probably has the largest, an 80-m-long ship's hull, in which 20 turbines are powered by oscillating columns of air and water. During two years, the system has produced up to 150 kW of electricity. It is believed that output could be increased by a factor of 10 with some redesign.

As an energy resource, tide power is difficult to harness; it is not constant, nor does it occur on a regular daily schedule because of the orbit of the moon. Only a few locations in the world have a daily tidal range (the difference in sea surface height from high tide to low tide) great enough to justify the huge cost of building a dam to generate electricity.

One of the few suitable sites is Passamaquoddy Bay, an arm of the Bay of Fundy between Maine and New Brunswick, but so far construction of a dam even at this high-tidal-range location has been considered uneconomic. Another potential site is the estuary of the River Severn in Britain; but again, cost is the prohibiting factor.

In Brittany, France, a tidal plant was built across the River Rance in 1966. It consists of twenty-four 10-MW turbines that together can generate 240 MW in whichever direction the tide is flowing. However, operating and maintenance



experience with the plant has not been encouraging; on average, the plant has operated for only about a quarter of the time, or 2000 hours a year.

Satellite power system

The orbiting satellite power system (SPS) is a concept designed to circumvent the problem of intermittent energy supply suffered by other solar setups; the satellite would be positioned far enough from earth to receive a nearly constant supply of sunlight, effectively avoiding the phenomenon of night. During the spring and autumn equinoxes—two periods a year of about 43 days each—the sun's rays would be blocked for about 75 minutes a day when the Earth's shadow fell on the SPS, but such interruptions would be quite brief in comparison with the normal terrestrial day-night cycle.

The SPS is generally envisaged as a very large photovoltaic electric power generator. Its components would be launched into geosynchronous orbit by a space vehicle whose gross lift-off weight would be about four times that of the Apollo Saturn V launch vehicle. The SPS would collect solar energy and convert it to electricity by an array of photovoltaic cells of approximately 50 km^2. This dc electricity would then be converted to microwaves and transmitted to a 30-acre (130-km^2) receiving station on Earth. The microwaves would be reconverted to dc and then to ac electricity before being fed into a utility system.

The SPS concept has been evaluated by DOE and the National Aeronautics and Space Administration (NASA), who consider that an SPS might be constructed around 2000, with two satellites (and their ground stations) to be built each year for a period of 30 years.

However, there are several practical considerations that pose serious problems for SPS. For instance, environmental concerns surround the concept: long-term medical and biologic implications for humans, animals, and birds of beaming microwaves to earth; effects of ionospheric heating on local weather and regional climate; and radio frequency and electromagnetic interference to airplanes, radar, and other communications equipment from SPS microwave transmission. As yet, the effects are unknown.

The NASA plan involves 60 satellites, each of which would deliver approximately 5 GW of power at the utility interface. (For comparison of scale, a typical new fossil fuel generating station made up of 6 units may produce 1 GW.) Such large single units of capacity, positioned, as they would be, remote from Earth, would constitute an enormous reliability risk. In the event one unit fails, the capacity lost would be equivalent to the output of five conventional 1-GW generating stations.

In addition, the question of vulnerability of an SPS needs to be examined in the light of a threat to what might become a major component of the future U.S. electric power system. Also, international agreements would have to be obtained before any launching in order to allocate geostationary orbit space and microwave frequencies for the SPS.

NASA researchers estimate that each satellite and ground receiving antenna, plus associated equipment, would cost $10–$20 billion (1977 dollars), with the entire 60-satellite system costing from $600 billion to $1.2 trillion. This gigantic bill includes expenditures for developing the space transportation, training crews of 600 to assemble the SPS in space, and obtaining solar cell and satellite materials in the quantities required (which would consume much of the global supply of some materials at present levels of production).

In a report published in July 1981, the National Academy of Sciences stated that although solar power satellites might hold great potential for the twenty-first century, it would be premature to spend R&D funds on them in the 1980s. Further, much of the needed research for SPS will be conducted for other purposes. The report documents a review of the 3-year, $20 million DOE–NASA program by the Satellite Power Systems Committee of the National Research Council, the NAS operating arm.

The committee concluded that the program, which evaluated economic, social, political, and environmental aspects of SPS, was well conceived but extremely optimistic about costs. For instance, the committee found that the costs of crystalline silicon cells may be 10–50 times higher than the cost assumed in the program. Also, projected costs for transport to low Earth orbit were low by a factor of from 2 to 3. Moreover, the committee pointed out that aerospace projects are themselves suffering from cost overruns. Whereas the NASA program estimated an SPS to cost about $4000 per kW of installed capacity around 2000, the committee's best estimate stands at $10,000 per kW. This last figure is approximately 10 times the present average cost per kW of a conventional baseload electric power plant.

Many novel alternatives to fossil fuel combustion have been investigated in the overall R&D planning process. Those with the higher costs and risks have been given lowest priority and are, for the time being, losing federal support. Nevertheless, those concepts may be revived at some time in the future when, for reasons now unknown, they may appear more attractive. ■

Further reading

Biofuels: A Survey. Special report prepared by John R. Benemann, June 1978. EPRI ER-746-SR.

Evaluation of Biomass Systems for Electricity Generation. Final report for RP1348-7, prepared by Battelle, Columbus Laboratories (forthcoming).

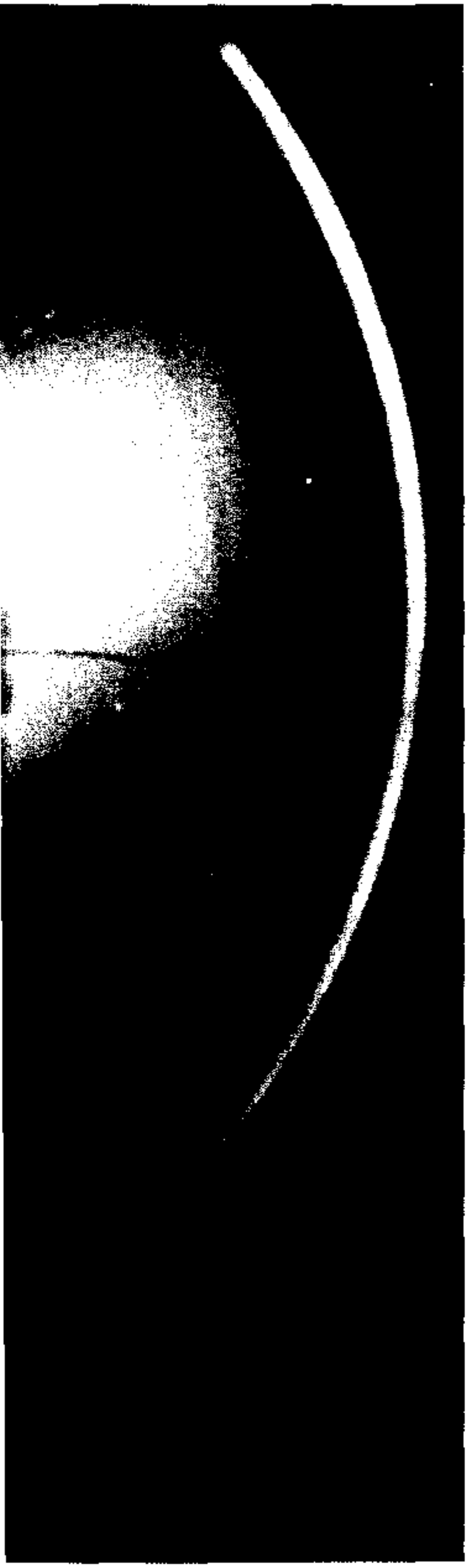
Feasibility Study of Cogeneration Using Wood Waste as Fuel. Final report for TPS79-736-1, prepared by Rocket Research Co., August 1980. EPRI AP-1483.

Feasibility Study of Wood-Residue-Fired Cogeneration at Heppner, Oregon. Final report for TPS79-736-2, prepared by Schuchart & Associates, Inc., April 1980. EPRI AP-1403.

Ocean-Thermal Energy Conversion: A State-of the-Art Study. Special report prepared by Massachusetts Institute of Technology, July 1979. EPRI ER-1113-SR.

Satellite Power System: Utility Impact Study. Final report for TPS79-752, prepared by Systems Control, Inc., September 1980. EPRI AP-1548.

This article was written by Jenny Hopkinson, feature writer. Technical background information was provided by Edgar DeMeo, Advanced Power Systems Division.



Fusion: From Science to Engineering

With the vision of an unlimited and readily accessible fuel supply, several nations of the industrialized world have committed themselves to continued development of fusion technology. Research on scientific feasibility is well under way, and the shift to solving the immense engineering problems is now getting started. These problems are sufficiently complex to place the commercialization of actual power-producing fusion facilities at least 40 years in the future. A great number of questions about the nature, scale, and purpose of fusion reactors remain unanswered, clouding the direction future development efforts should take.

Fusion power research in the United States is moving from the phase of basic scientific research—that is, understanding the physics of fusion—to the phase of engineering development. This transition opens up a wide variety of potential pathways to an actual energy-producing plant.

Scientists and engineers are fairly confident that fusion energy break-even (as much energy produced as is required to set up the conditions for energy release) can be achieved within 5 years in fusion devices now being constructed. A U.S. reactor that will produce net energy (significantly more energy produced than is needed to operate the device) is probably an additional 10 years away, and a first commercial demonstration plant is perhaps 20 years in the future, although other nations—most notably, Japan—have expressed confidence that they will be able to reach this target earlier.

The long development time necessary to demonstrate a working fusion reactor is a measure of the extreme difficulty of the undertaking. A controlled fusion reaction requires that the gaseous fusion fuel be heated to incredibly high temperatures (100 million degrees Celsius) and that the plasma formed be suitably contained and kept away from the reactor's walls.

The formidable scientific and engineering obstacles that these requirements pose would probably remove controlled fusion from consideration as a promising future energy option were it not for the potential payoff. The promise, in brief, is that if fusion power systems could be developed, there would be a virtually unlimited supply of fuel available to run them. Earth's oceans are vast reservoirs of deuterium, the fusion fuel most likely to be used, at least initially. Deuterium can be extracted from ocean water by an uncomplicated and economical process, and the world's supply of fusion deuterium fuel would last well over a billion years at current world energy consumption rates.

The present transition from fusion science to fusion engineering means that basic decisions have to be made. Tradeoffs involving issues of technology, versatility, performance, and cost will affect these critical decisions, which, in turn, will determine the type and scale of fusion devices to be used in early commercial fusion plants. The engineering choices made in the near term will profoundly influence the course of fusion energy development for the next 20 years.

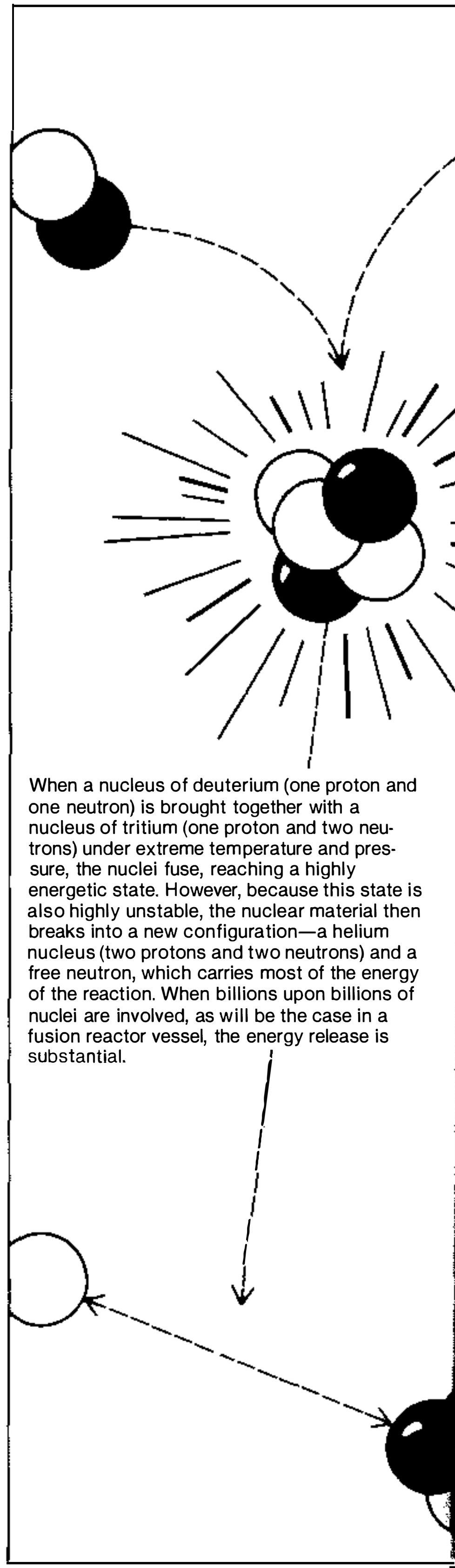
Magnetic confinement

To date, fusion energy programs in the United States, as well as those throughout the world, have emphasized research aimed at demonstrating an energy break-even device. Creating such a machine is not an easy achievement, regardless of whether the fusion device is based on the magnetic or the inertial confinement approach.

The leading contender in magnetic confinement is a doughnut-shaped (toroidal) configuration called a tokamak. An alternative type of magnetic device has a linear geometry. For example, the mirror machine is a straight tube surrounded by magnets along its length, with stronger magnetic fields at its ends; the plasma particles stream toward the ends, where the stronger fields reflect them back. Of all the variations of both toroidal and linear configurations, the closest approach to the conditions required for fusion burn has been achieved in tokamaks.

The biggest magnetic fusion device and the nation's first that will be capable of producing a significant quantity of fusion energy (although not electricity) is the tokamak fusion test reactor (TFTR) being built at the Princeton Plasma Physics Laboratory. Its startup is scheduled for August 1982.

Second in size to the TFTR is the mirror fusion test facility (MFTF), now under construction and scheduled for operation in 1985 at the Lawrence Livermore National Laboratory. This machine employs superconducting magnets of unprecedented size and is also designed to



When a nucleus of deuterium (one proton and one neutron) is brought together with a nucleus of tritium (one proton and two neutrons) under extreme temperature and pressure, the nuclei fuse, reaching a highly energetic state. However, because this state is also highly unstable, the nuclear material then breaks into a new configuration—a helium nucleus (two protons and two neutrons) and a free neutron, which carries most of the energy of the reaction. When billions upon billions of nuclei are involved, as will be the case in a fusion reactor vessel, the energy release is substantial.

FUSION BASICS

Nuclear fusion involves joining, or fusing, the nuclei of light chemical elements through the application of extreme temperatures and pressures. These conditions are necessary to speed up the motion of the nuclei enough to overcome the electrostatic repulsion that normally keeps them apart. When this happens and the nuclei fuse, nuclear particles are freed, and the extremely rapid motion of these particles represents a release of energy that can be recovered for practical use in the form of heat.

However, heating a gas to the temperatures required also has another effect—it causes electrons to be stripped from the nuclei. The resultant mixture of positively and negatively charged particles is called plasma. As the plasma is heated, it expands; unless it is contained, it becomes thinner and thinner until its low density makes substantial fusion energy release impossible.

The sun, which is a huge fusion reactor, accomplishes the reaction with relative ease. There is no plasma containment problem because the enormous mass of the sun holds the plasma by gravity to densities well in excess of those necessary for the fusion reaction. But there is no way to provide such a large gravitational field in a nuclear fusion device on Earth. Nor can a plasma density be achieved on Earth that would permit a fusion reaction at the relatively low temperature of the sun (15 million degrees Celsius); on Earth, the temperature must be higher—about 100 million degrees Celsius.

Heating the plasma can be accomplished by a number of means, including electric currents, radiofrequency waves, and neutral-beam heaters. Containment of the plasma is a much more formidable problem, however, because the plasma would immediately be cooled to subfusion temperatures by contact with any sort of physical container. There are two containment methods presently being pursued, differentiating fusion research into two areas: magnetic confinement fusion and inertial confinement fusion.

With magnetic confinement, large magnetic fields are used to control the plasma, which responds because it is made up of free charged particles. The magnetic field contains the plasma and keeps it from touching the walls of the physical container. Many configurations have been proposed for such a magnetic bottle, the most highly developed of which is the toroidal (doughnut-shaped) tokamak.

In inertial systems, brief but intense pulses of laser light or of atomic particles are used to irradiate a succession of fuel targets, or pellets (which can be as small as $\frac{1}{500}$ the size of a grain of rice), that contain fusion fuel. This irradiation compresses and heats the fuel to the density and temperature required for fusion ignition. The resultant rapid burning of the fuel yields a microexplosive energy release.

The fuel that will probably be used in early fusion devices is a mixture of two isotopes of hydrogen—deuterium (heavy hydrogen) and tritium (double-heavy hydrogen). Such a mixture makes up the plasma in magnetic devices and at high pressure is inside the pellets used with inertial devices. Deuterium is easily extracted from ordinary seawater; tritium occurs only rarely in nature, but can be bred from lithium by using well-understood nuclear processes. Such breeding will provide tritium to replace that which is burned in the fusion reaction, thus closing the fusion fuel cycle.

Tritium breeding is accomplished in the fusion blanket, which surrounds the reaction chamber. The blanket also serves the essential function in a fusion power plant of converting the nuclear energy released from the fusion reaction into thermal energy, which can then be used to generate electricity. The blanket can also be used to breed fuels for conventional fission power plants from relatively plentiful nonfissile material in what is known as a fusion-fission hybrid reactor.

Whether the fusion blanket is used to generate power or to produce fuel, its development is seen as a complex engineering challenge that is of prime importance to the future application of fusion technology. □

achieve the equivalent of break-even conditions (using hydrogen only).

A number of operational toroidal machines around the country are noteworthy because of the technological variations and innovations they are being used to investigate. For example, in 1978 the Princeton large torus (PLT) achieved plasma ion temperatures of about 65 million degrees Celsius, using neutral-beam injectors for heating, and in 1980 confirmed the scientific feasibility of using radio-frequency waves to heat plasma. The poloidal divertor experiment (PDX), also at Princeton, has essentially pure plasma at 11 million degrees Celsius.

The Oak Ridge National Laboratory has demonstrated steady-state operation of its first version of the Elmo bumpy torus—a toroidal configuration that differs from the tokamak in that the magnetic fields of the torus are not smooth. The capability for such continuous operation, not yet achieved by tokamaks, is particularly important for the development of commercial systems.

The Doublet, in operation at General Atomic Co. near San Diego, was designed to improve magnetic confinement while reducing the size of the magnets, which are among the most expensive components in magnetic fusion devices. General Atomic has also built and is testing another toroidal machine that it hopes will attain ignition of fusion fuel by ohmic (resistance) heating alone.

Magnetic confinement fusion, represented by these and other experimental devices, is technically more advanced at this stage than the other option, inertial confinement. The federal government has established the magnetic approach as its choice for fusion engineering development in passing the Magnetic Fusion Energy Engineering Act of 1980. This legislation established a goal to build and successfully operate a magnetic fusion demonstration facility before the end of this century. It further mandated that base programs for fusion energy research be maintained, including a strong R&D program in advanced fusion fuels, and that appropriate measures be implemented to ensure the availability of an uninterrupted supply of scientific and engineering talent in support of the magnetic fusion energy effort.

To pursue these ends, the act authorized the establishment of a magnetic fusion engineering center. The initial purpose of the center would be the definition, design, and construction of the next-step fusion machine—the fusion engineering device—by 1990. The act also stipulated that DOE define a structure for the fusion engineering center and draw up a comprehensive program management plan for the center's research. Because of embroilment regarding recent budget actions and program reevaluations, the fusion engineering center still remains undefined.

Inertial confinement

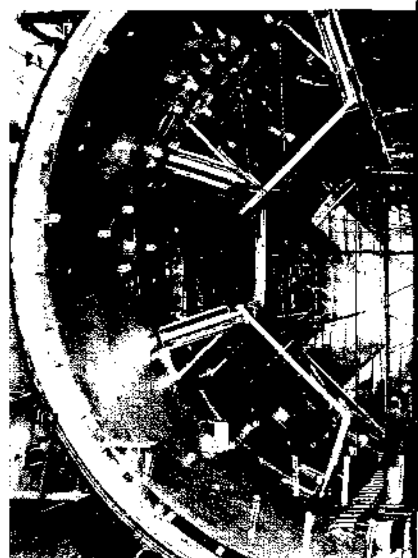
In the inertial confinement approach to fusion, a pulsed-energy source, called the driver, is used to compress and heat a succession of fuel targets injected into a reactor. Lasers were the first drivers used in such an application, but more recently particle-beam systems using beams of lightweight ions (e.g., hydrogen or carbon) or heavy ions (e.g., uranium) appear to have far better potential for achieving necessary driver requirements.

At this time there is no federal funding for commercially oriented inertial fusion research; only research for military applications is supported. Such research includes simulation of weapons effects and study of the physics of ultrahigh material densities. EPRI is continuing to study the commercial engineering development needs of inertial fusion. Fortunately, the DOE military applications program does provide funding for certain related research, such as driver development—a necessary element of any future commercial inertial system.

The laser inertial approach has been pursued through research on a number of large devices, including Shiva at the Lawrence Livermore National Laboratory, Helios at the Los Alamos National Labo-

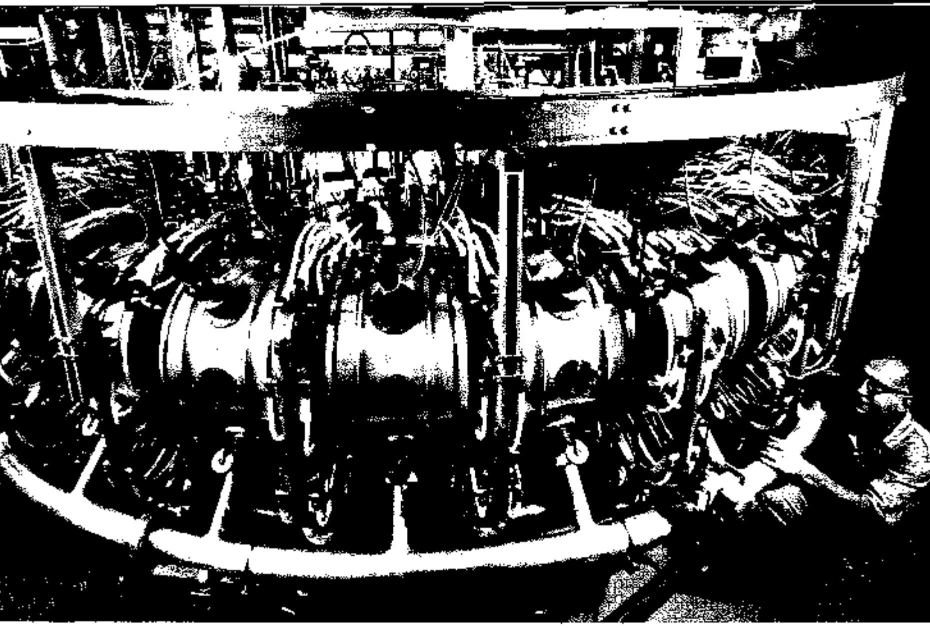
The Elmo bumpy torus, a steady-state magnetic confinement fusion device, uses electr rings to provide a stable environment for a toroidally confined fusion fuel. This system, operating at Oak Ridge National Laboratory, has provided the initial data for the design ar construction of a much larger Elmo system under the direction of McDonnell Douglas Corp.

A vacuum chamber and magnetic field coils are key components of the mirror fusion test facility, which is under construction at Lawrence Livermore National Laboratory. When completed, the facility will test the vali ity of the tandem mirror concept for fusion confinement.



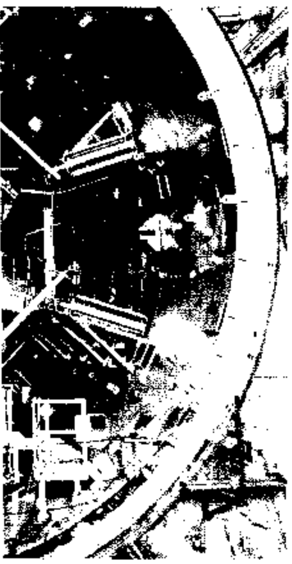
The particle-beam fusion accelerator at San Laboratories is developing and demonstratin the light-ion inertial confinement approach t fusion. After the successful completion of p let implosion and burn tests, expected by 19 it will be upgraded to a device that will allow energy break-even tests. (right)

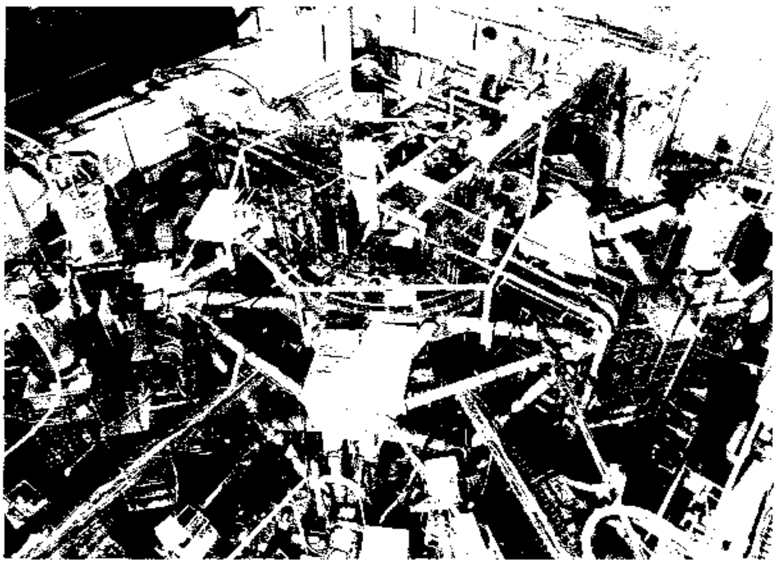
The poloidal divertor experiment at Princeto Plasma Physics Laboratory has demonstrat the ability of a magnetic divertor to purify ar maintain a clean fuel in a stable tokamak sy tem. (far right)

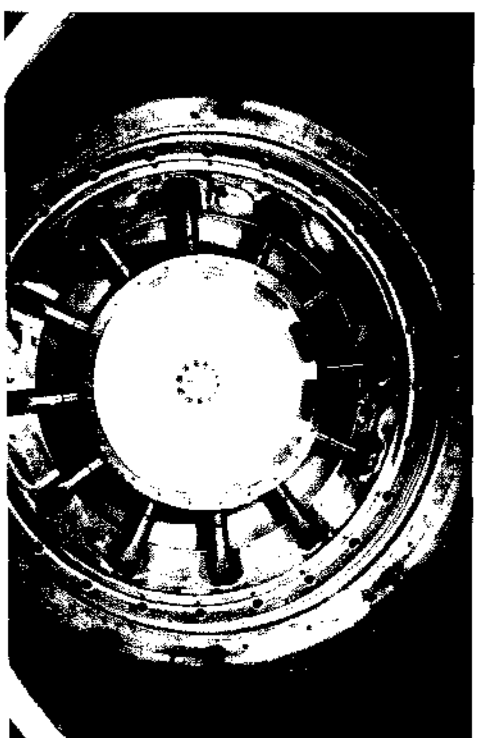


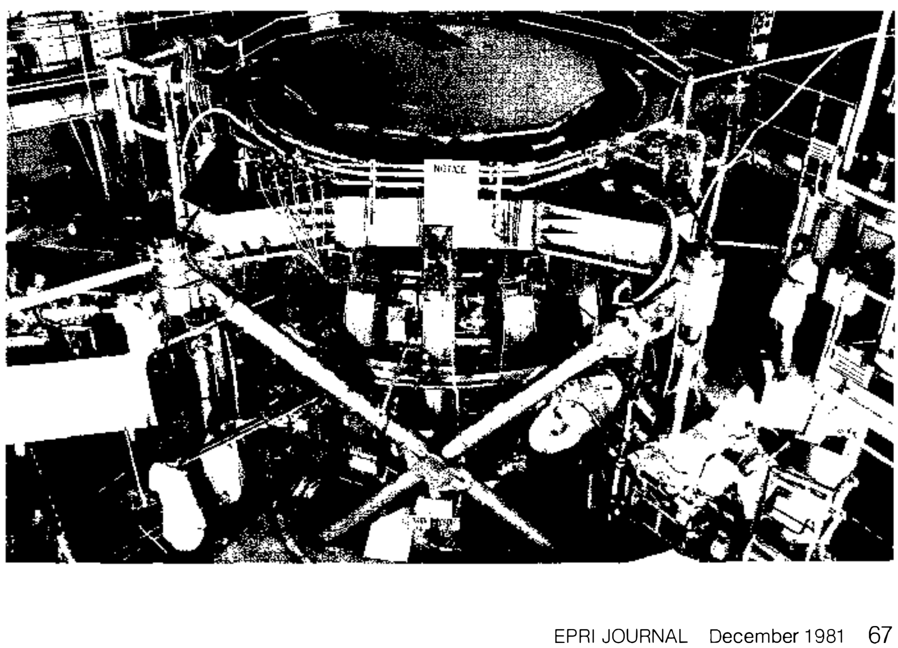
The large-tokamak facility at Princeton Plasma Physics Laboratory has used neutral-beam heating to produce fusion-reactor-like conditions of 65,000,000°C ion temperature and classical fuel confinement. Recently it also demonstrated sufficient heating with radio-frequency power. (center)

A scale model of the tokamak fusion test reactor shows the blanket module and test stand in place between the large toroidal magnetic field coils. This facility is under construction at the Princeton Plasma Physics Laboratory. When completed in 1982, it will be the first to test the ability of a system to make measurable fusion power.









ratory, and Omega at the University of Rochester. Because research has shown a need for even higher laser driver energies, larger systems are now under construction, notably Nova at Livermore and Antares at Los Alamos. Although the laser serves as an excellent tool for scientific development, the more recently introduced particle-beam drivers appear to offer significant advantages for ultimate use in commercial power production. These include better beam production efficiency (25–45%, as opposed to 8% for the laser) and higher coupling of the beam energy into the target. Additionally, the particle beams use lower-risk technology and overall appear to offer lower cost per unit of energy delivered to the target.

Sandia Laboratories has built and operated a light-ion (hydrogen ion) machine called PBFA–I, which will be used to conduct heating and fuel-pellet implosion experiments in 1982. The device has a circular array of 36 power modules that provide high-energy ions to be focused on a central target. When sufficient success at target compression and heating (the so-called significant burn) is attained, expected by 1983, the machine will be upgraded to PBFA–II, which will have more than three times the output of its predecessor. It is hoped that PBFA–II will attain break-even target burn during 1985.

Many believe that there are significant engineering advantages to the inertial confinement approach for producing commercial fusion power. Conceptual designs point to the possibility of a development path with smaller-scale facilities, conventional liquid-metal loops for energy extraction, and physical isolation of the driver from the radiation environment of the reactor vessel containing the fuel.

Whether such advantages materialize as the development of the inertial techniques approaches the level of magnetic fusion remains to be seen. EPRI is conducting a technical risk assessment for inertial confinement fusion that will examine the technical uncertainties and develop a research plan to deal with them. It is hoped that this project will help clarify the issue of the relative advantages of the two approaches.

Engineering challenges

The research programs of the last few decades that investigated the basic science of fusion have also yielded many results in engineering and technology development. There have been significant advances in such areas as magnets, plasma heating, lasers, high-vacuum systems, and various types of instrumentation. Through reactor design studies, many of the technology requirements for fusion plants have been defined, and as a result, specific important areas for future research have been identified.

Probably the area most crucial to the development of a commercial fusion facility is the reactor blanket system. This system is an essential part of a fusion plant because it provides the practical link between nuclear fusion reactions and usable output (energy or fuel). The engineering problems for this system are perhaps more complex than for any other fusion plant component, and blanket development is likely to be a costly and lengthy endeavor.

Although EPRI is conducting a number of projects on blanket systems, its main effort is the design and development of a blanket module to be tested for tritium breeding characteristics on Princeton's TFTR. It is anticipated that early fusion reactors will use tritium as one fuel component. Tritium will have to be bred to ensure a fuel supply. The test conditions will be less severe than those expected in a commercial-scale machine, but this research will nevertheless increase confidence in the blanket design and provide experience with large-size lithium-compound fabrication, operation of a module in a reactorlike environment, and module instrumentation.

A technology option that hinges directly on blanket research is the possibility of using fusion reactors to breed fuel for fission reactors. The breeding process would be accomplished in much the same way as for tritium except that plentiful, nonfissionable heavy elements, such as uranium-238, would be loaded into the blanket in addition to the heat transfer medium. Such fusion-fission hybrid reactors could be designed either as dual-purpose machines (that is, to generate electricity as well as to breed fission fuel) or to breed fuel exclusively.

EPRI is currently evaluating whether work on such a fusion-fission hybrid should be a major effort in its fusion program. Certain scenarios for future energy supply and demand indicate that there could be shortages of fission fuels early in the next century. If this should prove to be the case, the continuation of the fission energy industry will depend on finding new sources of fuel. It has been estimated that one fusion-fission hybrid of less than 1-GW (e) output could supply the annual fission fuel needs of 10 or more conventional 1-GW (e) fission power plants. Of course, the worth of developing the fusion-fission hybrid is predicated on the reestablishment of a robust fission-based nuclear power industry, a reversal of the current trend.

The utility role

Although fusion remains high on the DOE priority list and its budget remains relatively intact, support from the electric utility industry is considered of growing importance as engineering development proceeds. The Magnetic Fusion Energy Engineering Act includes the expressed intention that the fusion engineering center be an industrial organization operated in an industrial fashion; nevertheless, the specific balance of government, industry, and utility involvement has not yet been established.

Because the utilities are almost certain to represent the major market for any fusion devices that are developed, a full understanding of their unique operating environment will be essential in designing an attractive machine. If the research produces a machine that does

FUSION RESEARCH IN OTHER COUNTRIES

Several countries besides the United States, including the Federal Republic of Germany, France, Great Britain, Japan, Italy, and the USSR, are pursuing ambitious programs of fusion research in efforts to develop commercially useful fusion reactors.

A group of western European nations is working jointly on fusion through the European Atomic Energy Community (Euratom). Euratom has just received a recommendation from a scientific review committee (composed of scientists from universities and from the aerospace, electrical, and nuclear power industries) that funding for fusion R&D be increased 30% over the next five years.

In addition to the funding increase, the committee recommended that the joint European torus (JET), a tokamak about the size of Princeton's TFTR, be pushed ahead as fast as possible and completed in 1982. JET is now under construction at Culham, England. The scientific review committee also recommended that Euratom "initiate a substantial and well-balanced program in fusion technology, mainly focused on the solution of the technological problems of NET (next European torus)."

Another joint international project, involving the United States, USSR, and Japan, is the international tokamak reactor (Intor), under the aegis of the International Atomic Energy Agency.

In addition to constructing a large tokamak with superconducting magnets, the Soviets plan to build a tokamak that they say will achieve a continuous fusion reaction by the late 1980s. Stephen Dean, president of Fusion Power Associates, a trade organization, cautions that "these two Soviet devices, taken together, will demonstrate the engineering practicality of fusion before 1990, well ahead of the current U.S. timetable." It is notable that the USSR has as a research goal the development of a fusion-fission hybrid—that is, a fusion plant that will produce fuel for use in fission power plants.

The magnitude of Japan's commitment to fusion energy is such that some Western observers think the Japanese will be the first to demonstrate a fusion power plant. Japan's JT-60 tokamak, about the size and power of the TFTR, is scheduled to begin operation in 1984.

In addition to the Japan Atomic Energy Research Institute, builder of the JT-60, Japanese universities and industry are heavily involved in fusion research, including laser research at Osaka University, studies of heliotrons at Kyoto University, work on a stellarator and bumpy torus at Nagoya University, and research on magnetic mirror machines at the University of Tsukuba.

In March of this year, Japanese scientists recommended a fusion energy development plan that is the world's most ambitious: it calls for Japan to have a 400–800-MW (e) demonstration fusion reactor on-line, generating electricity by 1993. Thus the Japanese plan to skip the intermediate engineering facility that has usually been considered a necessary development step and go immediately to an experimental power reactor. □

not respond to the utilities' needs—a fusion white elephant—it is not likely to be bought and used. The utilities need a reliable device that meshes readily with existing operation and maintenance capabilities.

Identification of such utility needs and evaluation of the potential of various types of fusion devices to meet them has been a major objective of the EPRI fusion program. Using technical risk assessments, the program is now identifying the technical uncertainties associated with engineering designs of systems that may be desirable for utility end use. With this information, the requisite research and technology development plans can be formulated.

The crucial question that must be answered is what is the best development path to follow. The answer is not yet clear, but it will ultimately emerge from other fundamental questions now being explored. For example, what should the ultimate goal of fusion be? Utilities may prefer that it not produce power, but rather that it be a source of fissile fuel that can be used in a stable of well-understood, in-place fission reactors. Should the development path be one of lower physics risk—advancing the plasma confinement concept that now appears to be closest to achieving breakeven? What if this "low-risk" option proves to be unsuitable for utility system integration? Should all activities be focused on magnetic fusion, or should a parallel activity be mounted in inertial fusion? Should, in fact, several configurations for each of these continue to be nurtured to promote flexibility in ultimate applications? If this is done, what criteria should be used to narrow the field during the development effort?

Confronting such a complex of choices makes it apparent that careful planning is necessary to ensure a well-balanced, supportable, and eventually productive development plan. Commitment to a single approach at this time may be premature. It should be apparent that fusion still has a long way to go before demonstrating engineering feasibility and even further for economic credibility. Those supporting fusion R&D must be fully aware of this and convinced of the importance of protecting the support of such long-range research.

Involvement of the utilities is clearly desirable at these decision crossroads to establish what it is they want from fusion and, just as important, what it is they do not want. Such user viewpoints are critical to a comprehensive program management plan, the fusion engineering center, and the fusion engineering device. It would appear that the fusion community and the utilities now have a unique opportunity for jointly directing the development of a new energy source of far-reaching potential. ■

Further reading

"An Overview of Inertial Fusion Reactor Design." *Nuclear Technology/Fusion*, Vol. 1, No. 3 (July 1981), pp. 302–358.

"Capturing a Star." *EPRI Journal*, Vol. 2, No. 10 (December 1977), pp. 6–13.

"How Industry Can Lead the Fusion Engineering Effort." *Fusion*, February 1981, pp. 23–33.

Magnetic Fusion Engineering Act of 1980, Public Law 96-386. *Congressional Record*, October 7, 1980.

"The Next Step in Fusion: What It Is and How It Is Being Taken." *Science*, Vol. 210, No. 4473 (November 28, 1980), pp. 967–972.

Prospects for Fusion Power. Stephen O. Dean, editor. Elmsford, New York: Pergamon Press, 1981.

"Prospects for Inertial Fusion." *Fusion*, March/April 1981, pp. 30–36.

"Progress Toward a Tokamak Fusion Reactor." *Scientific American*, August 1979.

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Policy Impact

What future lies ahead for renewable resources in light of reduced federal support? Some experienced Washington observers offer their opinions.

Renewables—solar, geothermal, hydro, and fusion—received strong emphasis during the Carter administration, and support for research, development, and demonstration projects accelerated at a rapid pace. The Solar Energy Research Institute was established in Golden, Colorado, and the president even brought renewables into the White House with the installation of a solar hot water heating system.

But the climate surrounding renewables changed with the inauguration of a new administration dedicated to trimming the federal budget and reducing inflation. Whereas the Carter budget for direct R&D support for solar, geothermal, and fusion rose to nearly $1.5 billion, the Reagan administration has requested deep cuts in the solar and geothermal R&D budgets. Only the fusion budget will survive essentially intact.

Also discussed within Washington energy circles is the possibility that the administration will attempt to eliminate some of the indirect support, notably the tax credits currently available to homeowners, businesses, and industries for the installation of solar and other alternative energy equipment.

What implications do these actions—taken or postulated—hold for the future of renewable resources? The *EPRI Journal* recently talked to several individuals within the Washington, D.C., energy community who have observed or participated in federal activities in renewables over the past several years and who have some tie with or knowledge of private industry. Although this group of observers can by no means be considered a scientific sampling, their opinions can help shed light on the current status of renewable resources in this period of uncertainty.

As might be expected, there was no one perspective shared by all individuals. Opinions ranged from guardedly optimistic to generally pessimistic to a feeling that the federal role will not make much of a difference.

"I think it's reached a point it would have anyway," said Llewellyn King, publisher of *Energy Daily.* "And that's the business of when do you stop pampering a technology and let the market take over. I think you will see a low level of growth as a genuine market develops as opposed to an artificially stimulated one. I think that alternative energy is here, although it's not here on the grand scale that some envisioned, and it never will be."

"With the exception of wood-based biomass systems, I am pessimistic about the ability of the renewable energy industries to survive, let alone contribute significantly," stated Bennett Miller, vice president for energy programs of Fred C. Hart Associates, Inc. Miller served as DOE's deputy assistant secretary for solar energy during 1980–1981. "In general, the renewable energy industry is an infant industry and has depended on federal R&D activities for much of its support over the past few years. Although there are some major firms involved, in many cases it is still a cottage industry. As such, when there is a dramatic cutback in federal support, it is going to impact the growth of that industry severely."

"I don't think that the federal role [in renewables] is really crucial," said Larry Hobart, assistant executive director of the American Public Power Association. "The important thing is, are these technologies economic in terms of additions to the energy supply? It wasn't federal funding that stimulated the interest of public power systems in renewables in the first place. It was the possibility that there might be available now, or in the short term, economic sources of energy from renewables."

Because renewables encompass many different technologies at very different stages of development, it makes sense to

Miller

King

Hobart

Melloy

Lovin

Endahl

Prichett

examine them individually. "You can't give a bottom line answer and say it's applicable to all renewable resources," stated Thomas Melloy, group director for renewable resources of the General Accounting Office's (GAO) Energy and Minerals Division. Wilson Prichett, alternative energy specialist at the National Rural Electric Cooperative Association (NRECA), agreed. "Some technologies are going to make it and some aren't."

On certain technologies—those at the extreme ends of the time spectrum—there was general agreement among the observers about future prospects. Almost everyone, for example, felt that neither fusion nor such advanced solar concepts as ocean-thermal energy conversion or the solar power satellite would survive without federal assistance. On the near-term end of the spectrum, there was general agreement that utilities and entrepreneurs are sufficiently interested in small hydro, passive solar, and (to some extent) biomass to develop the potential of these technologies without federal support. Regarding other renewable technologies, such as active solar heating and cooling, wind, photovoltaics, and geothermal, disagreement was more widespread.

Hydro and Biomass

Beginning at the near-term end of the spectrum, hydroelectric power, particularly low-head hydro, was one technology that most observers seemed to agree would be least affected by cutbacks in federal funding. "Hydro is the one source that most rural electric cooperative utilities are interested in," stated Lowell Endahl, NRECA's manager of energy research. "This is evidenced by the number of coops that have applied for permits."

"It's the resource with the most sex appeal of all," agreed Hobart of APPA. "It's an old approach to power production. Everyone knows how to deal with it. It's off-the-shelf technology. It can be operated remotely. You can buy turbine generators of almost any size, and projects may last for 100 years." Hobart explained that municipals have a particular interest in hydro because many of the sites are located in or close to cities. He expects that interest to continue, regardless of the federal role.

A similar feeling was expressed by Glenn Lovin, alternate energy applications manager at the Edison Electric Institute. "I think investor-owned utilities will pursue and develop hydro power and I think we will pursue and develop it without federal involvement."

There was some concern expressed, however, about the negative effect on hydro that might occur if changes were made in the current favorable tax and regulatory framework. By provision of the Public Utility Regulatory Policies Act (PURPA) of 1978, utilities are required to buy power at their avoided costs from small power generators. "In certain parts

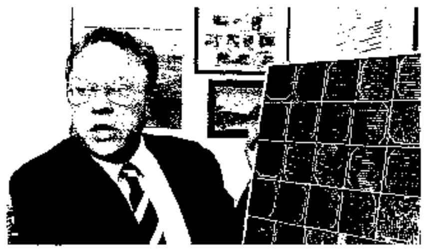
Gray

Maize

Johnson

Howe

Tenet



Maycock

of New England and the Middle Atlantic states, low-head hydro has a lot of promise made possible by PURPA," commented Kennedy Maize, formerly a reporter for *Energy Daily* and now with the Environment and Energy Study Conference of the Congress. "If PURPA were changed to eliminate the necessity of a utility paying essentially premium price for that power, it would hurt. Some small hydro would not come on."

Terry Johnson, legislative director of Solar Lobby, a citizen's interest group, also brought up the possibility that the tax advantages currently enjoyed by hydro may be on the same chopping block as other tax credits for solar. The law currently allows a 21% tax credit for private investors building small-scale hydro plants. Tampering with this tax advantage would hurt hydro, Johnson maintained, although he conceded that this technology is a little less sensitive than others to federal involvement.

Some observers also felt that conventional forms of biomass would be pushed by economics (in regions with sufficient quantities to fire small boilers) and therefore might be less affected than other technologies by federal funding cutbacks. "Wood-based biomass systems are near-term winners and don't need much federal help," stated Miller. "That's not to say that federal help wouldn't move them along more rapidly, but I think the state of the technology is such that industry can handle the required investment in development costs."

GAO has also examined federal work in municipal solid waste and, in a recent report, concluded that reduced federal funding for utility-related R&D projects would not cause any significant delays in the acceptance and use of this technology. Funding in this area, according to GAO, has been relatively small.

In other areas of biomass, the federal role appears more crucial. Johnson, of the Solar Lobby, expressed belief that reducing tax advantages for biomass would hurt the potential of alcohol fuel production. "It would be devastating," he declared.

Passive and Active Heating

Another renewable technology that most observers seemed to feel would remain viable despite federal funding cutbacks is passive solar, which incorporates energy-efficient design principles into buildings.

"Passive solar is totally here and probably never needed any federal help," stated Paul Maycock, formerly head of DOE's photovoltaic program and now serving the dual role of president of Photovoltaic Energy Systems, Inc., and senior associate of the Renewable Energy Institute.

King of *Energy Daily* was especially optimistic about the future of this concept. "These are really conservation devices much more than they are raw sources of energy," he noted. "They're assists. And the concept of solar-assisted conservation is now fundamentally ingrained. It has become institutionalized in our way of thinking. It's very akin to concern with the environment. And even if the environmental movement went away—which it's not going to do—we would still have that concern. Likewise, if all government support of renewables went away—tax credits, budget cuts, the lot—we would still have an industry out there. The job has been done. It's quite extraordinary."

Even though most observers were optimistic about the future of passive solar, some reservations were expressed about the depressed state of the economy in general and the housing industry in particular and about the limited possibilities for passive solar in retrofitting the existing housing stock.

Regarding active solar heating and cooling systems (SHAC), which can be roughly divided into hot water heating systems and space heating and cooling systems, there was a bit less uniformity of opinion among those interviewed. Some individuals were optimistic about the status of solar hot water systems, despite federal funding cutbacks. "It's probably the most solidly established technology," stated Alan Howe, director of government relations of the Solar Energy Industries Association (SEIA). "There really isn't a great deal of effort going on in DOE now in this area. Basically, I would think the budget cutbacks would have very little impact in that area."

"There's already a market for solar hot water," stated GAO's Melloy. "You can go to Sears and buy one of its systems in certain regions of the country."

But Miller of Hart Associates cautioned that domestic hot water systems will continue to be expensive and unless the economy improves, the firms involved will not be able to do the R&D necessary to push the cost down. "There will be a slowing down," he said.

Turning to active solar systems for space heating, many of the opinions were less optimistic. GAO's Melloy, referring to DOE's SHAC demonstration program, which included thousands of units in the commercial, residential, and military sectors, said, "Our reports showed that many of the systems were faulty. Where we had good data, the data showed that most systems were not economical. We saw one space heating system with a payback period of over 999 years. What would cutting off federal support for R&D and financial incentives mean? If these were typical solar projects and federal support were cut off at this stage, it could be the death knell to solar space heating and cooling, at least."

Melloy is not confident that private industry will pick up work in this area. "I think we're in a sufficiently uncertain period of time that we just don't know for sure. I think what is crucial is that what has been done with these technologies to get them to the point where they are now shouldn't be discarded without having some degree of assurance that the good ones will be picked up. A lot of taxpayer dollars have been invested in developing these technologies and promoting their use."

Most observers seemed to feel that the most detrimental action the federal government could take regarding SHAC would be to eliminate the tax credits currently available for installation of solar equipment. "It would totally gut the market," Miller said. "The fact is, the tax credits are a psychological boost."

Lovin of EEI, however, expressed belief that even with elimination of the tax credits, a market would still exist for solar in the home, although it would be a limited one. "We will continue to have rising electricity costs, and therefore the consumer will continue to look for ways to offset the electric bill. The market is there and will continue to be developed, but we just don't see a major spread of these applications in this country because of the expense and initial cost of installing the systems."

If the administration does propose elimination of the tax credits, will Congress acquiesce? Many felt that it would not. "There is a recognition on the part of the administration that the solar and conservation tax credits are quite popular and they would have a rather difficult time in Congress repealing them," stated Howe of SEIA. In fact, more than 260 members of the House and 60 members of the Senate have signed resolutions opposing repeal of the tax credits.

Wind and Geothermal

Wind is another technology for which advocates argue financial incentives are necessary. "If the tax credits were repealed, it would present a serious problem," stated Thomas Gray, executive director of the American Wind Energy Association. The tax credits for wind are 40% of the first $10,000 for residential users and 15% (in addition to the standard investment tax credit of 10%) for businesses. "The economics of the wind farm projects depends heavily on the tax credits and the stability of the investment climate."

Maycock believes wind has an excellent chance of surviving, given the current tax structure and PURPA, which allows producers to sell electricity to a utility at favorable rates. But he said that if these two incentives were eliminated, "we would have a very difficult time."

Several of the observers also mentioned reliability as a major factor in determining the future of wind systems. "It's going to be the ultimate determinant of who gets along and who doesn't," said

Gray of American Wind Energy. "Within the small wind field, you can already see that the companies producing hardware that stays up are moving ahead much more swiftly than those that don't."

Assessing the reliability of large wind machines (100 kW and up) as a group is difficult, Gray maintained, because there are so few in existence in the United States. He does not believe that the problem of reliability will be as severe with the larger machines because of the substantial financial investment that will be required. "The companies that are producing large machines will be very sure to do whatever they can to make certain their machines are reliable."

A number of those interviewed expressed belief that wind would survive federal cutbacks, but on a small-scale, local basis. "It may go in some areas, but it's not likely to sweep the country," noted Hobart of APPA.

"Large-scale wind machines are a very dubious proposition," stated King of *Energy Daily*. "Industry won't pick them up. I do think you will see industry marketing windmills for site-specific small-scale use—out on a prairie or in coastal regions or in some rural situations where their cosmetic impact is modified by space."

Geothermal energy is also a technology that many observers felt would survive without federal assistance, but would be local in nature and perhaps limited in its development. "Where it exists, utilities are interested in a geothermal resource," stated Hobart of APPA. "Our members in northern California are going ahead with geothermal development totaling a possible 350 MW. I don't sense that the federal expenditures are crucial. Access to economic resources coupled with the ability to transmit the resultant power are the key things."

"I don't think reduction of federal support will have as much impact on geothermal as on some of the other technologies," said Lovin of EEI, "because where you can identify geothermal resources, I think the utilities would consider moving ahead."

Melloy from GAO believes that some geothermal applications would go without federal support, but development of its full potential would not take place. GAO has been active in reviewing federal work in the geothermal area. One recent report examined the effect that eliminating funds for a particular project would have on geothermal development. In its report, GAO concluded that elimination of federal funds for the binary-cycle geothermal demonstration project near Heber, California (which is also supported by EPRI, San Diego Gas and Electric Co., the Imperial Valley Irrigation District, California Department of Water Resources, Southern California Edison Co., and the state of California), would impede the full development and widespread use of hydrothermal resources. Realizing the full potential of hydrothermal resources depends on development of the binary cycle, the report states. The utility industry has indicated that it needs a commercial-scale plant, such as Heber, to resolve economic uncertainties and technical risks that currently exist with binary-cycle plants. Without federal funding, it appears that Heber will be terminated, the report states, an action that would delay commercialization of binary-cycle technology and widespread use of hydrothermal resources. This is one example, Melloy pointed out, of a technology that would not go forward at this time without federal funds.

Solar-Thermal Electric

A similar belief was expressed about the future of the power tower, a solar-thermal technology. "I'm a firm believer that the project at Barstow, California, will not only work but will show the way," stated Miller of Hart Associates. "However, I think solar-thermal for large-scale, central power generation will be hard to come by without some up-front help from the federal government, at least in getting the manufacturing started."

"Solar-thermal has almost totally been financed through government R&D," stated Howe of SEIA. "Some major companies in the aerospace industry have invested a lot of money, and they are hoping the government will continue its partnership with them. If it does not, I really can't see how these companies could sustain the costs. The market is really with the utilities in these higher-cost, higher-temperature central receiver technologies. Unless the utilities invest and become partners with developing companies in this technology, I don't know that we will have the capital to do it."

"The power tower offers some potential, and if the federal government continues its support, it would offer some assistance in certain parts of the country for replacing imported oil," stated Lovin of EEI. "As it stands now, based on the other financial requirements of utility companies, I don't see any movement in this area, except to the extent that certain companies in certain parts of the country will look at it for certain applications in retrofitting old plants."

A recent GAO report analyzing federal funding for electric utility R&D projects identified solar-thermal energy conversion as one of the technologies for which demonstration projects would not go forward if proposed budget cuts are implemented. "The electric utility industry has R&D efforts in these areas, but because of financial problems, risks associated with demonstration, and the large investments required, it will not carry out demonstrations on its own," the report stated. "Without such demonstrations, it is likely commercialization will be delayed or perhaps not occur."

Photovoltaics

Discussion of the federal role in photovoltaics brought several different opinions. Maycock, who guided DOE's photovoltaic program until last March, was very optimistic and expressed belief that a reduced federal program would not delay the technology's reaching economic viability for more than a few years. "Photovoltaics will survive because it has investor appeal," he maintained. "And I think the momentum toward attaining economic viability in the mid-1980s is still there. We now have a rather large array of options dedicated to cost reductions in materials. We really need only one of these options to come through. Not only do we have a strong technology base but we also have a large amount of risk capital coming in, primarily from the oil companies. And it is coming from those companies that generally didn't have support from DOE. So I think there is a very good chance that we will see a healthy industry."

Maycock cautioned, however, that it is very critical that the next step in cost reduction for photovoltaic cells occurs. He said that this is the price that allows photovoltaics to compete with diesel fuel in a small diesel generator. This is important because it opens up "an awesome market" in remote parts of the world where water is pumped or electricity is made with diesel or gasoline generators. Most analysts put that price between $4 and $6 a peak watt installed, whereas the price of a module alone is now $9–$11 a peak watt, with a system's installed cost at three times that price.

"If $4 a peak watt is not met by 1984, it is going to be very difficult to get to the next step—$2 a peak watt—which makes photovoltaics a reality for the United States," he declared. But Maycock believes that industry will be able to meet this target, even without federal assistance. "I've had a chance to talk with industry, and I think we can pull it through."

There was concern expressed, however, that some small photovoltaic companies that depend on DOE funds would probably go under if they are not acquired. "If your perspective is a diversified industry, you may not have one," said George Tenet, director of photovoltaic and international programs for SEIA. "You will have large company participation, but there will not be many small companies left, and that may mean that some markets will not be addressed." Johnson of Solar Lobby agreed and noted that these smaller companies are often the ones that have provided much of the innovation in the industry.

The solar people also expressed deep concern about the effect that reduced federal funding would have on the photovoltaic industry's ability to compete in foreign markets. "Most of the photovoltaic market is now in the international arena," noted Howe of SEIA. "And most of it is in the developing countries that have no real central service system of electricity. We have severe competition there from the Japanese and the French industries, which are heavily subsidized by their governments. In fact, the Japanese government thinks this is an area in which it can capture dominance in the world market.

"The government needs to stay in the photovoltaics area," Howe continued. "We do need some assistance in perfecting different types of materials, as well as some assistance in the international marketing area, simply because we are being pressed very strongly by competition from countries that are heavily subsidizing their industries."

SEIA's Tenet pointed to another way in which reduced government support hurts the photovoltaics industry both at home and abroad. "The perception in world markets that your government values your technology and is willing to spend money on it means something to a foreign buyer. The perception that your technology may not be as good because your government is getting out of supporting it is something that will be difficult to deal with in the foreign market. The Third World really values what the government is doing with your industry."

Tenet also believes that the price goals DOE established for photovoltaics have hurt the ability of the United States to compete in foreign markets. "The price goals are unrealistic in the first place because they don't reflect all the costs associated with getting a product to the market, such as transportation, marketing, and systems costs," he stated. "And because of the faith that these foreign buyers have in government statements, they put off buying now because they think the cost may come down in a few years. The valid basis of purchase should be how the price of photovoltaics compares with other fuels."

Federal Support

Can any general conclusions be drawn from this diversity of opinions? Although no one answer applied to all technologies or was agreed to by all observers, it seems fair to say that the majority felt most renewables would survive federal funding cutbacks. Certain ones would not. Others would be slowed down and only achieve small-scale, local application. But enough would make it to keep renewables alive in the country. If the tax credits are eliminated, however, or such regulatory measures as PURPA are amended, the pictures will become considerably gloomier. Most agreed that these actions would be the ones to severely hurt the future of renewables in this country. ■

This article was written by Marie Newman, Washington Office.

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