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Cover: Renewable solar energy technologies are rising in a 25-year dawn to supplement finite resources of fossil fuels.

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The Phases of the Sun

I once heard the remark, "There was so much handwriting on the wall, the wall fell down." Such can be said today of the inevitable prospect of energy supply-demand inequalities as this century comes to a close. Just as inevitable is the acceptance of solar energy as part of the mix to fill the gaps. The questions of how much, when, where, and at what cost are at hand. And getting to the answers—in timely fashion amid an endless variety of proposals—requires the strong conviction of an advocate, but without the inflexibility of a fanatic.

A major difficulty in dealing with solar energy is the often-overlooked reality that the stages of technology development—in fact, the separate technologies—are as diverse within the solar field as they are between solar and other alternative energy resources. For example, proof of the technical viability and approach to commercial acceptance of solar hot water and space heating by no means reflects the state of development of solar cooling. By comparison, the latter is still well down the road ahead.

Another example where the signals seem conflicting is photovoltaic conversion. Single-crystal silicon cells are accepted as reliable and cost-effective for powering space vehicles. But they are hundreds of times too expensive for use in central electric power production on earth. The message here is twofold. First, attempting to reduce the cost of today's silicon cells, in my opinion, is the wrong way to go. Instead, a purposeful departure into different photovoltaic materials and/or cell geometries has a higher probability for economic success in large-scale applications. Second, this departure calls for very basic research and development. And while we can be reasonably confident of the prospects and potential, it would be foolish to flatly guarantee a scientific breakthrough.

Thus, the technologies of solar alternatives are a spectrum and the individual stages of development represent phases in time. Our expectations must be based on the recognition that each solar energy option is traveling its own course of technological development, from fundamental research through proof of technical feasibility to economic viability—and only then to commercial demonstration and practice.

Another factor often neglected is the highly developed and interacting system of industries into which new solar energy applications must be integrated. As consumers, we have become accustomed to reliability of products and services. It is essential, therefore, to ensure that the new solar technologies, their equipment, and their modes of operation are compatible with existing systems and are as reliable as those they are to displace. Over the long term, we can anticipate shifts in energy use and in consumer habits and practices as well. But let's not expect revolution in place of evolution. The difference is in the time frame, and nature favors the latter.

The time available in which to develop—and to accept—new technologies is limited, so we must be aggressive in solar research and development. On the other hand, our human and monetary developmental resources are limited, so we hasten slowly. But hasten we must, for there is considerable handwriting on the wall.

John E. Cummings, Manager
Solar Program

Authors and Articles

When the first issue of the *EPRI Journal* appeared just two years ago, "Solar Realities" opened a new avenue for EPRI's reportage to its members and the larger community of U.S. energy technologists. Solar achievement was then mostly a dispersed, "bootstrap" affair, largely the response of innovative individuals and firms to an intriguing whim or to what some of them, after 1973's oil embargo, were seeing as an imperative for survival. Most of the solar realities of 1976 were on paper.

Now, only two years later, both the consolidation and the extension of technology—not to mention the incentives of national policy in opening market channels and stimulating user interest—are yielding hardware to identify and test solar energy in conjunction with electric utility systems, which are foreseen as the largest and most widespread market for U.S. solar technology of any kind.

Thus, an 8-page solar energy review two years ago is supplanted today by eight separate articles—43 pages—in this special issue. And the editorial by EPRI's solar energy program manager, John Cummings, emphasizes the fact that solar energy comprises not one but several technologies, distinctive in their stages of development, their problems, their timing, and their promise.

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To assemble this review of solar energy meant special editorial organization in teaming the talents of EPRI technical staff members with *Journal* editors and writers. Sharing the leadership with John Cummings were Ralph Whitaker, feature editor of the *EPRI Journal*, and Brent Barker, its editor. Cummings, who introduces "The Phases of the Sun" (page 2), has been a student of solar and other new energy resources since 1971, when he undertook resource recovery analyses for the Atomic Energy Commission, including definition of an AEC-sponsored solar program. Later, as director of energy programs for Itek Corporation, he concentrated on strategies to commercialize solar-thermal and photovoltaic energy conversion processes. Cummings has been with EPRI since January 1975 and has managed its solar energy program since November 1976. He is a graduate of the Coast Guard Academy, with MS and PhD degrees in physics, and an MBA from the University of Arizona.

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Presenting "Solar Homes: The Winning Combinations" (page 6) combines the technical management of Jim Beck and the reportorial abilities of Barry Sulpor, manager of EPRI's News Bureau. Beck came to EPRI in 1974 to manage the Battery Energy Storage Test Facility project, which involved the cooperative efforts of a utility, DOE, and some 10 battery manufacturers. This transition from six years in utility system planning (including over four years with Boston Edison Co.) led Beck into management of EPRI's solar heating and cooling (SHAC) research projects, particularly the unique task of coordinating an EPRI contractor, 2 utilities, 2 residential builders 2000 miles apart, and 10 or 12 suppliers who share the task of designing, building, and monitoring the SHAC performance of 10 heavily instrumented houses. Beck is a 1968 electrical engineering graduate of Northeastern University, where he added an MS degree in 1969.

The prospect of "Spinning a Turbine With Sunlight" (page 14) particularly intrigues John Bigger, manager of solar-thermal conversion research projects, because his early professional work was with the Los Angeles Department of Water and Power, one of two California utilities now funding the design and construction of the industry's first solar-thermal plant. Following his graduation from Iowa State University with a BSEE degree in 1965, Bigger spent 10 years with the Los Angeles utility in transmission design and construction and in resource planning, with special emphasis on waste heat, geothermal, and solar energy. Bigger joined the EPRI staff in May 1976, and it was his summary lecture—as well as talks by "his" research contractors—at a September 1977 EPRI workshop that provided background for the article by feature editor Ralph Whitaker.

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It's an R&D challenge, not to mention poetic license, to put "The Sun on a Semiconductor" (page 20) as an energy resource for electric utilities. Margaret Laliberte reviews that challenge as it is seen by Edgar DeMeo, EPRI's project manager for photovoltaic conversion. DeMeo graduated in electrical engineering from Rensselaer Polytechnic Institute in 1963, then went on to earn MS and PhD degrees in engineering from Brown University, where his research specialty became solid-state materials. He taught at Brown for seven years and in the Naval Academy's science department for two years. DeMeo began his EPRI work as a consultant in advanced systems four years ago and joined the solar energy program staff in August 1976.

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How "Utilities Put the Sun to Work" (page 26) is the work of EPRI's public affairs specialist, Robert Taylor. But he had assistance from the 11 utilities whose varied solar R&D he reviews. In selecting these representative examples, Taylor was assisted by John Cummings and Louise Cleary, an EPRI planning analyst who compiled two nationwide surveys of the solar studies, experiments, and prototype operations conducted by utilities.

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Closely related to the experiments by utilities are the joint projects for which "EPRI Sponsors Solar Instrumentation" (page 33). Gary Purcell, another SHAC project manager, is responsible for this activity, applying the experience gained in 14 years of thermodynamic design and analysis for Lockheed Missiles & Space Co. Purcell earned his BS degree in mechanical engineering at Oklahoma State University.

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For "The Shape of SHAC Supply" (page 36), it's necessary to turn to EPRI's energy supply program and to Richard Urbanek. *EPRI Journal* staff writer Stan Terra worked with Urbanek to highlight early observations from a sponsored study of the SHAC industry's manufacturing and marketing patterns. Urbanek has been a staff member for new technology analyses in the Energy Analysis and Environment Division since he came to EPRI in 1974 after nine years as a research engineer with United Technologies Corp. A 1958 chemical engineering graduate of Lowell Technological Institute, Urbanek earned MS degrees in chemical engineering and industrial management at Massachusetts Institute of Technology.

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The professional landscape of the new Solar Energy Research Institute in Colorado is described in "Solar's Golden Horizon" (page 39). Stan Terra traveled to Golden for a day of interviews to compile this collage of managerial perceptions.

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Recognizing the holistic role of "The Earth as a Solar Heat Engine" (page 43), John Kenton departed from his own role as EPRI's communications specialist in nuclear technology. He conferred with Ed DeMeo, who holds management responsibility for EPRI research in wind and other indirect solar energy resources, and with John Benemann, an EPRI consultant in biomass conversion. Kenton's own editorial research led him into reports by and correspondence with DOE, NASA, Lockheed, and Britain's Central Electricity Generating Board.

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Reviewing the major influences on solar energy R&D would not be complete without the Washington Report. To inaugurate this new monthly feature in the *EPRI Journal,* Marie Newman of the Institute's Washington office attended January hearings of the Senate Subcommittee on Advanced Energy Technologies and Conservation Research, Development, and Demonstration. Her report on DOE's solar research directions and budget requests for the coming fiscal year appears on page 54.

Another monthly feature of the *Journal,* R&D Status Reports from EPRI's four technical divisions, does not appear in this issue but will be resumed in April.

Purcell Cummings Bigger Sulpor Laliberte Terra

Urbanek DeMeo Beck Taylor Barker Whitaker

Solar Homes: The Winning Combinations

Will a given solar heating or cooling system reduce or add to a utility's need for standby generating capacity? And how can we find out ahead of time? Answers are expected soon from several EPRI experiment

"With today's soaring utility rates and shortages, solar energy is a readily available source of relief," claims an advertising brochure from a Houston, Texas, manufacturer of solar energy systems.

In Wagoner, Oklahoma, a doctor and his wife moved out of a trailer and into the state's first modern solar dwelling in June 1976. They recently reported that one of the biggest bonuses has been the saving in fuel costs. They said they pay roughly half of what their neighbors do for utilities.

By the end of the century, as many as 2.4 million single-family residences may be using solar heating and cooling, according to a report by the Sheet Metal Workers International Association. And in 1977 alone, plans for at least 2000 housing starts had solar energy as the primary heat source, asserts Harold B. Olin of the U.S. League of Savings Associations.

This push to use solar energy to heat and cool our homes and warm our water is good for everyone because it helps replace scarce fossil fuels and saves money for the consumer in the long run. Right?

Well, maybe yes. And then again, maybe no.

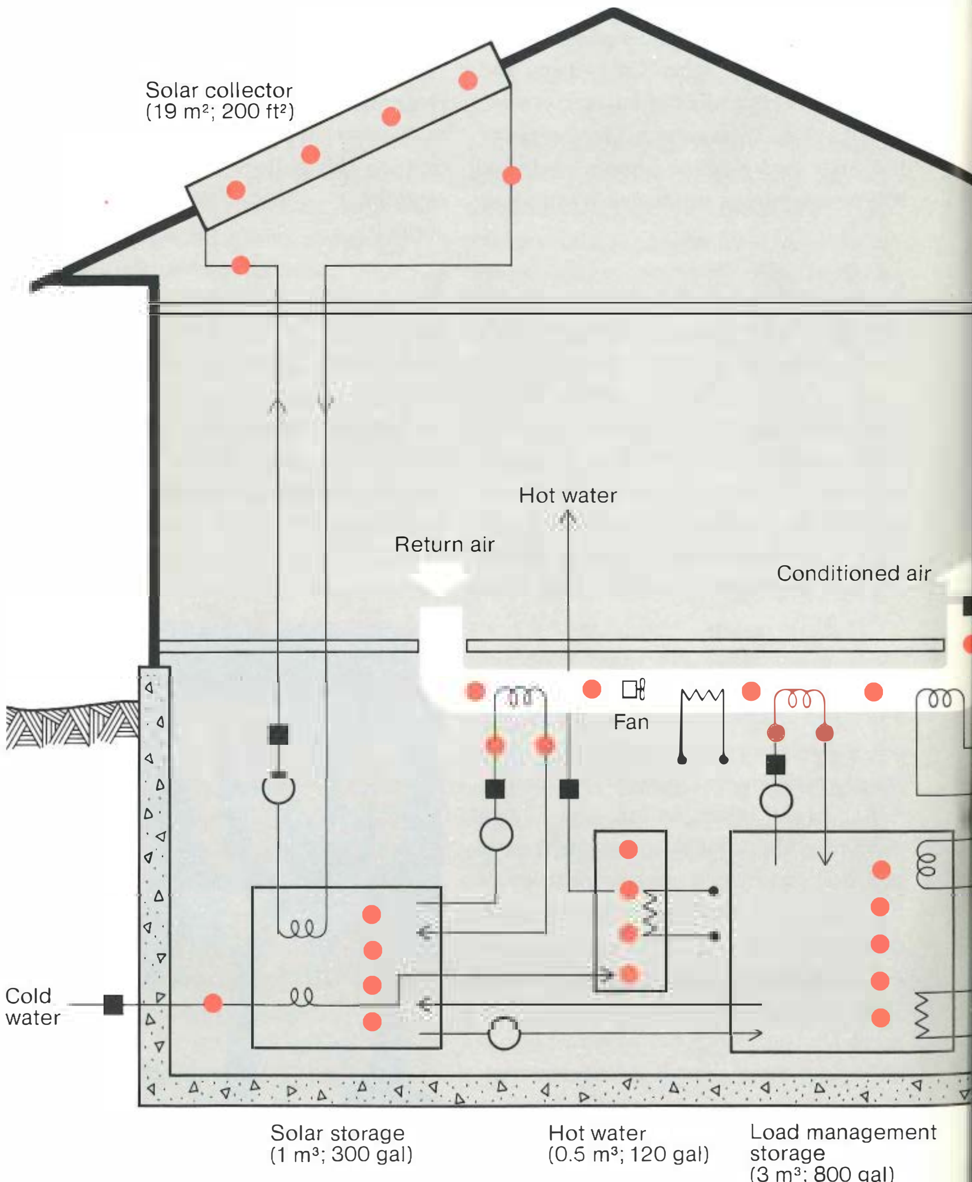
Several utility specialists contend that such systems could either turn out to be heaven-sent or give consumers and utilities a solar-size headache.

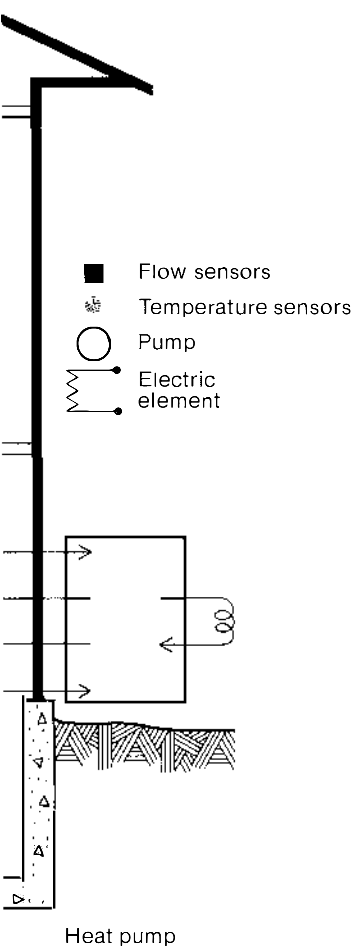
Solar-electric puzzle

"There are several areas that must be addressed immediately for solar heating and cooling systems to be beneficial to utilities and to their customers, too," states Jim Beck, project manager in the EPRI Solar Program.

According to Beck, there are hundreds of ways in which solar heating and cooling components can be combined. But which configurations will work best—that is, be compatible with a given utility—has never been thoroughly investigated.

"Depending on the characteristics of a particular utility, such as the fuels it





Many possibilities for space heating and cooling, as well as for water heating, are provided in EPRI's heavily instrumented solar houses now being built in New Mexico and New York. This representative system is designed to supply forced-air heat and is equipped with a liquid-medium solar collector loop, extra hot water energy storage for load management, and a heat pump.

The heat pump subsystem can operate in six modes: drawing energy from the outside air to heat either the forced-air stream or the stored water, exchanging with the water to either heat (in winter) or cool (in summer) the air stream, and cooling either the air stream or the stored water by exhausting heat to the outside air.

Fed into a computer, tape-recorded data from this entire system yields a complete "heat balance," and the computer program permits simulation of what would have occurred with many lesser systems—for example, systems without the load management tank, or without the solar loop, or without the heat pump, or using only electric energy in conventional fashion. The result is a compilation of energy requirements, in quantity and by time of day, that permits assessment of cost and electricity generation impacts on the utility of many possible solar and other energy-conserving designs.

uses, its rate structure, and its electrical loads, some solar systems will be more economical than others," says Beck. "If consumers are able to choose systems that are known to be compatible, everyone can save money and energy."

The relationship between the utilities and solar heating and cooling, in fact, often seems like a jigsaw puzzle composed of thousands of little pieces. For example, there are hundreds of ways to piece together solar systems. But which ways will fit into and work best with the utility system? And then again, what if solar heating and cooling really takes off? What will be the effect on utilities? How will it, for instance, affect a utility's peak electricity demand? Expansion plans? Fuel needs?

The point is that there are few homes in the country designed to be totally reliant on solar energy. Most installations are integrated with some supplementary heating and cooling source, which can be switched over when temperatures cannot be maintained by solar energy or storage systems. The fact that people still rely on their utility during periods of bad weather is the main utility concern.

Money saved or spent

In recent testimony before the California Assembly Committee on Resources, Land Use, and Energy, Bill Seavy, solar coordinator for Pacific Gas and Electric Co., explained that the periods of extended cloudy and/or cold weather, when solar customers need their utility, "are the same exact periods when maximum amounts of energy are used by nonsolar customers." He added that solar systems may, in some cases, aggravate energy demand peaks.

How could solar heating and cooling systems cost the utility money, and, in turn, the customer? Simply stated, utilities must have enough generating capacity to meet times of high electricity demand, even if only a few hours a day, a month, or a year. For the rest of the time, the generating equipment is idle or not being used to its fullest capacity, but its fixed costs still accrue. Those costs must be recovered in the few hours when the plant does run, which translates into higher electric bills.

Solar rates

A study on the issue of solar-electric rates was conducted a couple of years ago by Franklin Institute Research Laboratories (FIRL) and two eastern Pennsylvania utilities to evaluate the effects on electric utilities of residential solar heating systems to the year 2000.

One of the conclusions reported by Harold G. Lorsch of FIRL is that "under all rate structures that recover the cost to serve through an energy charge alone, electric utilities will suffer revenue deficiencies from solar heating customers unless these customers are charged a different energy rate than the conventional heating customers."

Lorsch says this is because only the energy-related costs are reduced by the solar system. The other components of the utilities' cost to serve—demand-related costs and customer-related costs—are identical for solar and conventional customers. The result is that utility revenues decrease in proportion to the energy saved from the home's using solar energy, while utility costs are reduced by a much smaller amount.

"In most economic studies of solar heating, it is taken for granted that a given fraction of energy reduction from solar energy use results in an equal fraction of cost reduction to the heating customer," says Lorsch. "This is incorrect when backup heating and/or cooling is gas-fired or electric, unless the solar heating customer is to be subsidized by all other utility customers."

No easy answer

Another study that touched on this subject, conducted by SRI International for ERDA (now DOE) found that the rate structures used to determine the costs of auxiliary heat for solar space-heating systems can have a significant influence on the economics of solar heating.

The report on the study, "Solar Energy in America's Future," says it is "certainly possible" that rate structures could evolve that severely handicap the use of solar systems, so that the careful design of rate structures for both gas and electric utilities "will be an important implementation measure to encourage solar use."

Released in March 1977, the report seeks to show some of the key concerns surrounding the solar-electric rate issue and how present rate structures may work against electric utilities and their customers—both solar and nonsolar. It draws the hypothetical example of a utility having its peak loads in the summer to meet air conditioning demand. Solar heating installations would not alter this characteristic, but they would reduce the utility's winter loads by replacing electricity in that season. The advent of solar energy would thus accentuate the difference between summer and winter demand on the utility's generating capacity, meaning that a still larger *proportion* of its annual output would be produced during the summer peaks.

According to the SRI report, since electricity generated during peak load periods is more expensive to produce than baseload electricity (by as much as eight times) and since rate structures usually do not reflect this cost difference, widespread use of solar heating in this example would result in a loss of profit to the utility or would require hearings for utility rate increases.

The SRI report also states that very high market penetration of solar systems may further complicate the situation by creating a winter peak. "It would be possible to reach the point where solar systems relying on electrical backup become so common that the peak load for a utility would be shifted from summer to cloudy, cold winter days," the report notes. And because the auxiliary heating requirements of the solar heating systems would be the cause of the peak load, this could warrant a higher price for peak-time electricity.

Unique solar homes experiment

What are the questions for utilities in the solar-electric issue? "It boils down to each utility's wanting to know the best solar system for its service area," explains John Cummings, manager of the EPRI Solar Program.

Why is this important? "Two reasons," says Cummings. "One is to determine what the impact will be on the utility's load curve if solar heating and cooling is introduced on a large scale. This is a planning tool. The other reason is that the utility can help government agencies develop incentives for encouraging installation of the most beneficial systems by individual users."

To help utilities accomplish these goals, EPRI has embarked on a $2 million research program involving two important elements:

- A two-year project to develop a computer model for predicting the effect of solar heating and cooling on utility systems

- A three- to five-year project in which ten experimental houses are being built —five in Albuquerque, New Mexico, and five in Wading River, Long Island, New York—to test different solar system configurations and validate the computer model

The contractor is Arthur D. Little, Inc. (ADL), of Cambridge, Massachusetts. According to Dan Nathanson, manager of ADL's energy systems group, more than 80 experiments will be conducted, metered, and analyzed in the second project.

"An interesting point about the test program is that we don't have to *do* 80 different experiments in the houses," states Nathanson. "By taking enough data we can deduce certain things, such as how electric resistance heating may compare with heat pumps under various conditions."

As an example, Nathanson notes that in one of the houses, by varying the ways in which a heat pump operates, technicians can determine how that same heat pump would perform under 18 different solar heating and cooling configurations.

The equipment in each home is so designed that it can be operated in several ways. "One of these modes will prove to be preferable," says Nathanson. He adds, "Other modes will permit operation in alternative system configurations so that comparisons among systems can be made." In this way, major equipment types, as well as variations due to lifestyles and energy conservation measures, may be evaluated among the 10 installations. In addition, all the equipment being installed in each home is already on the market, and there will be no attempt to improve it.

"If the appropriate information is obtained from the system tested, the performance, not only of that one system but also of conventional or simpler systems, may be derived and can be applied to other homes and other lifestyles and climates," he explains. Nathanson adds that it's likely there are several good solar-electric combinations, not just one or two.

Confirming a computer model

The experiments that will be conducted during the course of the EPRI solar homes project are often touted as being the most "comprehensive and carefully planned solar heating and cooling experiments ever undertaken." And, indeed, they may very well be.

They are based on a two-year effort by EPRI and ADL, in which 24 utilities fed into a computer model such information about the characteristics of their utility systems as their costs to serve customers, electricity demand, fuel costs, and weather conditions. Researchers also fed in simulated data on different residential characteristics, such as heating systems, number of rooms, and heat transfer of walls. Solar equipment simulations were provided as well.

In this way, researchers at ADL and EPRI developed more than a hundred combinations in which solar-electric systems could be combined. Some of these configurations had favorable economic impact on the utilities and their customers, while others had only marginal impact.

In short, homes are now being built and equipment is being installed and will be monitored for two purposes: to verify the accuracy of the computer program, and to provide experimental data for other uses, including better component design.

If the solar homes project indicates that the computer program is wrong in some cases, researchers can make adjustments. Once the experiments are completed and compared with the computer program, and adjustments are made, EPRI can confidently suggest that utilities use the computer program. In fact, the computer program will be the only one in the country from which utilities can obtain information on combining solar and electric energy systems in a way that takes account of utility costs.

EPRI points out that the computer model is flexible. If economic factors change, and fuel costs, time-of-day rates, or other costs change, the computer model can be altered to accommodate them. Significant technical improvements can also be accommodated.

The 24 utilities that participated directly in the computer program were: Alabama Power Co.; Arizona Public Service Co.; Consolidated Edison Co. of New York Inc.; The Detroit Edison Co.; Duke Power Co.; Nevada Power Co.; Northeast Utilities Service Co.; Pacific Gas and Electric Co.; Pennsylvania Power & Light Co.; Public Service Co. of Colorado; Public Service Indiana; Southern California Edison Co.; Tennessee Valley Authority; Utah Power & Light Co.; Long Island Lighting Co.; Public Service Co. of New Mexico; Baltimore Gas and Electric Co.; Central Maine Power Co.; Florida Power & Light Co.; Santa Clara Electric Dept.; Idaho Power Co.; Public Service Electric and Gas Co., New Jersey; Salt River Project Agricultural Improvement and Power District, Arizona; and San Diego Gas & Electric Co.

Total costs

"Our work for EPRI—both the computer program and the experimental solar homes—is a first in solar R&D," Dan Nathanson emphasizes. "This is the first national effort to identify the best solar systems for utilities and their customers by carefully considering what impact the different systems will have on utility operations and customer costs. In effect, the experiments will take some of the snakeoil out of the solar heating and cooling business."

Why is it so important to know what those impacts are? Nathanson says that utilities need the information in planning additional generating capacity, which, in turn, involves planning for equipment procurement, construction, fuel needs, and so forth.

The ADL program manager notes that the best solar systems are not necessarily the ones that "appear to save the homeowner the most energy—the total cost of energy must be evaluated, examining both sides of the electric meter." This is because unless the overall system is properly designed, the utility could still need as much generating capacity for peak periods, adding to costs for backup energy.

Conceptual basis for tests

In conversations with EPRI and ADL staff members on the solar homes project, several terms are often echoed—terms like load management, energy conservation, heat pumps, and energy storage. If these terms are understood, correctly combined, and applied, it could very well enhance the successful advent of solar heating and cooling.

Load Management What is load management? Defined simply, it is a means for a utility or its customer to control the timing of power use. It allows the customer to call for power at precisely those times when it is the cheapest for the utility to supply it, such as late at night or during other off-peak periods.

Energy Conservation How does energy conservation enter the picture? "The best way to conserve energy, of course, is to use less," says Nathanson, "but the first step in solar system design is to reduce the heating and cooling demand of the house." Without this conservation step, solar heating and cooling will not be efficient.

As part of the EPRI experiments, the 10 houses will include many energy-conserving measures, such as tighter construction, improved insulation, and double glazing of windows. One of the houses, for example, will have six-inch studs (heavier than normally used) to permit increased thickness of outside wall insulation.

However, the amount of insulation—or where or how it is installed—is not as uncertain as is the relationship between component combinations and total energy costs. The total cost includes expenses related to utility fuel usage, power generation investment, and transmission and distribution, as well as the costs for the residential solar heating and cooling equipment and its installation.

Heat Pumps What about heat pumps? The costs surrounding heat pump operations, as well as the most effective and economical ways of using heat pumps, are a good example of the type of information researchers hope to obtain from the EPRI experiments.

Electric heat pumps, which are devices that work like refrigerators in reverse, are twice as efficient as electric resistance heating during the course of a winter. They extract energy from relatively low-temperature thermal sources, such as outside air, and convert it to a higher, more usable temperature for space heating. Or they may pump heat from a water storage tank to warm the house. Heat pumps can also be used for cooling by removing the warm air from inside a home and sending it outdoors. Finally, they can operate in a multimode fashion —for either heating or cooling.

Heat pumps were first introduced twenty years ago, but lack of reliability caused their downfall in the market-

SOLAR HOUSES VARY IN SIZE AND STYLE

EPRI's solar houses, being built by Clarendon Construction, Inc., of Long Island, and Mossman-Gladden of Albuquerque, will not look very different from other houses in the $65,000–$80,000 price range. In Albuquerque, the solar collectors have been integrated into the roof architecture. The houses are flat-roofed and single-storied, built on concrete slab foundations, and not unlike other popular Albuquerque homes.

The plans for the New Mexico houses, each having about 170 square meters (1800 ft^2) of living space, include a small heating and air conditioning room that will contain most of the heating, cooling, and hot water equipment and the instrumentation system. Very large thermal storage tanks for load-managed heating and cooling will be buried at the rear.

Solar collector panels were integrated with the roof by the addition of a clerestory above the living and dining room areas. (A clerestory is a partially raised roof with windows beneath it.) The houses are oriented so that clerestory windows face north. Solar collector panels are mounted in the opposite south-sloping clerestory wall, and a slanted false ceiling hides the solar plumbing and backs of the panels.

The Long Island houses are also typical of their area. They have either three or four bedrooms; two are ranches, two are colonials, and one is a Cape Cod.

Each house is of wood-frame construction, built on a concrete foundation and basement. All have pitched roofs and an overall floor area of about 185 square meters (2000 ft^2). In four of the houses, solar collectors are mounted over an attached garage, and in the fifth the collectors are on the main roof. Placing collectors on the garage rather than on the roof of the house means less cost in some cases.

ADL's Nathanson points out that because of large basements in the Long Island homes, all load management equipment and instrumentation can be located there. Included are the 0.6–0.9-cubic-meter (200–300-gal) storage tanks containing water heated by either solar collectors or electric heat pumps. A portion of the basement is walled off to isolate this equipment, although there is limited access to it.

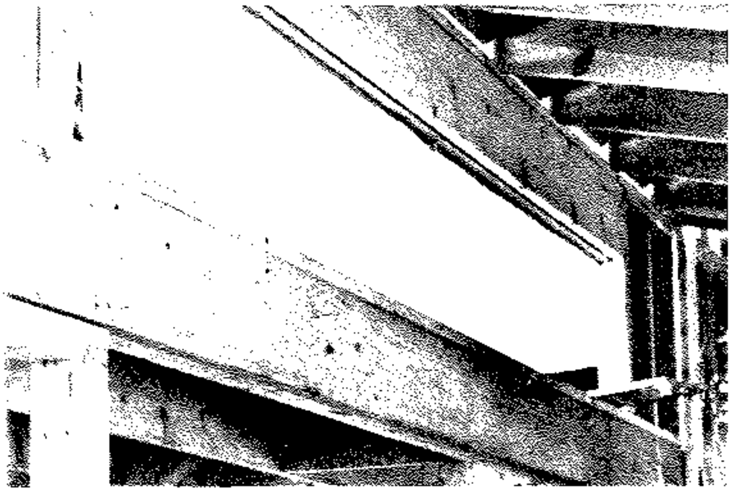
Local utilities participating

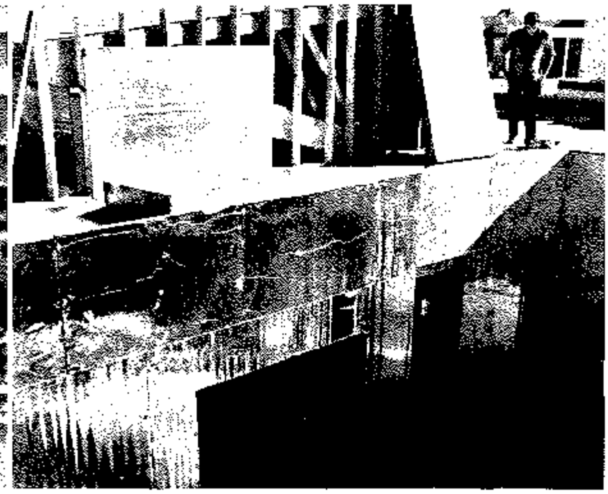
A unique point about the tests is that local utilities are participating in the EPRI–ADL program: Long Island Lighting Co. in the Northeast and Public Service Co. of New Mexico in the Southwest. The two utilities will provide technical assistance on the project, as well as perform routine monitoring and minor repairs on the systems.

The developer-builder will own the houses and rent them to families during the test period, scheduled to begin in May, but tenants will have options to buy them when the research project is finished.

Will the occupants be asked to be more energy-conscious than if they were living elsewhere?

"Frankly, we are going to ask them to live the same as if they were in any other house," answers EPRI's John Cummings. "We don't want them tinkering with the equipment or trying to be more energy-conserving than they normally are. If they acted in any unusual way, such as keeping the house at 50° during the winter, it would distort the test data."





Construction of EPRI-sponsored solar houses is marked by sharp weather contrasts early in February. Record blizzards in Long Island put work at a standstill, and wind-carved cornices of snow outline the garage gable framing that will receive solar collectors. Sunshine and shadow dapple EPRI's Albuquerque site, where footings and reflective insulated walls are topped by clerestories that will support south-facing solar collectors and frame north-facing windows.

place. Since then, however, they have been improved, and the idea of using solar energy along with heat pumps has recently captured the attention of many energy specialists. A variety of heat pumps will be installed for testing in several of the experimental homes, and will be tested with different load management techniques.

Energy Storage Water is the medium most often used to store energy in a home. A special water tank can be placed in the basement, garage, nearby shed, or underground. The homeowner may find it economical to warm the stored water by turning on an electric resistance heating element during the night. Later on, perhaps in the early morning when his family is getting up and using a lot of electricity, the homeowner need not rely on the utility but can get energy (for space heating or cooling or for hot water) from the storage tank.

And this would be good for everyone. Why? Because the energy stored in the tank would be energy that the utility supplied during its off-peak hours—relatively cheap energy from coal- or nuclear-fired power plants that might otherwise be idle. If the homeowner had no storage tank, he would rely on the utility during those peak times of electricity demand, when the cost of supplying electricity is high. (Costs are high then because combustion turbines, which rely on expensive petroleum fuels, are generally used to meet peak electricity demands.)

By storing solar energy, the homeowner could avoid calling on the utility during peak periods, even on cloudy or cold days. One way he could do this is by using the energy from solar collector panels to heat up rocks in a bin, then circulating air over the heated rocks and throughout the house. Or the collectors might provide heat to warm the water in a storage tank. In addition, it might be cheaper for both homeowner and utility if solar collectors were used in combination with heat pumps to heat the rocks or storage tank. Sometimes solar collectors would be used, sometimes heat pumps, depending on utility rates and other factors.

The important point is that the homeowner works with his utility to even out power demand and save money.

Experiments planned

In the Long Island and New Mexico test houses, temperatures throughout the heating and cooling systems, flow rates, daily amount of sun, equipment performance, and energy use will all be metered. A full weather-monitoring station will also be erected.

Because each house will have its own monitoring system, technicians can compare, for example, the efficiency of several heating and load management schemes. Computer tapes recording this information will be analyzed once a month. Eventually, the entire monitoring system will be automated. Initial test data will be available as early as June 1978.

Some of the specific questions that will be answered through this experiment are questions on storage systems. What kinds of storage are best? Under what conditions? Is one storage tank enough? Should there be one storage tank for hot water, another for heating, and still another for cooling? Are the extra costs for more than one storage tank justified?

"Using a single integrated tank for both solar and load management storage—in other words, storage that the homeowner supplies himself during off-peak electricity periods—reduces capital costs," explains EPRI's John Cummings. "But under certain conditions, separate tanks may improve solar heating performance and provide flexibility for seasonal changeover."

Other answers include identifying the most economical ways of using heat pumps. This may not be simple. For example, when is it best to use them directly for heating and cooling, and when is it best to use them in conjunction with load management? What are the extra costs in switching over from direct use to load management? Again, are the costs justified? What is the most cost-effective operation for a particular region? In the Southwest, evaporative coolers are common. Might it make sense there to have heat pumps that work only for heating and to have evaporative coolers for cooling? One Albuquerque house will address this point.

Federal efforts different

To the outsider, a question about the EPRI project may well come to mind: How is it any different from the federal government's solar energy program or the hundreds of other private and public solar experiments under way throughout the United States?

EPRI's Jim Beck answers that most of the federal government's program, administered through DOE and HUD, is geared to creating a market for solar heating and cooling systems. Beck says this is being done by provision of grants for solar equipment to people with homes and commercial buildings that meet certain specifications.

"The government is interested in creating a demand right now for solar equipment, to encourage suppliers to produce solar equipment in larger quantities and bring the prices within the reach of the general public," explains Beck.

But unlike the EPRI program, these projects, for the most part, are not planned experiments instrumented for taking data. "Even in those few homes or buildings where measurements are being taken, the data are mainly for evaluating component performance, not the impact the systems may have on the consumer's electric bills and the utility's cost to serve," he says.

"In fact," John Cummings emphasizes, "half the thrust of EPRI's solar experiments is to help the federal government understand the needs of the utilities in making solar work." Until the EPRI program, he says, all efforts in solar heating and cooling were directed to creating a market for solar energy so that it could be substituted for expensive gas and oil fuels. He says the EPRI experiments are different because they go one step further by identifying the best ways of accomplishing this substitution.

Cummings recognizes that the federal effort serves a needed purpose, as do the solar experiments being conducted by individual utilities, solar equipment manufacturers, and others. But, he says, none of them will actually have developed test data on the best types of solar-electric systems for various regions of the country. And that's the difference.

Why now?

But why undertake an experiment of this magnitude now? Critics of the EPRI study note that solar heating and cooling, even though it is gaining momentum in the marketplace, cannot make any great impact on utility systems for several years.

One reason the EPRI experiments are needed now, counters Cummings, is that it takes a long time to build a power plant. Depending on the plant type, construction and licensing can take from eight to twelve years. If a sizable portion of off-peak capacity can be used in conjunction with solar energy by people who now use peak-time power, some amount of new generating capacity can be deferred.

For planning purposes, utilities have to forecast their customers' needs ten or twelve years into the future, adds Jim Beck. The results of the EPRI experiments will help them by providing a computer model that they can use in forecasting the possible effects of solar heating and cooling on their power systems.

Dan Nathanson states that while some larger electric utilities may be able to afford studies on solar heating and cooling, "every utility in the country shouldn't have to do its own solar project." But even those utilities that have studies under way can benefit from the EPRI experiments, says Nathanson.

Finally, the ADL manager makes the point that the government may mandate some "interesting incentives" to encourage people to use solar heating and cooling. If that happens, utilities may already have adequate information from the EPRI study to respond positively to those incentives.

Solar incentives

In fact, that is already happening in some states, including California, where Governor Jerry Brown signed a bill in September 1977 allowing Californians to deduct 55% of the cost of installing solar heating devices from their state tax bills, up to a maximum of $3000 over a four-year period.

The California Energy Commission estimates the new law might encourage the installation of as many as 170,000 solar units from 1977 to 1980. If that estimate is correct, California will waive some $87 million in taxes during that time—in effect, a multi-million-dollar subsidy to develop solar energy.

At the same time, Richard M. Cooper, special assistant to James Schlesinger, Secretary of DOE, says tax credits proposed for solar residential installations under the president's energy plans are 30% of the first $1500 expenditure and 20% of the next $8500. He says the administration believes solar installations should be subsidized through the 1980s to assure wide penetration of the residential market, both new and retrofit; then the industry would be able to stand on its own.

How else can the results of the EPRI study be used? Beck says the test results will provide utilities with the data needed to structure equitable rate schedules for their solar and nonsolar customers. It is also possible, he states, that once the utilities have the EPRI study results they may encourage their customers—through rates or public information programs—to install those systems found to be best for their mutual purposes. For example, one result of the experiments will be better information on the life-cycle costs and economic benefits of different solar system configurations—that is, how long it will take the consumer to get his money back from buying and installing solar collectors, heat exchangers, storage tanks, heat pumps, and other equipment.

Colorado Springs example

This result has already been achieved by one community, Colorado Springs, whose combined municipal utility was funded by DOE to test eleven solar heating and cooling equipment configurations in one house. The data evaluation (sponsored by EPRI) shows that one configuration, a solar-assisted heat pump system using stored hot water as the heat pump source, gives the best combination of capital, energy, and operating savings.

The city therefore instituted electric and gas rates to encourage purchase and installation of the favored solar system. Colorado Springs has concluded that if residents respond as hoped, the city's expenditures for energy and for utility equipment should be minimized over the seven-year period analyzed in its study. This use of energy rate incentives, based on thorough solar system performance evaluation, is an example of how information from EPRI's Long Island and New Mexico experiments may be applied in the future, with the Institute's computer model making it useful in many regions of the U.S.

Related experiments

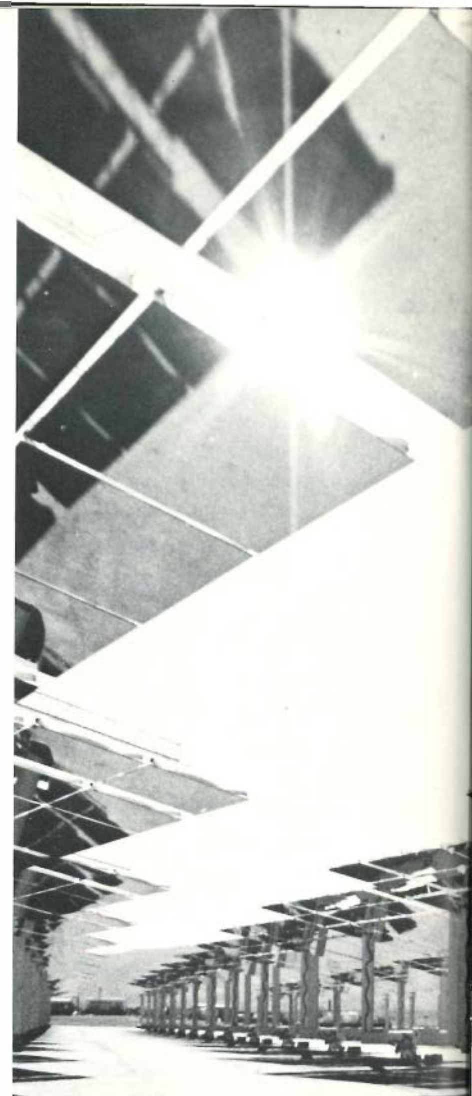
Linked to the solar homes project is another set of experiments EPRI is to begin late this spring. It will be similar to the solar homes project, except that it will focus on existing commercial buildings.

Although the studies are designed for use by utilities, Cummings notes that the data will be available to everyone—government officials, architects, builders, and solar equipment manufacturers.

How many homes will be using solar energy, for example, by 1985? Nobody knows for sure. However, the president's goal is 2.5 million homes. One thing is sure: the utility industry will be able to plan for it, and that's good news for all solar enthusiasts.

Spinning a Turbine With Sunlight

It's all done with mirrors in plants that concentrate solar energy to drive turbine generators. Eight years of development have gone into designs that will work at commercial scale, and the push today is on three fronts: test those designs for pilot plant use, develop higher solar conversion efficiencies, and cut hardware costs.



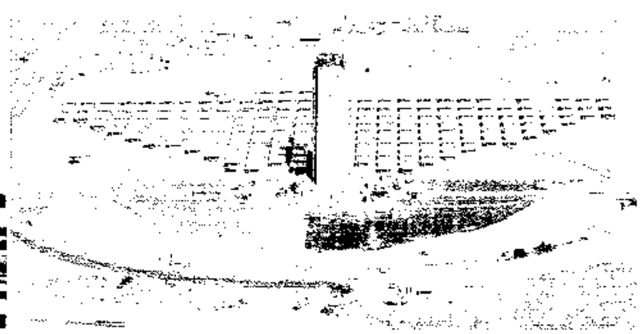
Today's research toward the generation of electricity from solar energy features a "power tower." Envision a boiler atop a tower, its feedwater—or perhaps some other fluid—heated by the converging solar beams reflected upward from a field of hundreds or thousands of focusing mirrors that track the sun from dawn to dusk. Add a system of risers, downcomers, and pumps; a heat exchanger and a turbine generator in the tower base; and insulated tanks filled with oil and rock to absorb and store a modest thermal reserve. Linked by electronic circuits, sensors, and switches; controlled by a computer; and monitored by utility operators—such a solar-thermal power plant puts the ultimate renewable energy source, the sun, on-line for electricity generation by U.S. utilities.

Or does it? How tall a tower, how many mirrors, and how big a boiler? For that matter, what working fluid, what cycle efficiency, and how much electricity? How many hours (and what kind) of energy storage and, therefore, how dependable and how valuable to an electric utility? What kind of demand service: peaking? intermediate? baseload? These questions go beyond simple concepts of solar-thermal processes.

But the answers are vital to the scale and the configuration of solar-thermal plants. They are vital to the economics of solar-thermal electricity. And they are vital in addressing the questions of ultimate interest to energy policy planners, utility managers, and electricity consumers everywhere: How many plants? Where? When?

Dividing the thermometer

Solar-thermal energy conversion for electricity generation can be divided into two categories for orderly understanding. These categories may be defined by temperature regime and hence by their suitability for various applications. One category is the intermediate-temperature range between 100°C and 400°C (lower temperatures are useful only for space conditioning and for water or process heat). Intermediate solar-thermal systems are adaptable to total energy use, that is, production of steam-generated electricity, rotating shaft energy, and steam or water itself at temperatures high enough for many industrial and commercial heating process requirements. (The term *total energy* is something of a misnomer as it implies all the energy needed



The nation's first comparative field evaluation of solar-thermal receivers begins this year at Albuquerque, New Mexico (left and below), where 222 Martin Marietta heliostats (shown in face-down position) will focus solar energy on test units in the north-facing bays of a 60-meter (200-ft) power tower. EPRI-sponsored 1-MW (thermal) Brayton-cycle receivers will be included in the test sequence, together with DOE-sponsored 5-MW (thermal) Rankine-cycle units.

when in fact it simply denotes production of energy in three forms.)

The second category, the high-temperature range, 500°C and above, is especially useful for electricity generation. This category, of course, is the one of major interest to electric utilities. Its capital cost is greater, but its energy conversion efficiencies are higher and its kilowatthour costs therefore will be lower. Understandably, its development is oriented to large capacities, remote siting (because of the acreage needed for collector fields), and—for dependability—the incorporation of energy storage in the form of thermal media or fossil fuels.

Solar-thermal systems can be designed in two ways. What we call the power tower features a central boiler, or receiver, surrounded by heliostats (tracking mirrors) that reflect and focus solar energy on the receiver. The other option uses distributed receivers. In many designs the mirrors are trough-shaped and fitted with heat-absorbing pipes (the receivers) along their focal axes. The working fluid is distributed through a pipe network, is solar-heated in its passage through the receivers, and is then returned to the turbine generator or to thermal storage. This concept avoids the cost of a tower but adds the cost and complexity of extensive insulated piping.

Setting the objectives

Temperature regime, conversion efficiency, and system configuration thus distinguish the two solar-thermal categories. To some extent they also distinguish the complementary goals of research by the U.S. Department of Energy and EPRI. For both technical communities the objective is to develop a completely renewable energy source. The federal program emphasizes solar energy as a substitute fuel (energy displacement). EPRI's program invokes a further concept, that of a substitute generating unit or entire plant (capacity displacement). For a utility, it is not only the total amount of solar "fuel" that must be ensured. The steady, timely supply of fuel is also necessary; hence the importance of energy storage that enables the solar-thermal facility to dependably displace one or more conventionally fueled units. Without storage, either the solar-thermal capacity or its backup becomes an additive capital cost on the utility system, and solar energy loses its potential economic edge.

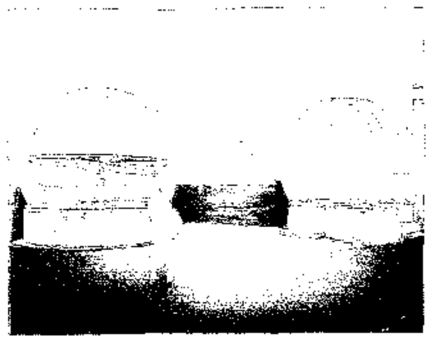
DOE's solar-thermal research and demonstration efforts include such applications as process heat generation, irrigation water pumping, and total energy supply. But it is clear that population and economic pressures will continue to call for more electric generating capacity, and if either high- or intermediate-temperature systems prove technically and economically feasible (at whatever physical scale), electric utilities will be the major market. Therefore, DOE and EPRI programs emphasize the central receiver concept and a physical scale most useful for centralized power generation (rather than modules for dispersed siting). To trace the origins of these programs and to link the various R&D projects that are converging on the field test phase today, it is necessary to go back only about eight years.

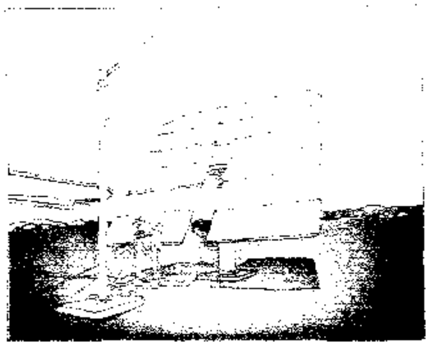
Defining the path

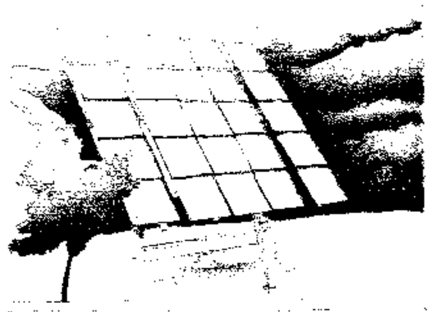
DOE's $400 million annual program in solar energy (all types) began with a budget of about $100,000 under National Science Foundation auspices in 1970. In 1972, technical assessment studies singled out the central receiver concept. It was seen to have the best technical potential for early development because existing technology and equipment for a water-steam Rankine cycle could be used.

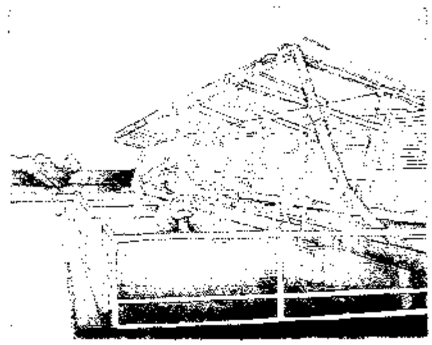
But the technology needed more precise definition for this judgment to be conclusive. For electric utility use in particular, what would be the detailed requirements, the optimal size, the best operational mode (peaking, intermediate cycling, or baseload service), and the minimal energy storage for continued output in cloudy weather? Answers to these questions were sought under a federally sponsored mission analysis, or in utility terms, system requirements definition and impact analysis.

The initial answers were a nominal generating capacity of 100 megawatts to help meet intermediate electric utility demands, encompassing six hours of









Solar-thermal heliostat prototypes produced under DOE sponsorship show various design approaches in materials and mechanisms. Distinctive Boeing bubbles shield aluminized polyester reflectors stretched on lightweight frames. Material and cost savings are somewhat offset by optical losses through the bubbles and the resultant need for more heliostats.

McDonnell Douglas heliostat (as chosen for pilot plant design) uses 12 flat glass mirrors in a 6.4 meter (21-ft) square array, with an H-shaped steel frame that permits the mirrors to be faced downward for storage.

Martin Marietta design is similar but employs 25 mirrors, each 1.2 meters (4-ft) square. More than 220 heliostats like this are being used at DOE's Albuquerque solar-thermal test facility.

Honeywell's "tilt-tilt" design draws its name from a fixed-azimuth frame that can be varied in elevation while its four mirror panels rotate about their own axes to track the sun.

In contrast to power tower heliostats, this distributed solar collector uses fixed reflective "slats" and an axial receiver that can be moved up and down for optimal focus and heat absorption as the sun moves.

storage. They led, in 1974, to congressional authorization and $20 million funding of a competitive design program aimed successively at conceptual design of a commercial-size plant, design and test of major solar components (heliostats, receivers, and thermal storage), and preliminary design of a 10-megawatt pilot plant for operation on a utility system. These initial efforts were to be followed by three phases: detailed design, construction, and operation of the 10-megawatt pilot plant, using one of the first-phase approaches; then (in the mid-1980s) a full-scale 50–100-megawatt demonstration plant; and finally, a commercial prototype.

Between mid-1975 and mid-1977 most of the early work was completed by three design teams headed, respectively, by McDonnell Douglas Astronautics Co., Martin Marietta Corp., and Honeywell, Inc. A fourth contractor, Boeing Engineering & Construction, undertook design of heliostats only. Each team confirmed the technical aspects of its design by the fabrication and testing of three heliostats, a 5-megawatt (thermal) receiver, and a thermal storage module. These units are now being readied for field testing at a $21 million test facility just completed for DOE in Albuquerque, New Mexico.

Testing the first generation

There are several variations and challenges in the subsystems to be tested. For example, both external and cavity-type receivers have been designed for the high concentrations of solar energy and the exchange of its heat to the working fluid. McDonnell Douglas favors the external receiver; Martin Marietta and Honeywell, the cavity-type. But it is apparent in the work to date that heliostat cost will be the determinant in solar-thermal plant economic feasibility. The federal program goal for this element is $70 per square meter of heliostat mirror surface area. Although designs to date have come in between $500 and $750 per square meter, the design contractors foresee reductions closer to the goal in future commercial experience.

DOE's first-phase development of solar-thermal system designs is now being followed by preparation for pilot-plant construction. In response to a federal request, 19 utility groups proposed sites and cost-sharing arrangements. The field was first narrowed to three areas, Texas (San Antonio), Arizona, and California (the southern desert). A California group was chosen: Southern California Edison Co. (SCE), the Los Angeles Department of Water and Power, and California's Energy Resources Conservation and Development Commission. Together they proposed an SCE site in the Mojave Desert near Barstow for the 10-megawatt plant to be built between now and 1981. In the fall of 1977, the McDonnell Douglas design team's concept was accepted as a technological baseline for the plant.

The estimated $120 million project cost is presently split two ways: DOE is funding the solar features and the two utilities are funding the conventional portions of the plant. Together, the utilities are sharing $20 million of the total project commitment.

Starting the second generation

Since 1974 EPRI's complementary solar-thermal research program has sponsored studies and tests of markedly higher-temperature, higher-efficiency systems. This departure uses the Brayton thermal cycle, distinguished by a working fluid that remains gaseous (perhaps air or helium), unlike one that changes phase (water to steam) as in the Rankine cycle. EPRI's work thus is moving solar-thermal research to a second, more advanced level of technological development. It also addresses economic feasibility by considering overall system impacts and requirements for electric utility application of solar-thermal units.

To this end, Boeing was awarded a contract in December 1974 for a closed-cycle, gas-cooled helium system (RP377-1). And in July 1975 Black & Veatch was awarded a contract for an open-cycle gas turbine system (RP475-1). Basic studies were essentially completed by July 1976 and have been succeeded by work on design and fabrication of 1-megawatt (thermal) "bench model" receivers that will be tested at Albuquerque—Boeing's receiver this year and that of Black & Veatch in 1979.

Like DOE's designs, both these projects envision a central receiver or power tower and an eventual 50–100-megawatt scale for commercial utility service. But there are important new considerations. In particular, the use of a gaseous working fluid and air cooling was specified because the major potential sites for solar-thermal plants lack cooling water in the volume needed for Rankine-cycle systems. Also, the inherently higher operating temperatures and power conversion efficiencies of Brayton cycles suggest that valuable cost economies may be attained to hasten the viability of power tower systems for electric utilities.

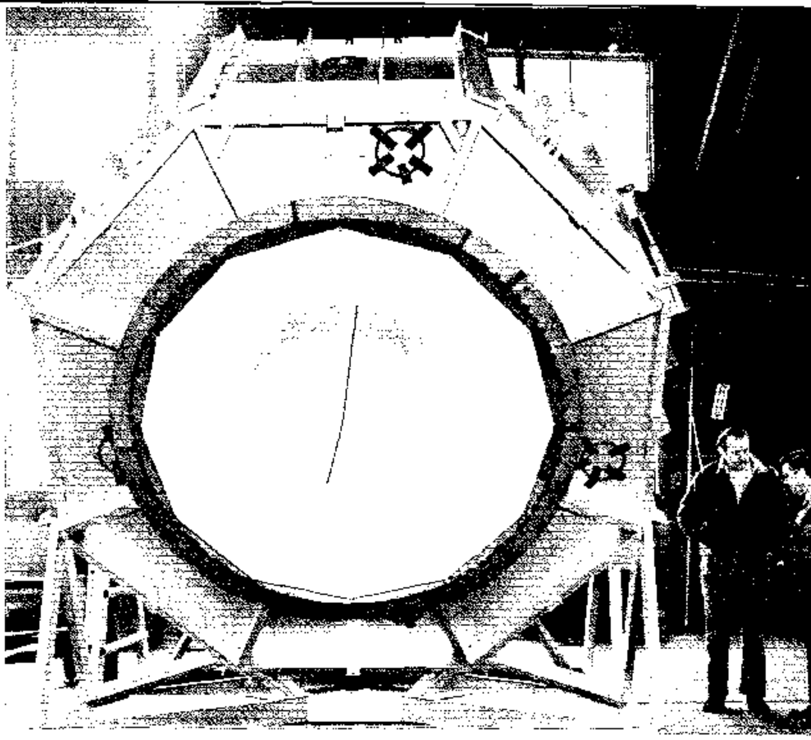
Closed-cycle gas turbine

The two EPRI-sponsored designs, though linked by common guidelines of cost, dimension, and capability, are distinctive. Boeing's closed-cycle concept proposes a pair of 50-megawatt modules and six hours of solar-thermal storage, using one of three means: phase-change heat in a salt, sensible heat in a refractory material, or heat in a reversible chemical reaction. The helium cycle operates at a solar-induced temperature of 816°C (1500°F) and pressure of 3.45 megapascals (500 psi), using a heat exchanger composed of U-shaped tubes of a metallic superalloy.

The receiver is a cavity, cylindrical in shape with a hemispherical lower section. For a 100-megawatt plant, the cylinder would be 39 meters (128 ft) in diameter and in height. The lower hemisphere has a 19-meter (62-ft) diameter aperture facing downward. Supported by struts above the tower to permit 360-degree optical access, the receiver aperture would stand 260 meters (850 ft) above ground.

Solar flux entering the aperture would reflect upward from the hemispherical walls to the heat exchanger tubes that line the cylinder walls—3 rows of 70 panels, each panel having 20 tubes and an exposed surface of 9.5 square meters (103 ft^2). Altogether, the receiver and its heat-exchange panels would weigh a total of 1500 tons. The turbine would be at the tower base for a "stand alone" system and its thermal storage (or at the top for a hybrid system using fossil fuel in lieu of thermal storage).

For the 1-megawatt (thermal) tests at Albuquerque, Boeing has built an octagonal receiver cavity that has 8 heat exchanger panels of 48 tubes each.



Aperture of Boeing's "bench model" solar-thermal receiver is defined by trapezoidal panels of high-alumina insulation board to protect against 1370°C solar flux. The tapered cavity interior reflects heat against Inconel 617 heat exchanger panels that line the 3-meter (10-ft) diameter octagonal section. The 4760-kilogram assembly is aimed at a 32° angle below horizontal for positioning at the 43-meter (140-ft) level in DOE's solar-thermal test facility at Albuquerque.

Open-cycle gas turbine

The Black & Veatch open-cycle gas turbine design proposes using regenerative turbomachinery that is available today: 60-megawatt nominal generating capacity from a single module, two of which would be required for a commercial plant. Instead of thermal storage, the design calls for a fossil-fueled combustor to feed the gas turbine when there is no sunlight.

The point of greatest technical challenge in the Black & Veatch design is the heat exchanger material, which must withstand compressed-air passage at 980–1065°C (1800–1950°F) and 931 kilopascals (135 psi). The choice was silicon carbide (a ceramic), and subsequent studies have concentrated on the design of fabrication and assembly techniques for the ceramic and its joints.

Four separate cavity receivers would sit atop this power tower, arrayed 90 degrees apart. This arrangement best accommodates the necessary ducting without compromising optical access by the solar flux. The four cavities would vary in dimension for best efficiency in their respective quadrants. They would be octagonal in shape and about 14.6 meters (48 ft) across, with 70 tubes in each. The heat exchanger tubes would be 12.2 meters (40 ft) high.

In this design, the turbine and its compressors are also on the tower, just below the receivers, whose apertures would be 213 meters (700 ft) above ground. Nominal weights would be 680 tons for the receivers and 800 tons for the turbine and two combustors.

To test this design in Albuquerque next year, Black & Veatch will fabricate a 1-megawatt (thermal) bench-scale cavity 3 meters (10 ft) across and 1.5 meters (5 ft) high, fitted with 96 ceramic tubes, each 3 meters (10 ft) high.

Cutting the capital cost

DOE's and EPRI's solar-thermal programs up to now are parallel. Yet they are also complementary, and they are based both on existing (first-generation) technology and on advanced (second-generation) technology. The parallels are basic: solar-thermal energy development, the power tower concept for electricity generation, and the near-readiness for testing of bench-model-scale subsystem elements.

The complementary quality is marked by policy goals: technical feasibility of fuel displacement for a variety of end uses in the federal program, economic as well as technical feasibility of both fuel *and* capacity displacement for electricity generation in the EPRI program. The Rankine-cycle water-steam components of the DOE program are today's technology. The Brayton-cycle solar components (though not the turbomachinery) of the EPRI program are a step into advanced technology.

Five separate efforts are now under way as DOE and EPRI seek to move solar-thermal power generation into a position of true economic viability. Their common objective is to achieve a unit (or plant) capital cost range of $1200–$1700 per kilowatt at commercial scale. Their means are twofold: development of higher-efficiency systems and reduction of solar-thermal plant (mainly heliostat) costs. The five efforts may be characterized as:

- DOE's project for advanced central receiver systems
- DOE's project for low-cost heliostats
- EPRI's heliostat cost study

▫ A multiagency project headed by Public Service Co. of New Mexico (PSNM) for establishing the feasibility of solar-thermal units to retrofit power plants in the U.S. Southwest

▫ EPRI's project to study problems and requirements of the solar-thermal interface with electric utility systems

Pushing the technology

Last fall four federal contracts were awarded to begin the multiphase study and development of second-generation solar-thermal receivers to operate at higher efficiencies than the water-steam design now headed for the pilot-plant stage. Two of them envision liquid metal (probably sodium) as the working fluid in the Rankine cycle. The developers for these $600,000 efforts are General Electric Co. and Atomics International (a division of Rockwell International Corp.). In another project, a third Rankine-cycle design (using a liquid salt) is being studied by Martin Marietta Corp. The fourth contract, awarded to Boeing, is for a Brayton closed cycle (using air), and it is substantially an extension of Boeing's research already done under EPRI sponsorship.

The study phase of these four contracts is to take 9–12 months. Like the earlier DOE work, they will yield baseline designs for commercial plants, detailed definition of pilot plants, and definition of subsystem elements and the experiments needed to test them. The second phase will see those subsystems through fabrication and test, which will begin in the fall of 1978.

Cost reduction is the objective of two roughly similar efforts by DOE and EPRI. The federal program entails four design studies for heliostats that can be produced and installed at a capital cost below the $500–$750 range (per square meter) of the heliostats to be tested at Albuquerque. These studies by General Electric, Boeing, McDonnell Douglas, and Solaramics, Inc., began last fall and are expected to take one year.

EPRI's work takes the existing heliostat designs produced for DOE in the 1975–1977 period and is an independent assessment of the cost reduction that may be possible through modifications in performance, design, manufacturing methods, and installation techniques, with Arthur D. Little, Inc., as the contractor (RP1091).

Pulling the potential market

Throughout the field of solar energy development one hears the terms *technology push* and *market pull.* EPRI's work is largely in the former, but a significant exception is the Institute's support of a study of the technology requirements and market for solar-thermal repowering of existing electric utility generating units. The problem is an intriguing one for utilities facing federal directives to convert generating units from oil or gas fuel to coal. But the notion of solar-thermal market pull remains elusive until numbers can be assigned to costs and benefits, and these in turn require definition in terms of plant technology and operation.

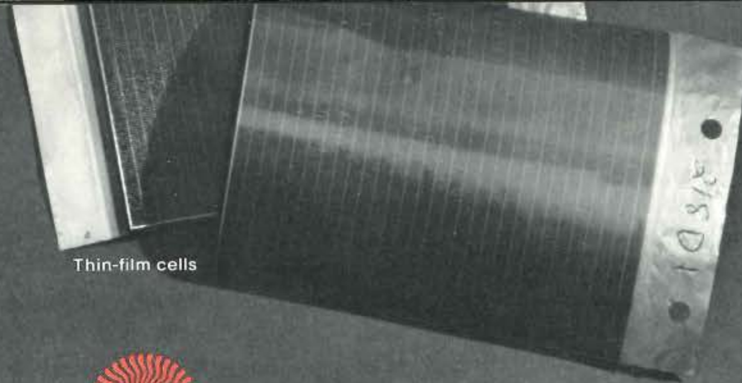
To evaluate possibilities in a prime candidate region, PSNM is the contractor on a one-year study (TPS77-730) of the potential for augmenting southwestern utility plants with solar-thermal "front ends"—that is, power towers with one or more generating units that would relegate some portion of the plants' fossil-fired capacity to a backup role. The work is being supported mainly by DOE, with additional funding from EPRI, WEST Associates (a regional organization of 20 electric utilities), and 4 individual utilities (Arizona Power Authority, Public Service Co. of Oklahoma, San Diego Gas & Electric Co., and Tucumcari Light & Power Dept. [New Mexico]). Findings should be forthcoming in the fall of this year. (WEST Associates is also conducting a three-year solar resource evaluation study in the Southwest, collecting solar radiation and weather data from a network of 37 field stations.)

Functionally related to the PSNM project is an EPRI-sponsored study by Westinghouse Electric Corp. to develop a utility planning methodology for adding solar-thermal capacity on a system (RP648). Actually, EPRI began this kind of research two years ago in studies with three utilities, Utah Power & Light Co., Arizona Public Service Co., and PSNM. During the first half of this year, Westinghouse is looking into computer models of six utility systems to ascertain criteria for the size, costs, and operating regimen needed for solar-thermal plants to be economic in system expansion plans. (The EPRI-developed models incorporate data and forecasts from real utilities, but with sufficient modification to cloud their identities while preserving authentic patterns and relationships of customer base, generation mix, weather patterns, load factors, and the like, as well as cost and rate data and experience.) In broad terms, the study is examining the interface between assumed patterns of system expansion and assumed parameters of solar-thermal generating capability—varying either or both to find the conditions in which solar-thermal can serve beneficially and economically.

The certainty of sunrise

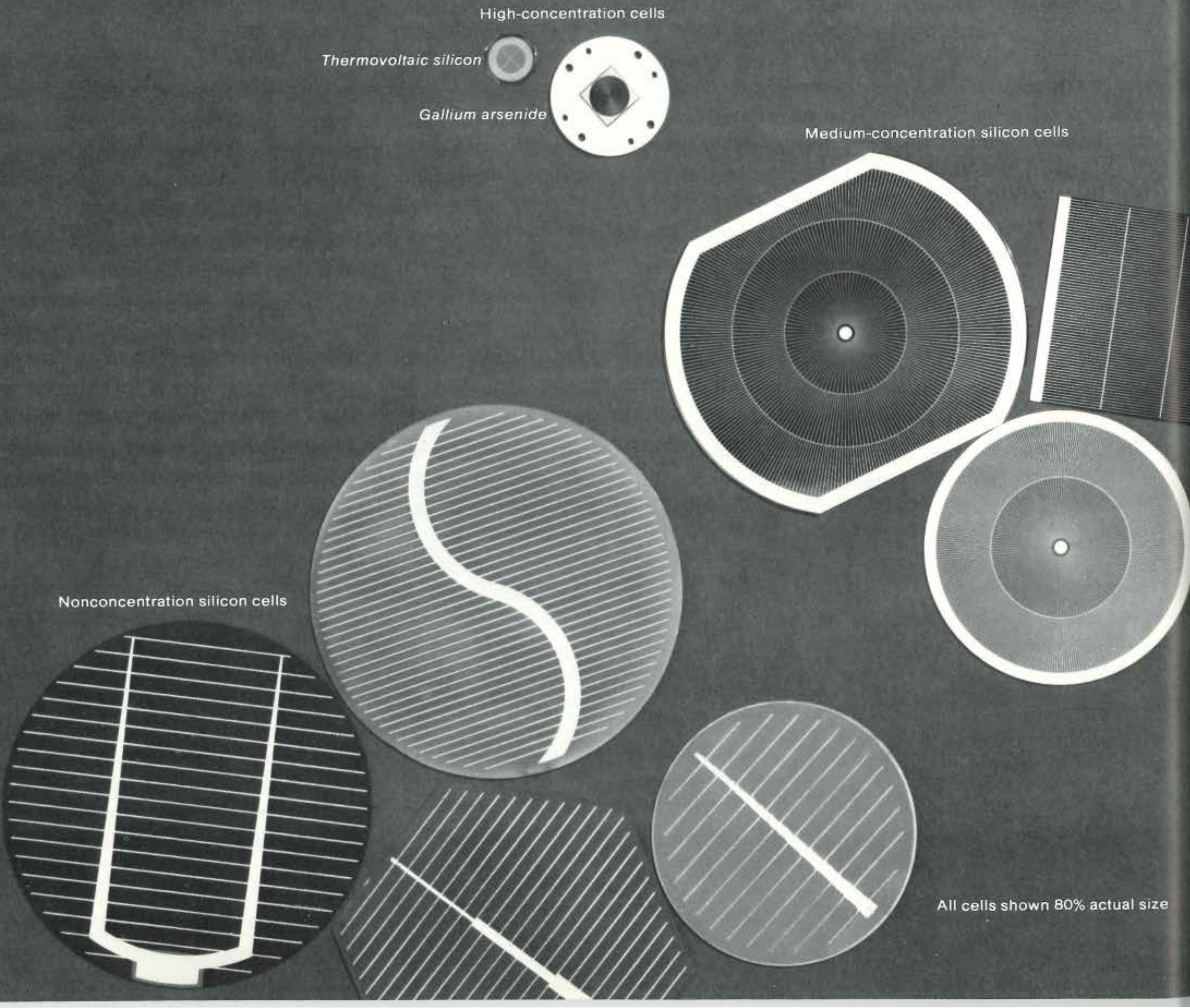
It is appropriate that EPRI's Westinghouse study concludes this qualitative review of major U.S. solar-thermal R&D. That study incorporates the familiar elements of requirements definition and impact analysis. It thus reveals the cyclic, iterative nature of the business, because the same two elements were the subject of the early federal solar-thermal study six years ago.

But the focus on what a solar-thermal plant can be and must do is becoming finer. The phases of the R&D sequence are clearly apparent. When the heliostats focus to build a head of steam in the first-generation pilot plant at Barstow three or four years from now, a second-generation pilot plant will be under construction, with a Brayton-cycle turbine generator (and fossil fuel for dependable capacity from storage). One way or another, using sunlight to spin electric utility turbines seems to be as certain as the sun's coming up.



The Sun on a Semiconductor

The cost of electricity from solar cells is many times higher than that from conventional energy sources. EPRI assessments and research suggest that new approaches in photovoltaic technology hold the most promise for bringing that cost down to a competitive level.



All cells shown 80% actual size

Solid-state technology, the revolution in electronics that brought us pocket calculators and video games with capabilities formerly reserved to respectable computers, has a lesser known side. It is photovoltaic conversion, the phenomenon that can transform sunlight directly to electricity.

Still largely unavailable to the general public, photovoltaics nevertheless has played dramatic roles in the past 15 years: providing internal power for Apollo spacecraft, lighting oil platforms miles out at sea, capturing energy for mountaintop communications stations, even running the automatic pilot on a transatlantic yacht. But whether or not photovoltaics will turn on the lights in your home is a question for the next 15 years.

Photovoltaic technology developed from the breakthroughs in electronics, beginning in the 1950s, that introduced semiconductor materials into electric circuits. Conventional solar cells share the technology of a calculator's microprocessor to the extent that both employ thin pieces of single-crystal silicon as part of their electric circuitry. But there is a basic difference in how that silicon is put to use. For microprocessors, it is fabricated into tiny chips on which thousands of complex circuits are etched. These circuits route electricity that originates elsewhere. In solar cells, however, the silicon is used to generate electricity when it is exposed to light.

To simplify how the process works in a conventional silicon solar cell: a particle of light of an appropriate wavelength striking a silicon solar cell contains sufficient energy to free an electron of a silicon atom from its chemical bond within the silicon crystal. The electron is now free to wander within the crystal, leaving behind a "hole." The hole can also move when an electron from a neighboring bond exchanges places with it. Such movement of electrons and holes, of course, is the essence of electricity.

To arrange the moving electrons and holes into a useful electric current, silicon crystals are doped with other elements, a process that either adds extra electrons (creating an *n*-type semiconductor) or creates an excess of holes (a *p*-type semiconductor). A solar cell typically consists of *p*- and *n*-type silicon regions. When light falls on the cell, freed electrons tend to migrate to the *n*-type region, holes to the *p*-type region, resulting in a voltage across the junction between them. Conductors on the front and back surfaces of the cell allow connection to an external circuit, through which the cell's electric current then flows.

Silicon cells manufactured commercially typically achieve 12–14% conversion efficiencies. When individual cells are connected in arrays, the resultant array efficiencies today are 6–8%, mainly because the arrays (as presently manufactured) are not completely covered with cells.

System offers many advantages

A photovoltaic electric system has several unique and attractive features. It produces electricity directly, bypassing the need for the intermediate conversion stages to thermal and/or mechanical energy required by all other solar electric technologies. Solar cells themselves contain no moving parts, and components potentially have very long lifetimes. Maintenance costs may therefore be significantly lower. Moreover, the system can operate with diffuse solar radiation, that is, the sunlight that arrives on earth by reflection from clouds and particulates in the air. Finally, a photovoltaic power system is inherently modular. A solar cell will produce electricity just as efficiently when used in a system generating several hundred watts for an off-shore oil rig as when used in a multimegawatt central power station. The role of photovoltaics in the electric generation picture, therefore, is potentially many-sided.

Why so expensive?

With so many attractive features, why are photovoltaic systems still limited to government experiments, NASA satellites, and a few remote small-scale applications? The answer lies in the high costs of the present manufacturing process.

Refining silicon to the degree of purity required for today's photovoltaic devices and growing the high-quality crystals are energy-intensive processes. And purity is only part of the problem. Once refined, much of the silicon is actually wasted, either left in the crucible used for crystal growth or turned into sawdust in the wafer-cutting process.

The microelectronics industry faces this same problem, yet in recent years the costs of its devices have dropped dramatically. Can we expect this to occur in photovoltaics?

Microelectronics has been able to solve the cost problem through advanced technology that enables more and more circuits to be etched on a given silicon surface area—in effect, reducing the space required to do the same amount of work. Photovoltaics generally cannot follow that route. The amount of electricity that is generated by a solar cell depends directly on the amount and quality of sunlight that the cell traps. Reducing the area of the cell means reducing the capacity to produce electricity. Cells can be made thinner or sunlight can be concentrated on cells, but these approaches, as described below, require new concepts and/or new, expensive technologies.

The price tag for electricity that is generated by the silicon solar cells now in commercial use is far from competitive. The cost of a peak kilowatt of electric generating capacity is about $15,000. (A peak kilowatt is defined as output at noon on a clear day, with the sun's rays perpendicular to the array. At most times, therefore, the array output is less than its peak value.) Although this cost is down impressively from $200,000 per peak kilowatt in 1959, it is obviously far above today's conventional power plant cost of $200–$1000 per kilowatt of rated generating capacity. (Rated generating capacity is the output a given conventional power plant can be counted on to generate whenever it is operating.)

These very high costs have limited the growth of a market for photovoltaic devices. In 1977 that market was about 750 peak kilowatts. For comparison, a moderate-size diesel generating unit has a generating capacity of about 750 kilowatts. Remember, though, that the diesel unit can operate at that rated power level for extended periods, not having to contend with the intermittent reception of the sun's energy.

Research on many fronts

In attempts to reduce photovoltaic costs and encourage market expansion, government and corporate research efforts are proceeding on several fronts simultaneously. DOE's largest research efforts in photovoltaics aim at reducing the materials and production costs of the conventional single-crystal silicon approach. The department estimates that a cost of $500 per peak kilowatt for single-crystal silicon cells encapsulated in panels is likely to be economically viable in some applications and has targeted 1986 as the year to achieve that cost goal.

One key assumption underlying the federal program is that only extensions of presently established technology and its scaling-up to mass production levels are necessary to achieve the cost goal. A second is that the $500 per peak kilowatt figure can be achieved *if* an annual market of 500 peak megawatts of generating capacity exists. Solar cell producers and the federal government are attempting to identify those markets, for it is not yet clear what they will be.

It should be recognized, then, that although the achievement of DOE's 1986 cost goal may open up new markets for photovoltaic panels, it is not likely to result in large-scale utility photovoltaic applications.

In 1978 DOE plans to spend $30.5 million (of a total photovoltaics budget of $58 million) on R&D efforts in single-crystal silicon. A project to develop a process called edge-defined film-fed growth is an example of this type of approach. In this process, silicon is grown in a continuous ribbon of the width and thickness required for the solar cells, so the waste incurred in cutting individual cells from the conventional cylinder is eliminated.

Other photovoltaics experts believe that more than just the further development and scale-up of current technology is needed before photovoltaic devices stand a real chance of contributing significantly to electric power generation. Several novel and alternative approaches are therefore the subject of other research efforts.

Alternative approaches

The concept of thin-film solar cells is attracting much serious interest. In this process, a thin layer of semiconductor material, such as cadmium sulfide, indium phosphide, or amorphous silicon, is deposited on an inexpensive substrate, plastic or glass, for example. Since thin-film cells require much smaller amounts of active photovoltaic material and tolerate more imperfections in that material, their production cost levels will probably be considerably lower than those achievable with single-crystal silicon cells. Some of these devices have achieved 7–8% efficiencies in the laboratory. One type, using cadmium sulfide on which a layer of copper sulfide is grown, is approaching commercial availability, although at efficiencies of 3–5%.

The newly established Solar Energy Research Institute (SERI) plans to concentrate research efforts on thin-film approaches. Sigurd Wagner, branch chief of photovoltaics, hopes to draw research scientists from around the country, borrowing them temporarily from universities and industries and giving them the opportunity to pursue the basic research still needed in this development.

DOE, too, has increased its budget for alternative approaches; in 1978 it plans to spend $9 million in this area. Donald Feucht, branch chief of advanced materials, reports that his branch is currently investigating four thin-film technologies. In addition, several other R&D efforts of significant size are being conducted with corporate funding.

Other approaches intensify, or concentrate, the sun's rays onto solar cells. Such systems require a smaller area of cells per unit of output power. Single-crystal cells of several types, particularly silicon and gallium arsenide, are being developed for use in these systems. DOE is contributing to this effort, and planners at SERI feel the concentrator approach holds real promise.

Some of the alternative technologies are still just in the conceptual stage of development, so it is clearly too early to predict which of them may turn out to be most economically promising.

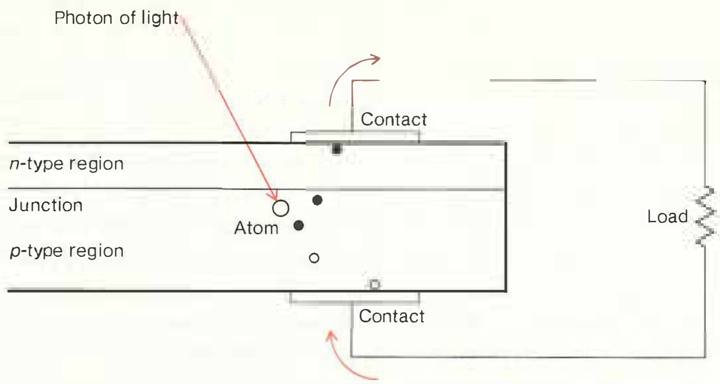
Says Edgar DeMeo, project manager for photovoltaic conversion at EPRI, "It's necessary to keep options open and to investigate new approaches that look promising. There's a danger of getting locked into approaches with which there is considerable experience and which can yield substantial near-term gains —only to realize that ultimately their cost and performance levels will never be viable for large-scale electric utility applications."

EPRI's contributions

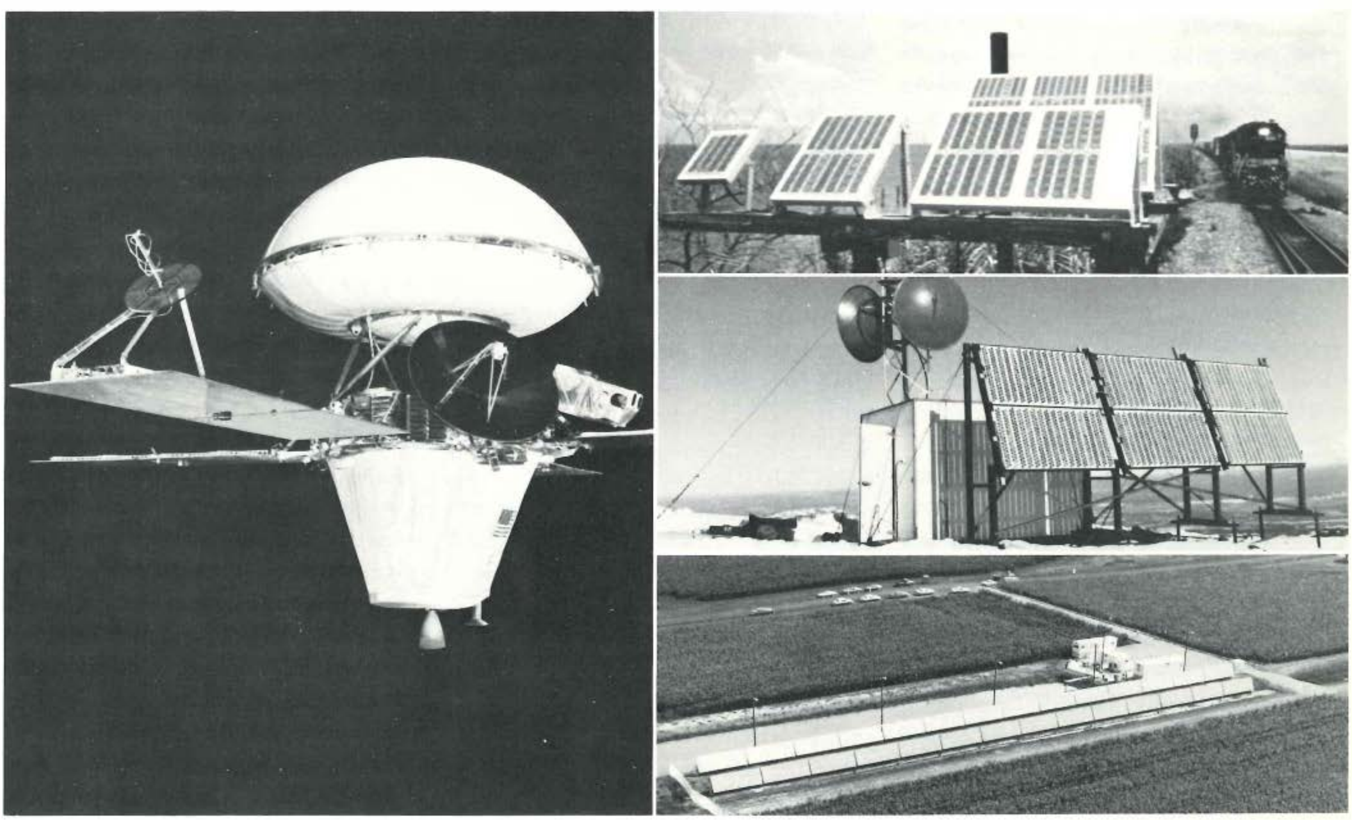
How does EPRI view its role in contributing to and influencing the direction of photovoltaics research? One thrust of EPRI's involvement has been analyses of the conditions that will enable photovoltaic power plants to be integrated into electric utility generating systems. As part of this effort, EPRI has recently published a special report, *Perspectives on Utility Central Station Photovoltaic Applications* (ER-589-SR). Written by DeMeo and Piet Bos, director of the New Energy Resources Department, the report describes a procedure for estimating allowable costs for photovoltaic central station power plants, based on busbar energy costs. The procedure involves deriving cost and performance goals for photovoltaic cells and panels and using those goals to assess which photovoltaic technologies are most likely to become competitive in large-scale applications.

"These are first-order values only,

Solar cell performance is a function of material composition and of the spectrum of photon energy (inversely proportional to wavelength) in the incident light. Energy conversion is triggered when a photon of sufficient energy penetrates the cell and dislodges an electron in the *p*-type region from its chemical bond. (In other photovoltaic devices the process may occur in the *n*-type region, or in both.) The electron (black dot) moves into the *n*-type region and the hole it leaves behind (white dot) moves toward the lower contact. The electron flows through the external circuit, constituting electric current, and thereafter recombines with a hole near the *p*-type contact. A crucial limitation on photovoltaic conversion efficiency is that some photons lack the energy to initiate this process and others have more energy than the process can use. This excess energy is wasted.



Outer space is the locale of the first routine use of solar energy for photovoltaic conversion, typified by solar cell arrays on the "wings" of a fragile Viking orbiter. High-value uses on earth followed, such as power for remote block signals (with battery storage) on the Southern Railway and a 900-peak-watt microwave repeater on an Alaskan mountaintop. More recently, an 80-acre Nebraska cornfield has been equipped with 97,000 solar cells (arrayed in two 100-meter rows), producing a peak of 25 kW to run a 0.06-cubic-meter-per-second (1000 gal/min) irrigation pump and the fans for drying 12,000 bushels of corn.



ball park figures," DeMeo is quick to emphasize. "They provide a useful framework within which we can evaluate research developments. But we don't intend them to indicate conditions that will guarantee utility acceptance of photovoltaic conversion as a large-scale power generation option. Our crystal ball isn't clear enough to make those kinds of predictions."

EPRI's analyses produced conclusions that DeMeo hopes will help establish priorities in photovoltaic R&D efforts. A significant finding was that the avenues most likely to lead to economical, large-scale utility applications will involve materials and/or concepts that are alternatives to established single-crystal silicon technologies. Specifically, thin-film devices in flat plate systems will probably be a viable approach if array efficiencies near 10% can be combined with cell costs under $20 per square meter. High-concentration systems, which involve concentrations greater than 100:1, also appear promising if cell conversion efficiencies of about 25–30% can be achieved. However, these systems may require forced cooling, which would be a marked disadvantage in some areas.

On the other hand, low- and medium-concentration approaches (i.e., 3:1–50:1) appear to have little potential in the long run. "These approaches have prospects for making quick, near-term cost reductions that will be very impressive," DeMeo points out. "But the difficulty is that these approaches may reach a cost plateau that's not low enough to achieve long-range economic feasibility. When—or if—it finally appears that it's not going to be a viable option, you run the risk of discrediting the potential of photovoltaic technology as a whole."

A second recent EPRI report, *Requirements Assessment of Photovoltaic Power Plants in Electric Utility Systems* (ER-685-SR), provides a more detailed analysis of the type that utilities will need in order to make realistic decisions about incorporating photovoltaic systems into their generating systems. Completed under a contract with General Electric Co. (RP651-1), it is an innovative effort in this area of analysis in that it adapts standard utility planning methods for use with photovoltaic systems. For this project General Electric developed analytic procedures that individual utility companies can use to estimate the value of photovoltaic generation to their own systems. These procedures were applied to three utility systems, and preliminary value estimates were generated.

The report concludes that the value of photovoltaic generation varies widely from one utility to another. In general, the flat plate and high-concentration, high-efficiency concepts hold the most economic promise in utility applications. Results presented include estimates of the energy displacement value that photovoltaic power plants will have. More important, results indicate that even without energy storage capability, these plants will have capacity displacement value as well, which means that because of the inclusion of photovoltaic power plants, some form of conventional electric generation will not need to be installed.

Sponsored basic research

EPRI is also funding basic research in new areas of photovoltaic technology. Through such efforts the Institute can ensure that the requirements of the electric utilities can be factored into the technology at the R&D level, as well as provide utilities with a strong basis for assessing current capabilities and future prospects. Work is under way at Stanford University to develop a novel concept known as thermophotovoltaic (TPV) conversion. In concept, this approach employs sunlight concentration, spectral shifting, and infrared energy recycling. These features potentially will increase the solar cells' conversion efficiency by providing light in a more usable wavelength range (through a high-temperature reradiator) and recycling light that is not used the first time it passes through the cell. Researchers are quite confident of achieving cell conversion efficiencies in the 30% range, which will probably be required if the concept is to become viable.

The TPV concept is still in the experimental stage, and several basic questions remain to be explored. For example, performance and operating lifetimes of the sunlight-concentrating components and the reradiator need to be investigated. The attractiveness of the concept is that high efficiencies can permit reductions in the required area of both the solar collector and the supporting structures, whose costs will be a major portion of total plant costs in any solar conversion power plant. The high concentration ratio, 300:1–500:1 at the cell, permits the use of the expensive converter that will be needed to obtain high efficiency.

A second EPRI effort, a thin-film research project, will get under way this year. The study aims at identifying either new or existing material systems that have prospects for achieving acceptable efficiencies at very low costs. By its direct involvement in thin-film research efforts, EPRI hopes to improve its basis for assessing the state of the art, encourage additional research activity, and establish a direct communication link with the research, development, and manufacturing communities.

"The way you get good information is by knocking heads on an informal basis with the people actually doing the work," says DeMeo. "We get that kind of information from our contractors. Then we can measure it against what we already know, determine what's still needed, and put out that message."

Market pull

Technological advances alone are not likely to push down costs of photovoltaic devices. Potential markets must exert a pull at the same time because production costs can be reduced only if some level of mass production capability exists. Some markets have been suggested that might support the industry during the early years and help drop costs to the point at which larger-scale applications become economically feasible. Off-shore oil rigs and remote microwave repeater stations are existing markets. The Department of Defense is interested in photovoltaic systems for remote communications facilities and for charging the batteries of portable field equipment. Yet another potential market is the cathodic protection of pipelines and tanks, a process in which voltage is applied to metals to arrest their corrosion.

What scale is most promising?

The markets just mentioned are commonly classified as distributed applications, as distinguished from larger-scale, centralized, or aggregated, applications. Clearly they can play a useful "holding action" role in the near term, hopefully providing sufficient market pull to sustain the development of photovoltaic technology until it reaches levels of large-scale viability. Yet distributed applications may also continue to provide important uses for photovoltaic generation systems.

"The strong advantage of photovoltaics is that it can work in either a distributed or an aggregated system," says SERI's Wagner. "There is no striking reason to think that one application would be greatly more advantageous than the other. We hope that the approach will function in both modes."

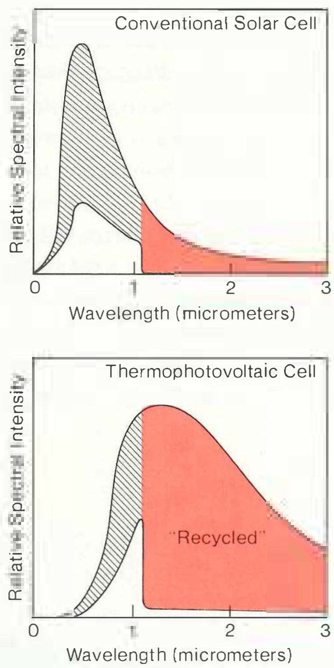
DeMeo points out that some of the factors that have driven conventional utility systems to centralized generation will not be applicable to photovoltaic power plants. Economies of scale will not be as important because the modular characteristic of the photovoltaic system permits a small power plant to generate electricity as efficiently as a large one. Environmental considerations, which have forced conventional power plants to be located away from population centers, will have reduced importance. Remote locations require long-distance electricity transmission systems, which in turn dictate one large power station rather than several scattered small ones.

However, a third factor, economies of maintenance, will still apply to photovoltaic plants in some form. Dispersing such systems to residential rooftops will create special maintenance problems, unless in actual use photovoltaic devices demonstrate unusually high reliability with very low repair requirements. DeMeo feels it is optimistic to assume that the devices will be trouble-free.

A new EPRI project funded this year will look at the technical and economic issues associated with distributed applications. The aim is to determine if they can produce and deliver electricity at competitive costs without sacrificing reliability. A second objective of the project is to assess the impacts—both positive and negative—on utility systems using distributed photovoltaic generation.

"We're not going to get definitive answers on this—that requires actual experience," DeMeo remarks. "But there is some experience with other distributed generation systems that utilities have been involved in, on-site industrial generation, energy storage, and fuel cell generation, for example. We hope to be able to draw on this experience to assess distributed applications on the basis of what we know about central station applications."

Thin-film, concentrated, or single-crystal silicon concepts? Distributed or centralized applications? The evidence supporting the choice of technologies and applications is still in the process of being generated. It will be a while yet before the verdict is in. Meanwhile, both research and technological advances and market expansion must continue if system costs are to come down so that photovoltaic technology can "come in from the mountaintop" and serve the energy needs of cities as well.



Useful and wasted proportions of incident light are shown by areas under schematic curves of spectral performance for conventional and thermophotovoltaic silicon cells. Photon energies up to about 1.1 μm produce the photovoltaic effect in silicon, with up to 50% efficiency at that wavelength alone. Overall efficiency of the conventional cell (unshaded area) is a maximum of about 22%. Shaded area denotes wasted light, and colored area denotes longer wavelength light that is not used.

The thermophotovoltaic device receives concentrated light that has been absorbed by a tungsten radiator (which is thus heated to about 1800°C) and is emitted with its spectrum shifted to longer wavelengths as shown. Wasted energy at wavelengths below 1.1 μm is greatly reduced. Because the silicon is transparent to the longer wavelengths, these wavelengths are reflected from a silver mirror on the back of the silicon and returned to the radiator. This "recycled" energy helps to maintain radiator temperature, enhancing the radiation of energy below 1.1 μm so that the overall energy conversion efficiency can be as high as 50%.

Utilities Put the Sun to Work

What is the real potential of solar energy for electric power systems? An increasing number of utilities are committing substantial amounts of time and money to R&D projects to find out.

Can the use of solar collectors be practical for internal climate control in Bismarck, North Dakota, where winters are long and severe? Temperatures there drop as low as −37°C (−35°F) and sometimes stay close to that level for the better part of a week. Blizzards a year ago dumped over a half a meter (2 ft) of snow during a 48-hour period. Dense clouds blot out the sun for days at a time.

Basin Electric Power Cooperative believes that solar collectors can contribute to its energy mix and is investing substantial amounts of time and funding to integrate 460 square meters (5000 ft²) of them into the existing heating, ventilating, and air conditioning (HVAC) system of its handsome new 6200-square-meter (67,000-ft²) headquarters in Bismarck.

The HVAC system is one of the most modern in the country. Its passive solar design accomplishes maximum energy conservation by reclamation and storage techniques. The building is nestled into the side of a hill where it is well insulated to minimize heat loss or gain, depending upon the season. It faces southeast for maximum natural utilization of the sun.

A 180-cubic-meter (60,000-gal) water reservoir with a capacity of more than 40 million Btu stores excess heat energy. Two electric centrifugal heat pumps move energy round the building to locations where it is needed.

The solar collectors that Basin Electric is tying into this system are next to the building (not on top of it) to facilitate later addition of extra floors.

Basin Electric has already invested more than $40,000 in design and engineering for its project. A total of more than $400,000 over a three-year period, cofunded with DOE, will ultimately go into it. This includes construction (now completed), instrumentation, and three years of computerized monitoring to determine what percentage of the total HVAC needs of the building can be met with solar panels throughout the year.

Severe winters shouldn't obscure the fact that the sun does shine in Bismarck in all seasons. Ambient temperatures above 38°C (100°F) are not uncommon in the summer.

"We want to find out how effective solar collectors can be in a northern climate," explains Ken Ziegler, assistant to the manager of community development and legislation for Basin Electric. "If the results are positive, as we think they will be, solar collectors could make a

North Dakota: Passive solar design for year-around conservation.

substantial contribution to our eight-state system in residential, industrial, and commercial uses. We need to find out when they will work, when they won't, and under what circumstances they will be cost-effective."

Basin Electric is a regional agency producing and transmitting wholesale electricity to more than 100 rural cooperatives in North and South Dakota, Wyoming, Colorado, Nebraska, Iowa, Montana, and Minnesota.

Roundup of utility solar R&D

What we have briefly described is one of 458 active projects, which were compiled from a telephone survey by EPRI during the summer of 1977 to determine the extent of solar energy research sponsored by electric utilities throughout the country. The lifetime value of these projects, conducted by 150 investor-owned, federal, municipal, and cooperative utilities, is estimated at $15–$20 million. This R&D effort does not include the multimillion-dollar solar research program that utilities fund through EPRI. In addition, there are undoubtedly a number of other utility solar research activities that have not been identified in the survey.

As would be expected, a substantial majority of the solar research projects in the EPRI survey deal with solar heating and cooling (SHAC) or related research. In EPRI's 1977 final count, this category accounted for 338 projects, or 74% of the total. The survey also identified 34 wind projects, 28 dealing with solar data collection, 22 solar-thermal power generation projects, 12 related to photovoltaics (solar cells), and 24 more that did not fall into any of these categories and were referred to simply as "other."

Full cycle—back to wood

One of the more promising "other" projects is a biomass development in New England where the Burlington (Vermont) Electric Department recently converted a 10-megawatt coal unit to burn a combination of wood and oil. The entire conversion was done in-house at a capital cost to Burlington of $25,000, not including labor. The converted plant has been in operation since early December 1977 and has exceeded all expectations.

"We are very pleased with all of the equipment," reports Thomas Carr, plant superintendent. "It is better than we expected and is already cost-effective. The wood-oil plant already operates more economically than it did as a coal-oil plant. In this state, with stringent emission control restrictions on burning coal, oil and wood now appear to be a much better bet than oil and coal. Although it is still a little early to tell, we anticipate far less problems with emission control because of the lower fly ash and sulfur content in the wood."

A mixture of hardwood and softwood, including many varieties of maple, spruce, and pine, are burned in the plant. Referred to as cull wood, this fuel is otherwise unmarketable. According to Carr, it is looked upon as "weeds that must be removed. Logging operators used to just pile it up and burn it, but now there are even restrictions on doing that. We can help them get rid of it."

To prepare it for burning, cull wood is run through a chipper that produces 50 tons of fuel per hour. The 10-megawatt plant burns 8–9 tons per hour.

Burlington has already completed a feasibility study on a 50-megawatt power plant that would burn 100% wood. With municipal voter approval, the plan is to have that plant (combined with a refuse-burning facility) on-line by 1982. The heated discharge water from the plant will be used to warm greenhouses. The plant cost is estimated at $75 million.

The 10-megawatt wood-oil plant is already producing competitively priced electric power. With the cost of available fuels going up and emission control standards becoming more stringent, wood appears to be helpful in this part of the country.

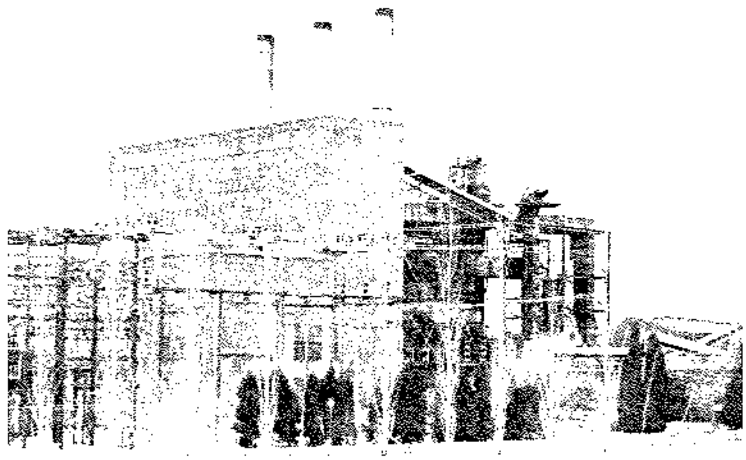
Forests cover 81% of Vermont. Studies indicate that the growth of "weed" wood is enough to produce 150 megawatts of electric power on a sustained-yield basis. In the words of Thomas Carr, "This project should have a very good effect on the economy of the state."

Data collection

Southern California Edison Co. (SCE) is participating in 13 solar research projects. One of these, a solar resource evaluation study, involves collection, organization, and analysis of solar radiation and climatic data in the southwest region, which is served by the Western Energy Supply and Transmission (WEST) Associates, a group of utilities.

As project manager for the group, SCE is coordinating and reducing the input data from participating utilities. The information is gathered from a network of 37 solar insolation and weather data collection stations. Twenty of these are in the SCE operating area and the other 17 are provided and operated by the other WEST Associates utilities. Plans call for nearly 50 stations when the system is complete.

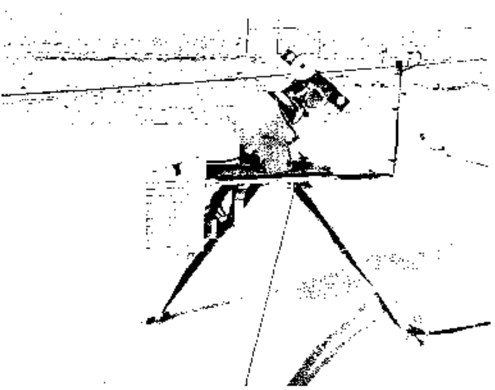
Vermont: 10 MW on wood chips and oil, 5 MW on wood alone.



The program was initiated in 1975 and is funded by WEST Associates at a rate of $50,000 per year. Initially planned for three years, it is being reviewed for possible extension.

The information gathered, relating to the amount of both direct and total sunlight reaching the earth's surface and to air temperature, is already being used by those designing a 10-megawatt solar-thermal electricity-generating plant at Barstow, California. It is also used as input for the design and installation of SHAC equipment and to influence and evaluate energy-efficient, passive solar architectural designs.

Southern California: Measuring insolation and air temperature for a solar map of the Southwest.



Cutting the cost of wind energy

Several years ago John Strickler, Jr., retired from aeronautical engineering, but his retirement did not quite "take." Today he is still engineering and designing, much to the delight and benefit of Puget Sound Power & Light Co. and Snohomish County Public Utility District.

The utilities and Strickler have teamed up on a research project to take maximum advantage of solar energy in a passive residential system and to augment that system with inexpensive wind energy. Puget Power is managing the work, which is estimated to cost $100,000 over a five-year period.

The primary obstacle to the development of wind energy has been its cost. Because wind is not constant, energy cost is substantially increased when storage batteries must be added to the windmill to provide continuous energy. If wind is ever to become a major energy source, costs must be kept at a minimum. One of the primary objectives of this project is to develop a total system, including thermal storage (concrete slab heating), at the lowest reasonable price. This means using commercially available products wherever possible.

Strickler constructed a 140-square-meter (1500-ft^2) house on Camano Island, about 50 miles northwest of Seattle. It faces south to get maximum exposure to the sun and is designed as a passive solar collector. Raw solar energy radiates naturally into the house, which thus does not require solar collector panels, mechanical or electrical systems, or heat storage facilities.

Two windmills designed by Strickler have been installed by Puget Power. They drive small generators, producing energy that is stored in the form of heat either in a concrete slab under the house (which has both a resistance cable system and a hydronic system) or in the domestic hot water system.

The hot water system uses standard electric water heaters, which have two heating elements, one connected to the windmill and the other to the utility system. When the wind is not generating sufficient energy to heat the water to the desired level, a thermostat switches in the utility system.

The space heating system works in similar fashion: When the wind generator produces enough energy, the heating wires or the hydronic system does the job. One objective of the project is to compare these two heating systems.

Comprehensive monitoring equipment has been installed by Puget Power to record data on the performance of the windmills and on the two heating systems in the concrete floor. On an hourly basis this instrumentation records over 50 different temperature points, wind speed and direction, and solar intensity. Windmill energy output and various energy-using devices are also being monitored. Data will be collected and analyzed over the next five years to determine the practicality of wind-generated electric energy as a supplementary source of power.

However successful the windmills prove to be, there is the obvious visual pollution problem, which might preclude their use in urban areas. In a rural setting they are not so offensive.

Testing a collector system

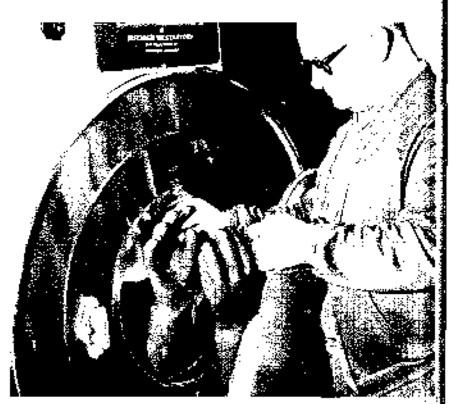
At The Toledo Edison Co. in Ohio, a 4.5-square-meter (49-ft^2) solar collector system is being tested. Its operation is part of a small-scale experiment in solar hot water heating, undertaken to determine how well the application would integrate with the utility system. A major concern is solar potential for meeting off-peak energy needs.

Located on the roof of the company's operations center, the small collector heats water for washing rubber gloves. The washing operation requires approximately 700 kilowatthours of electricity per month. During the first full month of operation the solar system produced 20% of the needed energy. The second month it accounted for 24%. The third month, even with only one sunny day, it produced 7% of the needed energy.

Toledo Edison has also installed two solar hot water heaters in employees' homes. These units are being monitored for at least one year to assess their economics and reliability.

In another project, Toledo Edison, con-

Ohio: Industrial wash water with a solar assist.



tracting with the University of Toledo, has retrofitted an existing house with solar collectors, a heat pump, an off-peak storage system, and a mini-computer heating control system. A complete instrumentation package has been installed. Data collection is just beginning.

Early SHAC demonstration

One of the earliest solar demonstration houses sponsored by a utility was built for Pennsylvania Power & Light Co. (PP&L) in 1973 at a cost of $145,000, including instrumentation. Its purpose has been to provide an experimental area for testing and demonstration of energy conservation techniques.

The main features of the house include solar collectors circulating an ethylene glycol–water solution (to forestall freezing), a 3-cubic-meter (1000-gal) water storage tank, 240 kilowatthours of rock heat storage capacity, a water loop that recovers waste heat as a heat pump source, a 2-ton heat pump, automatically operating drapes, and fluorescent lighting.

In its various operating modes, the system supplies forced-air space heat in any of five ways:

□ By exchange from solar-heated water storage

□ By exchange from the warm water loop via heat pump

□ By electric resistance elements in the air ducts

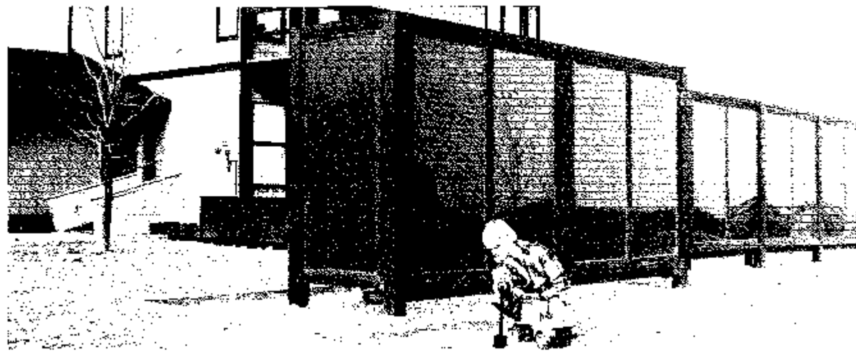
□ By exchange from off-peak electrically heated water storage

□ By exchange from off-peak electrically heated rock storage

PP&L has found that since the house itself is so energy-efficient, the solar system isn't markedly beneficial at today's fuel prices. The capital cost of the system is high compared to the value of the energy saved.

Since the completion of the energy conservation home, PP&L has sponsored the installation of six solar heating demonstration systems; conducted tests on four types of flat plate collectors; supplied

Pennsylvania: Solar fence screens the yard and heats the house.



load shapes and weather data for use in EPRI R&D projects; participated in an NSF-funded study of the implications of residential solar space conditioning for electric utilities; provided data for a DOE photovoltaic study; and begun work on a 45-kilowatt wind turbine demonstration.

Sun-power house

They call it the sun-power house in Lawrence, Kansas. It was built last year under the sponsorship of Kansas Power and Light Co. It started out as a load research project using a 6-cubic-meter (2000-gal) water storage tank for off-peak cooling during the summer. The water storage is still used for cooling during the summer, but it is also used as a heat pump energy storage unit during the winter.

The house is large—218 square meters (2350 ft^2)—but the design is so tight (including air-lock doors) that the 1.9-ton Dunham-Bush chiller (heat pump) is adequate for cooling, even during the hot Kansas summers.

On the roof, there is a 30-panel flat plate solar collector system, including 24 panels for space conditioning and 6 for domestic hot water heating. Passive solar features include a greenhouse for space heating, eave overhangs above windows to control solar gain in the summer, extensive glass facing south, and brick floors.

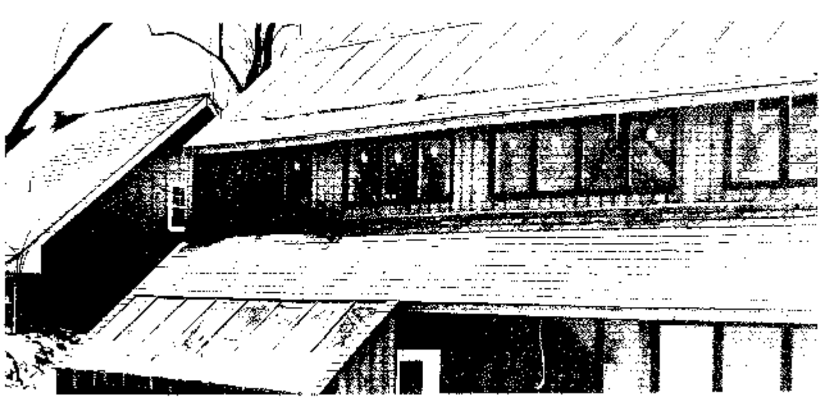
The house will be occupied by a family with two or three children. It is instrumented and will be used for data collection on energy consumption, solar contribution, and load characteristics for two years. It cost $125,000 to build, probably a real bargain for the solar energy information it will generate.

Solar space conditioning

The new 2500-square-meter (27,000-ft^2) Santa Clara (California) community recreation center is one of the first large buildings in the world to be both heated and air-conditioned by solar power.

When the building was being planned in 1973, the city instructed the architect

Kansas: 24 solar panels for space heat, 6 for hot water.



California: 2500 square meters of space conditioning for community recreation.

to make provisions for possible solar heating of the building. With initial assistance from the Lockheed Missiles & Space Co., Inc., Palo Alto Research Laboratory, and later funding from NSF, DOE, and the American Public Power Association, the building became a solar showplace. Overall responsibility for the project was assumed by DOE, but much of the solar installation work was done by field crews from Santa Clara's utility department.

Four hundred and thirty-six high-performance solar collectors (650 square meters—7085 ft²) are mounted on the south side of the building at an angle of 18 degrees from the horizontal. Water containing antifreeze and corrosion inhibitors is pumped through the collectors at a rate of 9 cubic millimeters per second (140 gal/min). During the summer the collectors boost water temperature up to 104°C (220°F) in order to drive the absorption water chillers that provide cooling to the building.

The system includes two underground storage tanks—one for 30 cubic meters (10,000 gal) of hot water and the other for 150 cubic meters (50,000 gal) of cold water. The two storage tanks allow the building to be heated and cooled at nights and on cloudy days without the need for either the backup boiler or the two 25-ton lithium-bromide absorption water chillers.

Computer simulations indicate that the solar system will provide 84% of the building's heating, 65% of its cooling, and 80% of its total space conditioning energy requirement on a year-round basis. The remaining energy requirement is met by the backup boiler and electrically driven pumps and fans.

In the heating mode, energy absorbed by the solar collectors is transferred either to the hot water storage tank or to standard fan coils distributed around the building. Air is blown across these units and into the rooms. When there is not enough sunlight available, energy can be transferred from the hot water storage, or the boiler can be activated.

During four to six months of the year there is enough solar energy available to drive the absorption chillers. These devices produce cold water at temperatures down to 7°C (45°F) and are powered by hot water from the solar collectors. The chillers keep the cold water storage at the desired temperature, and this water, in turn, is used as needed to cool the building. If necessary, the boiler can be activated to run the chillers.

The total value of the Santa Clara solar project is almost $1 million, with $667,000 coming from DOE.

Integration of solar electric systems

The Southwest Project involves 13 southwestern utilities (2 as advisers only), under the program coordination of Arizona Public Service Co. (APS). With funding by DOE, they are working with Stone & Webster Engineering Corp. to develop strategies for accelerating use of large-scale solar electricity-generating systems in utility networks. The funding for this is about $750,000.

The objectives of the project are to determine the current development status of solar electricity-generating systems; to define utility requirements for design and operation of these systems; and to determine penetration potential in the utility generation mix between 1985 and 2000.

The project is basically an analysis of resource and institutional requirements for solar electricity generation. It will set forth strategies that might be used by DOE in establishing policy and a plan for commercialization. This effort provides for input from state energy offices in the Southwest.

A similar Southeast Project was started in the fall of 1977, also with Stone & Webster Engineering, and a Northeast Project is getting under way, with JBF Scientific Corp. as the contractor. The latter projects also encompass solar heating and cooling.

Solar heat in the cloudy northwest

Who says the sun never shines in the Pacific Northwest? Certainly not two customers of Portland General Electric Co. (PGE), who are now into their second year of experience with residential solar space heating systems.

On one of their houses, PGE has installed 39 square meters (429 ft²) of double-glazed copper, 30% glycol-and-water, closed-loop collectors; an 11-cubic-meter (3750-gal) water heat collection system; and a 3.75-cubic-meter (1250-gal) tank for off-peak electric-supplement heat storage. Heat is transferred from the water to a forced-air system for circulation in the house.

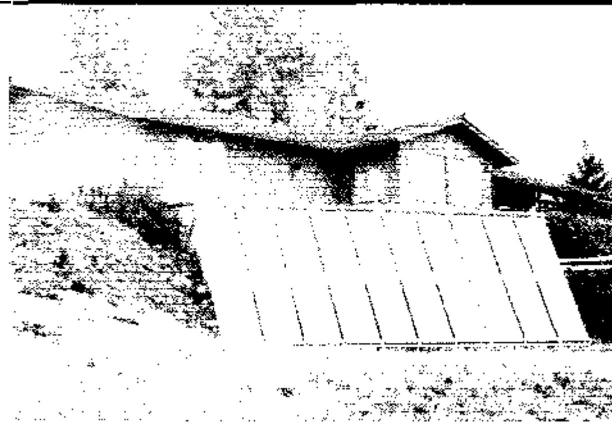
This two-story, 167-square-meter (1790-ft^2) house is fully instrumented with a 32-channel digital data logger.

The system works. During the first four months of 1977, solar energy contributed 53% of the 8000-kilowatthour equivalent heating requirement for the home.

In another, somewhat larger house (195 square meters—2078 ft^2) PGE installed 36 square meters (390 ft^2) of single-glazed copper, water-cooled collectors; a 19-cubic meter (6250-gal) solar water storage system (fire tanks); and a 3.75-cubic-meter (1250-gal) off-peak electric-supplement heat storage tank. A solar-assisted water-to-air heat pump completes the system. This house, too, was fully instrumented for monitoring.

During those first four months of 1977, the solar system provided 55% of the total 10,055-kilowatthour heating requirement of the house.

These two (out of six active) solar projects by PGE prove that the sun does shine in the Pacific Northwest and that it can make a contribution to space conditioning there. It's another question, of course, as to which is indeed the best solar design for a house, office building, or factory in the region, or what effect a large solar market would have on PGE's operations, costs, and revenues.



Oregon: Half the heat comes from solar-thermal storage

Broad solar program

Pacific Gas and Electric Co. (PG&E), serving the northern two-thirds of California, has made an extensive commitment to solar R&D. Its program, with a budget of $530,000 for 1977 and $650,000 this year, includes more than 50 projects.

PG&E is now studying the performance of 20 solar homes in its service area. The company has already built, and is now monitoring, four solar demonstration homes. Three more homes with passive solar conditioning are under construction. Solar equipment has been (or will be) installed in another 3 homes.

Six commercial solar installations, ranging from office buildings to a coin-operated laundry, either have been completed or are in planning or construction stages. Six others are being monitored.

PG&E is involved in six different SHAC materials and components testing projects, including flat plate collectors from various suppliers; solar water heating systems; swimming pool covers; and 93 square meters (1000 ft^2) of "water-wall" panels that combine energy collection and warm water storage.

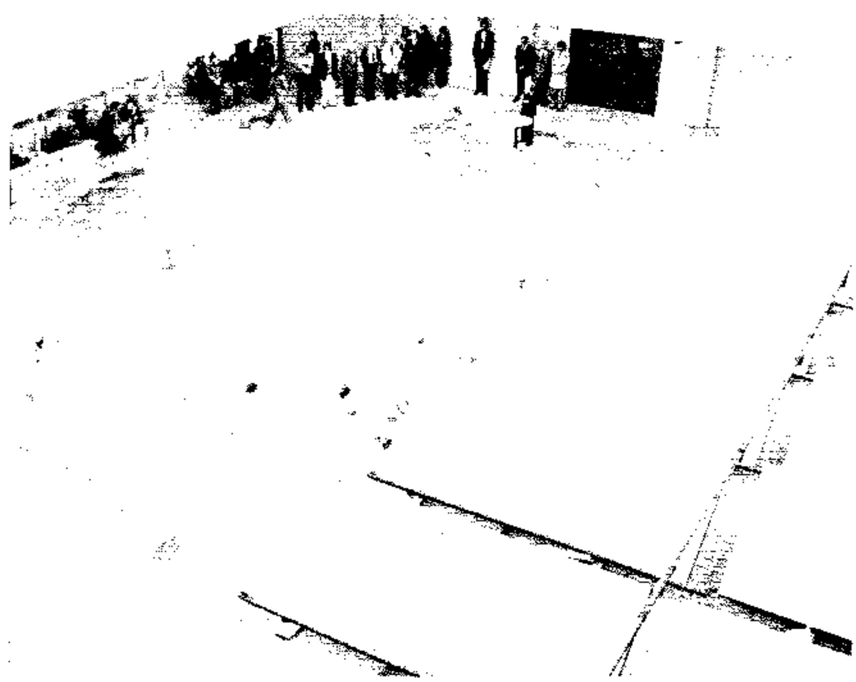
Still other PG&E projects relate to solar food drying, solar data collection, wind energy conversion, cogeneration of electricity and steam from waste wood combustion, and solar public information.

In an unusual project, PG&E installed a two-way meter for a homeowner in the San Francisco Bay Area who had designed and installed his own wind generator. When it produced more electricity than his home was drawing, the meter would reverse and he, in effect, would sell electricity to the utility.

Samples of a trend

These are but a few of the ways that electric utilities around the country are pursuing solar energy development. In addition to the dollars, they are investing hundreds of thousands of staff hours on their solar projects. It is thus apparent that more and more utilities are recognizing the potential of solar energy as it relates to their industry.

California: "Sun bath" for handicapped swimmers.



EPRI TO TEST SOLAR MONITOR

At EPRI headquarters in Palo Alto, an innovative monitoring system for solar water-heating installations will be tested on a system to be attached this spring to the third building of the Institute's new office complex.

The simplified monitoring system, designed and tested last year by Daystar Corp. for EPRI contractor New England Power Service Co., proved more reliable and economical than current systems. It was successfully demonstrated on a solar water-heating system at a Wakefield, Rhode Island, hospital.

EPRI "home base" testing of the monitoring equipment will provide additional and, more important, first-hand information on how useful it could be to utilities. For some time, utilities have complained about the cost and poor reliability of current monitoring systems.

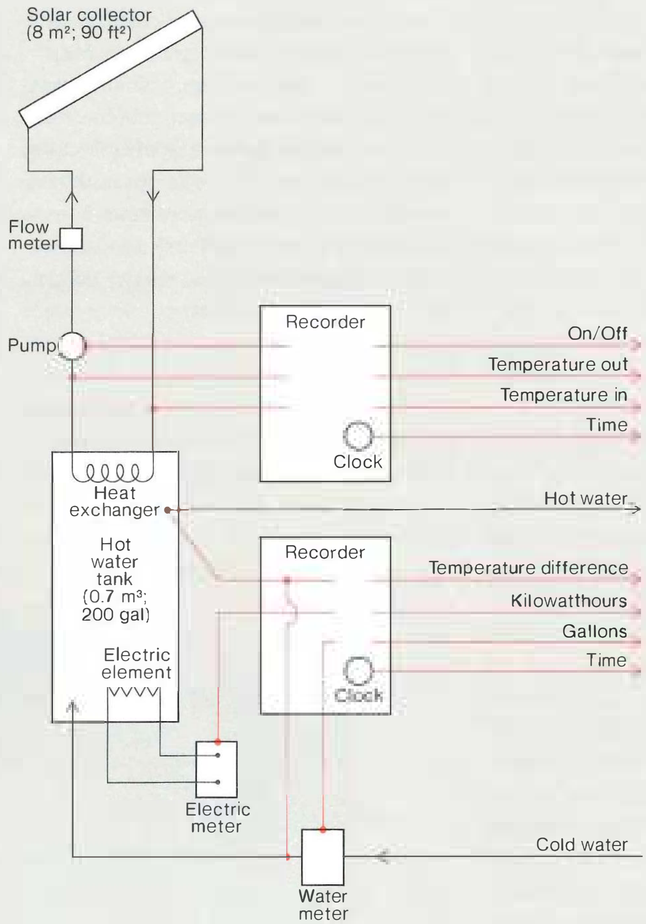
The Daystar setup makes use of recording equipment that utilities usually have (which saves money) and relatively few other components. As configured to monitor the hospital's solar system, it cost only about $2000—80% less than hardware for a comparably sized but complex system that some utilities are using today.

The EPRI solar installation will provide hot water for two restrooms in a two-story building. It will have about 8 square meters (90 ft^2) of collector area and 0.6 cubic meter (200 gal) of hot water storage for carryover on cloudy days.

Although modest, the system, when coupled with the monitoring equipment, will provide considerable information on how well solar systems work and how they affect electricity demand.

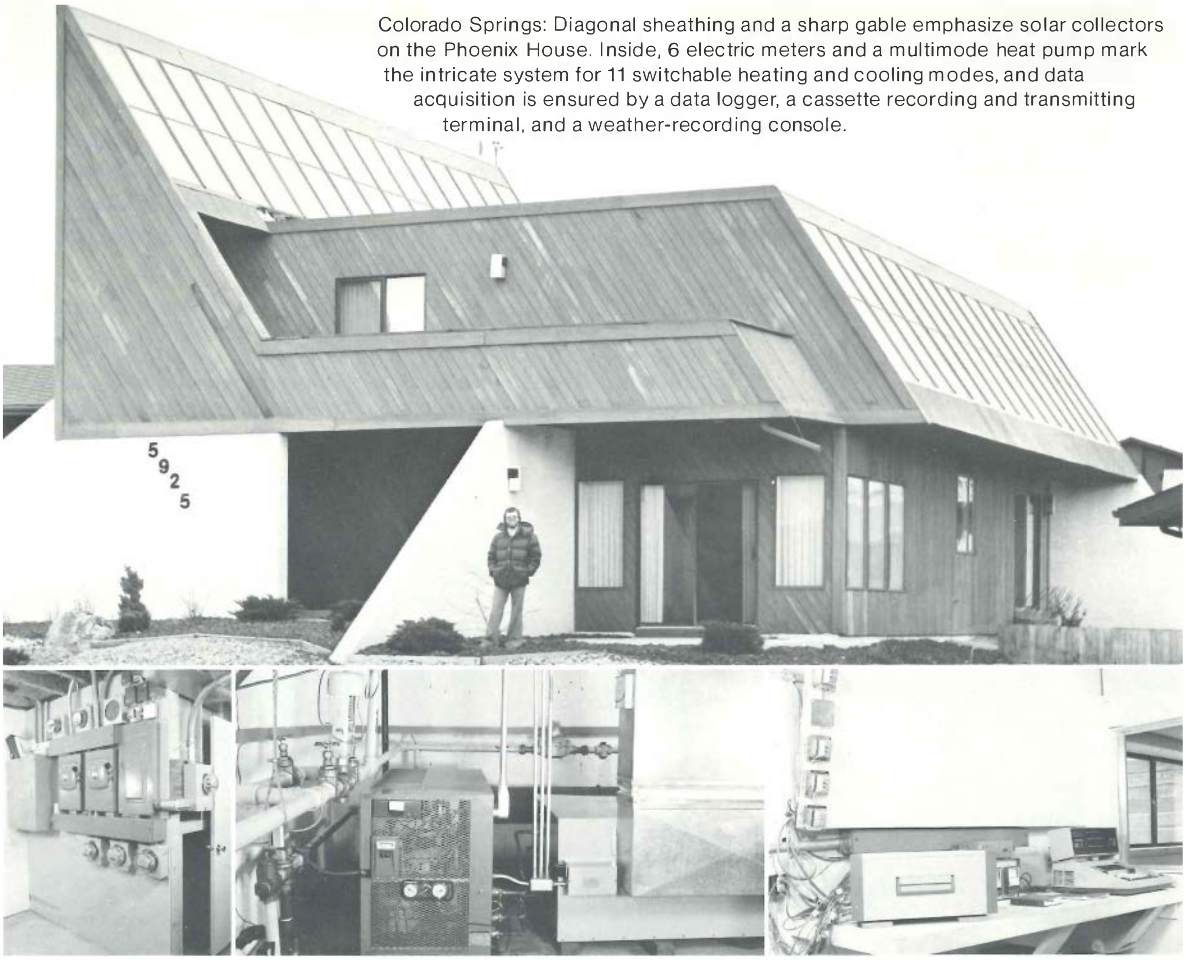
Data to be gained include the amount of solar energy delivered to the storage tanks, the amount of energy that is drawn from the tanks, the electric backup energy used, energy losses inherent in the system, and the amount of hot water consumed.

Two 4-channel digital pulse recorders monitor a pair of clocks and six sensors—all that's needed to calculate the solar-heated portion of total hot water demand in a new EPRI office building.



EPRI Sponsors Solar Instrumentation

Everyone will learn a little more a little sooner from the methodology being developed with EPRI-funded instrumentation and data evaluation.



Colorado Springs: Diagonal sheathing and a sharp gable emphasize solar collectors on the Phoenix House. Inside, 6 electric meters and a multimode heat pump mark the intricate system for 11 switchable heating and cooling modes, and data acquisition is ensured by a data logger, a cassette recording and transmitting terminal, and a weather-recording console.

Many electric utilities that are sponsoring solar demonstration projects have found monitoring their solar systems and evaluating the data to be expensive and difficult. Monitoring alone may account for as much as 40% of total project cost. A project may approach completion, and only then does it become evident that the budget allocated for monitoring performance has been used in system design or construction.

EPRI has received requests from time to time to assist in funding the instrumentation of utility solar projects. In the past two years, EPRI has selected five whose performance data and other findings will aid the development of a methodology for taking performance data—answering such questions as "What do I measure and how often?" Two to four projects a year will be added to EPRI's sponsorship over the next five years, enabling refinement of the methodology as a tool for member utilities to use in instrumenting further experiments.

Eleven solar combinations

The Colorado Springs Department of Public Utilities is sponsoring a project to evaluate solar-assisted heat pump systems (RP924). The Phoenix House is a 260-square-meter (2800-ft^2), two-story, single-family dwelling. It uses 70 square meters (750 ft^2) of pressurized-fluid, flat plate collectors; a 1.2-cubic-meter (400-

gal) uninsulated, buried water storage tank; and a heat pump to supply 3 tons of cooling and 6400 degree-days (°F) of heating.

Eleven configurations of solar heating and cooling (SHAC) equipment were analyzed. Study results show that a solar-assisted heat pump system, with water storage, resulted in the highest savings of customer energy and utility costs.

The Colorado Springs utility—which combines electricity, gas, and water service—used these results as the basis for establishing a rate structure to give homeowners the incentive to install the most favorable SHAC equipment to displace gas and electricity used for space conditioning. The other 10 configurations, it was learned, resulted in more costly options.

In this joint project with DOE, the EPRI-funded portion was the data analysis and evaluation. The study also considered several market penetration levels for the solar equipment and their impact on utility plans and operations.

Solar water heating

A project to study a hospital solar water-heating system (RP554) is being sponsored by New England Power Service Co. In 1976, South County Hospital in Wakefield, Rhode Island, constructed a solar water-heating system to supplement its hot water supply. Daystar Corp. was the manufacturer and installer of the solar hardware, and it also designed the EPRI-sponsored instrumentation package to monitor system performance. The project has been under way for over two years. Of the total weekly hot water energy requirement, the percentage supplied by the solar system has varied from a low of 25% in very cloudy weeks to a high of 88% in very clear weeks, with an average above 50%. These data confirm the design goals of the experiment; they are not the result of "tweaking" the system for optimal performance.

A new alternative in monitoring instrumentation, which EPRI decided to sponsor, was proposed after the project had been operating for six months. This included a low-cost, simpler monitoring system, which has been compared with the first one installed and found to provide more reliable performance and data that are nearly as accurate. It uses recording equipment that most utilities already have, thus minimizing their project costs.

Solar cooling comparison

Texas Electric Service Co. is sponsoring a project to compare residential solar-absorption and heat-pump cooling systems (RP923). Texas Electric and the University of Texas have cooperated to build, equip, and monitor a residence on the university campus at Arlington, employing both solar-actuated and vapor-compression (heat pump) cooling devices. EPRI is funding part of the data monitoring system and the analysis to compare the two systems in terms of performance, operation, and economics. The house has been occupied since early 1977 and has accumulated data for one heating and one cooling season.

Experience during the cooling season has shown the difficulty of storing water at 93°C (200°F) and maintaining that temperature to supply the absorption unit. (The house has concentrating collectors to produce water temperatures above 93°C [200°F].) The normal operating method for cooling has been to run the absorption machine for two weeks and then run the heat pump the other

Wakefield, Rhode Island: Solar energy heats half the hot water used by this hospital, according to data from the monitoring system on its instrumented network of storage tanks, pumps, meters, heat exchangers, and insulated pipe interconnections.

two weeks of each month. In this manner, a relatively fair comparison of performance is obtained for the two systems.

Solar heating and cooling

Under RP925, Southern California Edison Co. (SCE) will monitor a commercial solar-augmented heat pump. A one-story building occupied by a public television station in Huntington Beach, California, has been supplied with a solar heating system employing flat plate collectors to supplement 26 heat pumps that both heat and cool the building. SCE funded the solar system, and EPRI funded the monitoring system.

The solar system employs storage tanks not only to store solar energy for use in the early morning hours when the sun is still very low but also to store heat rejected from the building when an excess builds up in the afternoon. The design allows use of the solar system only, the heat pump system only, or a combination of the two.

Solar-assisted heat pump

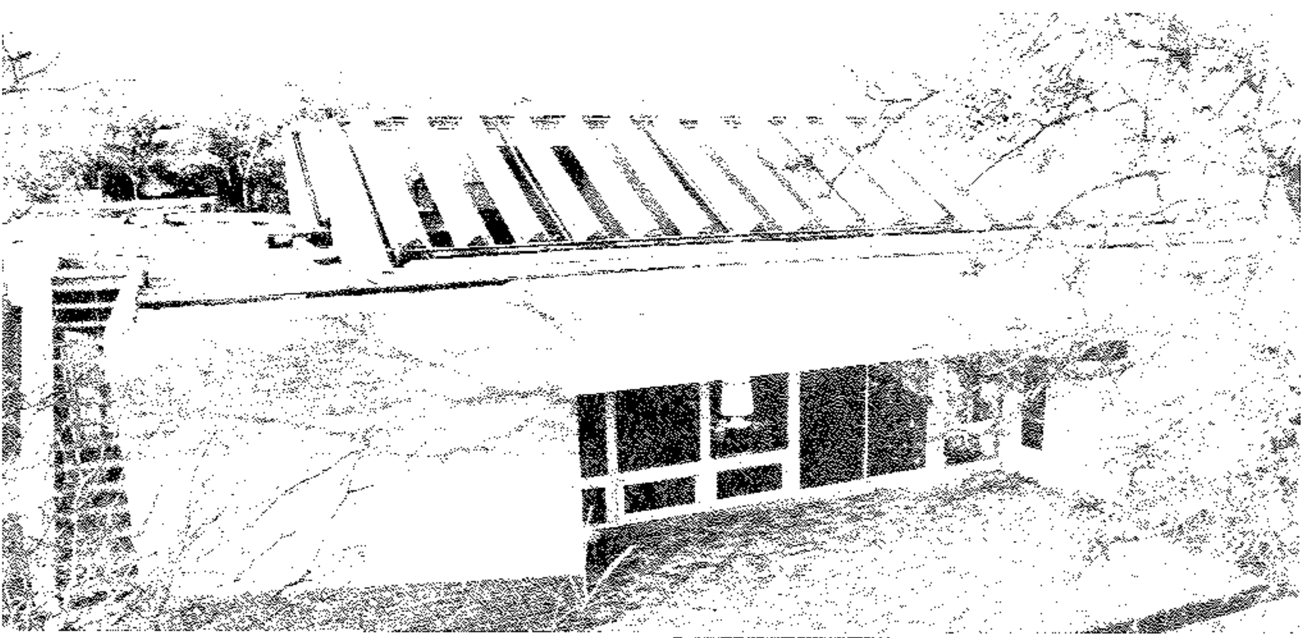
A project to study a residential solar-assisted heat pump (RP649) is being sponsored by Potomac Electric Power Co. A single-family house was built two years ago by a Potomac Electric employee, incorporating a solar-heating system assisted by a heat pump. During the heating season, the solar system provides most of the domestic hot water and a significant portion of the space heating. Cooling season requirements are provided by the heat pump, with the solar system providing nearly 100% of the household hot water. The system and heat pump have been operational for a year.

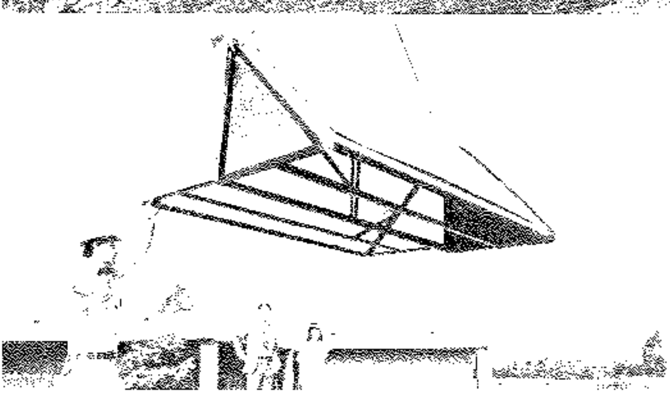
This project is jointly sponsored by Potomac Electric, DOE, and EPRI. The solar performance-monitoring portion of the project is being funded by EPRI.

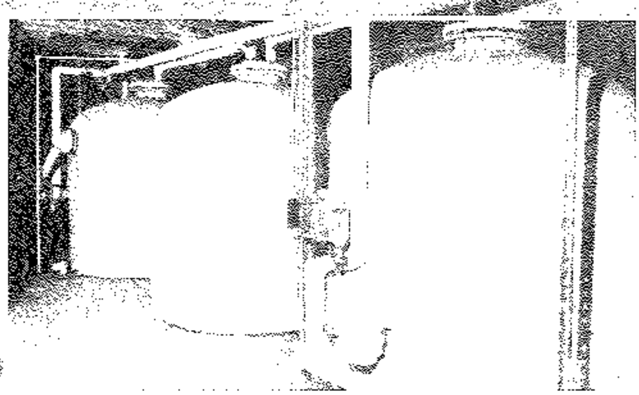
Publication of results

An interim report on the hospital solar water-heating project is available (ER-217). The final report on this project, and interim reports on the other four, will be published this summer.

Across the country: Arlington, Texas, house (top) features a comparison of solar-absorption and vapor-compression cooling systems Huntington Beach, California, office (left) has 15 cubic meters (4000 gal) of water to store either solar heat or rejected heat pumped from inside the building Naylor, Maryland, house (right) uses three 3.5-cubic-meter (900 gal) insulated fiberglass tanks of solar-heated water to supplement a heat pump for year-round forced-air heating and cooling.







The Shape of SHAC Supply

Rapid growth, high volatility, and equipment and installation problems reflect growing pains in the solar heating and cooling supply industry.

Because energy demands for heating and cooling represent a substantial portion of the potential growth in electric utility load, it is important to know how much of this load could be served by solar heating and cooling (SHAC). Until recently, however, most of the attention given to SHAC systems focused on demonstrating technologies and developing incentives for the installation of systems, with little attention given to supply. Supply, in the sense used here, encompasses a host of factors in the production, assembly, distribution, installation, and servicing of SHAC equipment.

Under contract to EPRI, the firm of Donovan, Hamester & Rattien, Inc. (DHR), is delineating the structure and characteristics of the emerging SHAC industry (RP1013). Later, using various assumptions for growth in SHAC demand, DHR will project what the solar industry may be like when the market for its products is much larger.

Industry growth patterns

The history of other developing technologies underscores the importance of cost, performance, reliability, durability, and other supply factors in determining the rate of adoption of new technologies. In the late 1950s and early 1960s, for example, the unreliability of heat pumps had a negative impact on demand for them. In large part the problems stemmed from installation mismatches, application errors by an inexperienced sales and service industry, and overextension of commercial distribution channels. These are all quite possible in the SHAC industry today.

Although solar energy is widely seen today as a technology of the future, the solar industry is not new. Between the 1920s and 1940s about 50,000 solar water heaters were installed in south Florida. By the 1950s, however, the installation rate had dropped almost to zero because of rural electrification and the advent of "big inch" natural gas transmission pipelines. More recently, the solar industry has experienced a rebirth and startling growth in the aftermath of the Arab oil embargo. Each year since 1973 the industry has more than doubled. This change is only partly economic—for example, the capital cost of gas utility expansion has tended to limit new gas service to clustered developments or tracts. SHAC seems to have evolved mostly in response to a market segment that wishes and can afford to innovate.

Along with its high growth rate, there is high volatility in the SHAC industry. For example, between June 1975 and June 1976 the number of companies manufacturing solar collectors increased 88%, from 83 to 156. Furthermore, half the companies reported in June 1976 had not been active in the solar business only six months earlier, while 28% of the companies producing in December 1975 were no longer active the following June (FEA Semiannual Solar Collector Survey). Such volatility often arises when an industry or market is easy to enter.

The industry seems to be stabilizing. For the last half of 1976 new producers —including companies resuming production—made up 34% of the total. Preliminary data for the first half of 1977 indicate that this figure dropped to 16%. In addition, the size of company operations rose sharply, with average production of solar collectors increasing 47%, to 940 square meters (10,100 ft^2) per company for the six-month period. Only 18 firms were producing at an annual rate exceeding 4600 square meters (50,000 ft^2).

Problems of unfamiliarity

Complicating supply (and demand) analyses of SHAC is the fact that exaggerated advertising claims, inferior equipment, and poor installation are all too frequent. These arise because the industry has many small, often inadequately financed manufacturers dealing with a fragmented construction industry and uninformed buyers. Such problems could lead to increased government regulation and the imposition of stringent standards.

Several states have begun efforts to control fraudulent SHAC business practices. The Florida state attorney general's office is currently litigating cases of deceptive franchising and retailing. On a more positive note, Florida also is cooperating with DOE in a $156,000 project to identify and carry out measures for the education and protection of solar buyers.

Fraud is not the only problem with solar installations, however. Many problems arise from well-intentioned dealers and installers who are working with systems that are new and largely unfamiliar to them. One example of this is a recently publicized and controversial report of solar hot-water heater demonstrations in New England under the auspices of New England Electric System. Unlike instances involving specially designed solar equipment, this project tested commercially available systems under realistic field conditions—that is, what a consumer would encounter in the market and in his own subsequent experience. Early results showed performance well below design goals. The problems encountered were similar to those of many mechanical products or systems in the early years of product development. The preliminary report indicated a need for more knowledge about installation and servicing. Many manufacturers were surprised to learn how poorly their equipment was being installed. Several of them suffered unexpected difficulties because of inadequate system design, limited technical experience with solar water heaters, business startup problems, incomplete performance tests, or inadequate financing. At present, the manufacturers and the utility industry are working closely to address these problems.

Preliminary EPRI findings

DHR's study for EPRI will identify the cost components in present prices for SHAC equipment and installations—such as materials, labor, distributor-dealer-installer markups—and will make informed estimates of how these categories will behave as the industry continues to grow. Particular research questions include: What are the potential economies of scale in production, assembly, transportation, distribution, installation, and maintenance? What are the potential learning curves that can be expected for assembly and installation?

Results so far available from the DHR study are fragmentary, and the following brief review should be considered merely illustrative of the scope of the research.

The solar collector is the only major item of new technology in SHAC systems. Table 1 shows the rise in manufacturing activity during 1976. The designations "liquid" and "air" refer to the heat-transfer medium being used. Low-temperature collectors are usually made of plastic or rubber and are used almost exclusively to heat swimming pools. Medium-temperature collectors generally operate in the 60–82°C (140–180°F) temperature range, are more sophisticated, and are composed of a metal absorber plate, double glazing of glass or plastic, and insulation, all contained within a rigid frame. The "special" category includes more sophisticated types of collectors, such as evacuated-tube and concentrating collectors.

The history for medium-temperature and special collectors is shown in Table 2. Production in the last half of 1976 was 177% greater than in the corresponding period a year earlier.

In late 1977 the basic factory selling price of a collector panel was generally between \$100 and \$130 per square meter (\$9–\$12/ft²), of which materials cost was about \$50 per square meter (\$5/ft²). Other factors, such as distributor and dealer costs and margins, and installation contractor markup, raised the installed cost to the user to \$270—\$430 per square meter (\$25–\$40/ft²), or about 3 times the factory price of the collector alone. At these prices and today's sales volume, the profitability of the various participants in the supply sequence is unknown.

Table 1
U.S. SOLAR COLLECTOR PRODUCTION

Collection Category	Collector Production (m^2/ft^2) January–June 1976	July–December 1976	Number of Manufacturers*
Medium-temperature, liquid	50,000/538,000	84,700/911,000	142
Medium-temperature, air	11,000/118,000	16,100/173,000	26
Special, liquid	4,400/48,000	12,600/136,000	14
Low-temperature	145,800/1,569,000	214,400/2,307,000	15

Source: Federal Energy Administration. *Solar Collector Manufacturing Activity*, July through December 1976. Springfield, Va.: National Technical Information Service. FEA/B-77/135

*Total as of December 1976. Some manufacturers are counted under more than one category.

Table 2
MEDIUM-TEMPERATURE AND SPECIAL SOLAR COLLECTORS

Period	Area (m^2/ft^2)	Number of Manufacturers	Average per Manufacturer (m^2/ft^2)
1974 (12 months)	12,700/137,000	39	320/3,500
January–June 1975	25,600/276,000	69	370/4,000
July–December 1975	41,000/441,000	102	400/4,300
January–June 1976	65,400/704,000	142	460/5,000
July–December 1976	113,400/1,220,000	177	640/6,900

Source: Federal Energy Administration. *Solar Collector Manufacturing Activity*, July through December 1976. Springfield, Va.: National Technical Information Service. FEA/B-77/135.

Many marketing approaches

Various marketing and installation strategies are under study and application in the industry today, all with the hope of lowering installed system prices and expanding markets. One highly speculative marketing approach would avoid going through traditional distribution channels. Dealer markup would be eliminated entirely, distributor markup reduced to 4–8%, and installation markup shaved to 25–50%, resulting in a total installed cost to the user of only about 1.5 times the factory price of the collector—far below the usual factor of 3. On the basis of experience in other industries, the commercial viability of this approach is very questionable.

Setting technical standards

The advent of government or industry standards for the construction and installation of solar equipment will have a major effect on the industry. Standards are evolving not only in federal and state efforts but within the industry itself. The federal government has been setting standards for equipment used in its demonstration programs. The National Bureau of Standards developed solar equipment standards that are now a part of minimum requirements for solar grants from the Department of Housing and Urban Development (HUD). These standards are the most comprehensive available for total systems and include not only the selection of collectors, tanks, and other components but also system configurations and installation conditions.

The HUD minimum standard will receive its first broad application this year in HUD's solar hot-water initiative program. In this program 10,000 installations will qualify for HUD grants, but only if the equipment has been certified as meeting the HUD standards. Additional requirements will include installation and maintenance manuals for the system and all components, availability of service and replacement parts, and sophistication of controls.

Other organizations are also active in the standards area. The Sheet Metal and Air Conditioning Contractors National Association has taken steps to control fraudulent activities by issuing solar installation standards. The Air Conditioning and Refrigeration Institute has been identifying laboratories having suitable equipment and personnel to test solar components. The American Society of Heating, Refrigerating, and Air Conditioning Engineers has issued equipment test procedures as ASHRAE Standard 93-77.

The solar industry itself, through the Solar Energy Industries Association (SEIA) and the Solar Energy Research and Education Foundation, is active in developing standards. Current thinking leans to adoption of measures resembling ASHRAE Standard 93-77. A further industry step will be taken when SEIA introduces its product certification program. An interim version is expected to be in operation in the first half of this year. Another SEIA project is the development of guidelines for advertising, based on Federal Trade Commission regulations.

Conjectural future

The federal government will probably continue to be important in shaping industry standards. It is not clear, though, how the current controversy over the value of standards will be resolved. Some observers see positive consumer benefits from standards. Others argue that premature introduction of rigid standards could stifle technological innovation in an infant industry. Whatever form standards eventually take, they will undoubtedly play an important part in shaping the development and structure of the SHAC industry.

Results from the DHR study are expected to be published in September of this year. Because all the costs involved in bringing SHAC systems to their end users will have been considered, EPRI and the larger business and technical community should gain an improved basis for forecasting the market growth of this developing industry.

Solar's Golden Horizon

Early commercialization of the most promising solar energy technologies is a major goal of the Solar Energy Research Institute.

Golden, Colorado, now has a notable resident to tout besides Coors. The Solar Energy Research Institute (SERI) settled in town last July. And although SERI is unlikely to outshine Coors in popularity, it promises to become a major center of solar energy research and development.

Created by an act of Congress in 1974, SERI is funded by DOE and is managed and operated under federal contract by Midwest Research Institute (MRI) of Kansas City, Missouri. MRI, in conjunction with the State of Colorado, was among 20 candidates that bid for the SERI contract. Colorado has given DOE an option on 300 acres on a foothill plateau east of Golden as the location for SERI's permanent facilities, to be occupied in about five years. The growing staff—currently numbering about 150 and expected to stabilize at around 600—is now housed in the new Denver West office complex in Golden.

SERI began with a budget of just under $5 million; nearly $12 million was budgeted for 1978, and $25 million is proposed for 1980. SERI's contract is to support widespread use of all aspects of solar technology, including direct solar conversion (photovoltaics), solar heating and cooling, solar-thermal power generation, agricultural and industrial process heat, wind power, ocean-thermal conversion, and biomass conversion.

Main thrusts

SERI's director, Paul Rappaport, a recognized pioneer in solar energy conversion and an authority on photovoltaic technology, sees two main thrusts for SERI: to identify commercially viable solar technologies and perfect them through research and testing and to conduct programs to create market demand and industry capability.

In his efforts to dispel "solar myths," Rappaport disputed figures on costs of energy from solar cells that were cited at a recent energy conference by Barry Commoner. "There is no way we can reach 50¢ per watt by 1980 and 14¢ per watt later on," said Rappaport of Commoner's prediction. "We at SERI can't deliver what some speakers are telling public audiences, and we have the best collection of solar experts under one roof," he told the conference.

Michael Noland, deputy director and a solar energy specialist who was director of MRI's Engineering Sciences Division, often speaks to groups about issues that determine solar energy's application, such as reducing system acquisition costs, accepting life-cycle costing in comparing solar applications with other energy forms, esthetics, environmental implications, reliability, storage, and readiness of technologies.

Noland points out that although sunshine is free, converting it to energy is currently expensive. "Solar energy," he says, "is not likely to replace much of the need for other energy resources in the next two or three decades. However," he adds, "with the right approaches, a goal of 8 or 10% solar by the year 2000 is both extremely worthwhile and reasonably ambitious." Noland, who wrote the MRI proposal that won the SERI contract, sees as a potentially serious barrier to developing a solar industry the appearance on the market of some poor quality equipment that doesn't perform properly. There is an urgent need for government and industry to establish standards, he stresses, or the consumer may shy away from solar before it can prove itself.

SERI is recruiting some of the best talent available to serve in these main roles: to provide solar energy program planning support to DOE; to conduct programs in solar energy information dissemination, education and training, technology commercialization, and international solar development; and to assist DOE in technical and administrative management of selected elements of the national solar energy effort, providing technical advice and counsel as requested. SERI also will serve DOE in evaluating the content, progress, and direction of the national solar energy program and lend leadership to that effort.

SERI: Organized to expedite commercial success of solar technologies

DOE On-Site Representative

Director

Dr. Paul Rappaport

Public Information Office

Special Programs Office

Deputy Director

Dr. Michael Noland

Plans and Operations Office

Intergovernmental and Regional Programs Office

Assistant Director, Administrative and Technical Services

Dr. F. V. Morriss

- Accounting, Finance, and Budget Branch
- Contracts Branch
- Procurement and Laboratory Services Branch
- Personnel Services Branch
- Word Processing and Secretarial Services Branch

Assistant Director, Research

Dr. J. C. Grosskreutz

- Research Operations
- Test and Measurements Group
- Materials Branch
- Photovoltaics Branch
- Bio/Chemical Conversion Branch
- Thermal Conversion Branch
- Systems Analysis Branch
- Resource Assessment Branch

Assistant Director, Information, Education, and International Programs

Dr. Alex Kotch

- Deputy Assistant Director
- Conferences Group
- Information Systems Branch
- Education and Training Branch
- International Programs Branch

Assistant Director Analysis and Assessment

Dr. M. Simmons

- Policy Analysis Branch
- Economics and Market Analysis Branch
- Institutional and Environmental Assessment Branch
- Program Assessment Branch
- Program Planning Branch

Assistant Director, Technology Commercialization

Dr. K. Zaininger

- Deputy Assistant Director
- Technology Evaluation Branch
- Market Development Branch
- Communications Branch
- Passive Technology Branch

Commercialization

A major effort at SERI will be directed toward dealing with the varied and complex considerations of getting solar technologies into the marketplace. This responsibility rests with the Technology Commercialization Division under Karl Zaininger, who joined SERI after many years with RCA Laboratories in Princeton, New Jersey, where he headed the Solid State Device Technology Laboratory.

"What we are really after," Zaininger says, "is to help bring into being, hopefully in a short time, a growing, self-sustaining, and profitable private industry that is based on solar energy technologies." Among the early tasks of his technology evaluation branch is a survey of the state of readiness of the various solar technologies that exist today, Zaininger notes. The initial survey report is due out in April.

Zaininger lists domestic space and water heating and swimming pool heating as the "in-hand solar technologies" that will be given early priority in SERI's commercialization efforts. Next in line he sees solar cooling of houses as promising. While large-scale solar-powered cooling systems have been demonstrated in buildings, solar cooling of houses will require further development. And a major effort in the near term will be given to wind power and to photovoltaics, which Zaininger believes could enter the market within three to five years.

Zaininger points out that SERI will guard against urging onto industry the technologies that are not ready either technically or economically. "The worst thing we could do," he says, "is to push a technology that is not ready."

Equipment standards

Attention will be given to the critical area of equipment standards and certification. Zaininger explains that SERI sees its role as a catalyst in stimulating industry to set its own standards.

Through a market development branch, Zaininger will attempt "to establish good lines of communication with all the players in the game—from manufacturers to consumers." Zaininger's staff will keep in touch with architects, builders, labor unions, lending institutions, insurance companies, utilities, regulatory agencies, and so on, to determine what barriers there are to solar technologies in each of these areas.

"Coming from private industry," Zaininger points out, "my feeling is that we cannot get carried away with a missionary approach that solar energy is good and everybody should have it right away, forgetting that there are problems."

Research outlook

SERI's Research Division will carry a major share of the institute's work. Directed by Charles Grosskreutz, an authority in solar-thermal power technology, the several research branches will conduct long-term experimental research in high-risk, high-payoff areas, offering expert technical advice. They will evaluate new university research proposals for DOE; provide leadership and coordination in solar energy research and development; and support DOE in the technical management of selected research programs and the development of major solar energy experimental and test facilities.

Grosskreutz, who once headed a Black & Veatch study team under contract to EPRI, explains that three areas are seen by SERI as offering "near-term and far-term opportunities for significant contributions" to solar energy research: thermal conversion, including heating, cooling, and industrial process heat; photovoltaics, or direct conversion of sunlight to electricity; and biomass, deriving fuels and electricity through biochemical conversion. SERI also will look into other technologies, such as ocean-thermal energy conversion and wind energy.

"We think there is a vast market for solar-generated industrial process heat," says Grosskreutz, noting that SERI is well along in preparing a map of the United States that shows the extent of industrial process heat demand and indicates the range of temperatures and pressures. SERI has proposed to DOE a major test facility for process heat with various kinds of collectors, variable load capability to simulate industrial environments, and storage systems that can be tapped into the test loop to see if known demands for heat can be supplied by solar.

"Yes, SERI will do rese[illegible] storage," Grosskreutz says, point[illegible]t "storage is an old issue ar[illegible]vere a good way to store [illegible]ilities would have found it [illegible]cause they need it." Gros[illegible] that chemical storage hold[illegible]romise. It's a process whereby [illegible]s stored by a solar-induced chemical reaction or a chemical phase change within a material so that the energy can be retrieved by reversing the process, he explains.

In photovoltaics, SERI will be working on low-cost, thin-film devices as a backup in case silicon technology doesn't meet the cost goals for solar cells. "If the cost of photovoltaics could be brought down significantly," Grosskreutz says, "then utilities would find them attractive. Because they are modular, you can have small arrays delivering 50 watts, or large arrays generating several kilowatts, or stack them and get up into the megawatt range." He sees the largest use for utilities in dispersed systems.

As for a forecast of what percentage of total energy solar will contribute by the year 2000, Grosskreutz says, "I've lived long enough to know that making that kind of prediction is fraught with all kinds of pitfalls. So I'm not going to give you a number."

Materials reliability

Grosskreutz notes that SERI is one of the few places where research is being done on materials and components used in solar energy conversion systems. "This is absolutely necessary," he says, "because one of the big problems in any solar system is how long it will last. Utilities certainly want to know that."

Gordon Gross, a physicist and principal scientist at SERI who had been with MRI for nearly 25 years as a scientist and engineer, explains that the role of the materials branch is to attempt "to eliminate the materials barriers to progress of any given solar technology." His group will come up with "statistics and values needed to enable the reliability engineer to build a system so he can predict its lifetime," Gross says. "I think the most important thing that is going to come out of our materials operation for the utility industry will be this reliability information."

Early work in materials problems will involve investigation of general surface physics, selective absorber coatings, and degradation of glazing materials. Laboratory test equipment is expected to be in place sometime this summer.

Gross explains that the materials group will also be generating performance data that will be useful to the industry in setting standards and ratings. "SERI has to walk a careful line in this area of standards," he says. "We can't play a majestic role by proposing standards and trying to force them on an unwilling industry. We will simply assist in evolving mutually acceptable standards."

Data developed through materials analysis and testing will be fed into SERI's data bank and disseminated to industry and other interested parties through workshops and seminars and via Karl Zaininger's commercialization group.

Information and education

Other major SERI programs are carried on by the Information, Education, and International Programs Division and the Analysis and Assessment Division.

Under Alex Kotch—an organic chemist with extensive experience in private industry, at the National Science Foundation, and as a professor and associate chairman of the chemistry department at the University of Wisconsin at Madison—the information, education, and international programs effort includes gathering and disseminating solar energy information; maintaining a solar energy information data bank and library; facilitating participation in solar programs at the university and other educational levels. The group will also be involved in training solar researchers and helping to develop solar energy curricula and training programs; conducting national and international conferences; aiding DOE in implementing agreements concerning solar activities with less-developed countries; and identifying foreign market opportunities for American solar energy industries. SERI is already assisting DOE to develop a plan for a $100 million jointly funded U.S.–Saudi Arabian solar R&D project.

Economic and social factors

Melvin Simmons, formerly deputy head of the Energy and Environment Division at the Lawrence Berkeley Laboratory of the University of California, directs the analysis and assessment activities, which involve analytic evaluation of the issues that underlie decisions influencing widespread commercial development of solar energy. Simmons' group also makes economic feasibility analyses; recommends program priorities to DOE; and studies environmental, institutional, and social factors that will influence commercialization. In addition to providing lead responsibility for social research in solar energy, the group helps DOE plan and evaluate the overall national solar program and monitors market developments and the impact of past government energy policy actions.

National or regional scope

A passing cloud is casting a temporary shadow over SERI. It is still undetermined whether the four regional SERI planning offices, which now report directly to DOE in Washington, will report to SERI in Golden, with Golden coordinating their activities once they become operational. Presently, the regional offices are planning to work with local and state agencies and industry to achieve application of the solar technologies that best suit the needs of each region, whereas SERI in Golden is charged with overall support of the national solar R&D program. But SERI management in Golden would like to have a more direct hand in coordinating the activities of the regional offices.

DOE Secretary James Schlesinger is expected to rule on the matter after completion of a special 90-day study on all aspects of the SERI organization. Don Kornreich, head of the SERI Interim Project Office at DOE and director of the study, has said that his report will be sent to Schlesinger early in March. Depending on the outcome, SERI staff members in Golden may have occasion to toast each other with a tall glass of Coors.

EPRI–SERI EXCHANGE

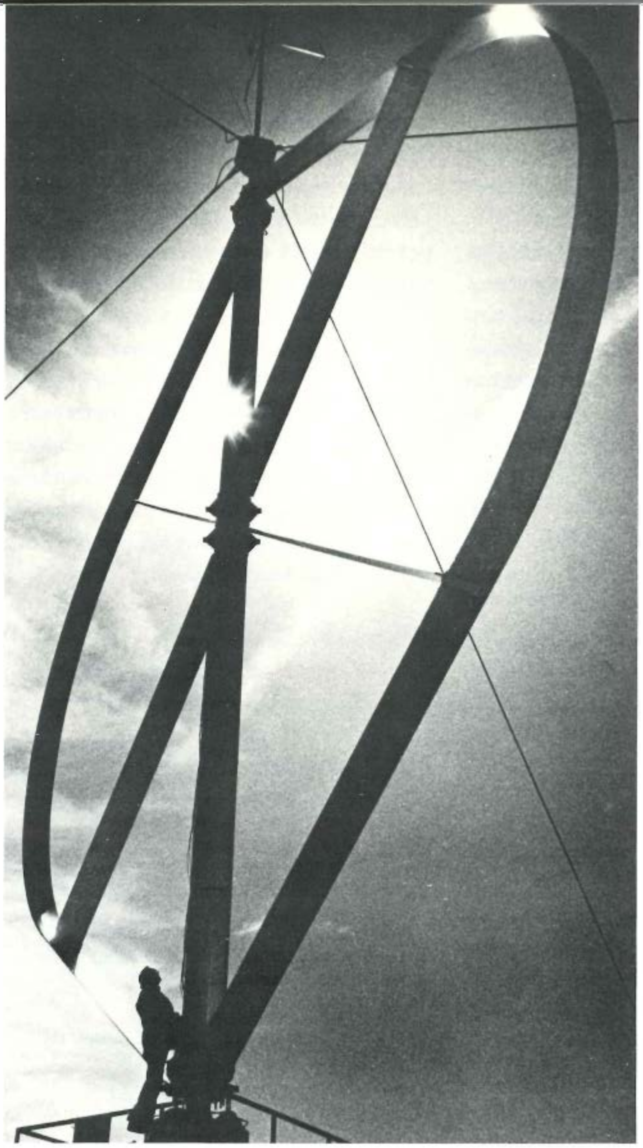
Shortly after SERI began operations, EPRI moved to establish a close working relationship by inviting key SERI technical staff to participate last September in a semiannual review and workshop on EPRI's solar program. At the workshop, SERI's research director, Charles Grosskreutz, presented SERI's goals, plans, and initial efforts.

Continuing the practice, senior SERI management is taking part in an EPRI solar program review in San Diego, California, March 6 and 7. EPRI solar project managers are briefing SERI staff on the objectives and activities of each solar subprogram. Also, selected EPRI solar contractors are presenting findings of projects that address utility requirements and impacts of solar heating and cooling systems, "power tower" solar-thermal electricity generating systems, and wind and photovoltaic energy conversion systems.

According to EPRI solar program manager, John Cummings, the general purpose of the EPRI–SERI briefings is "to inform SERI of technical, operating, and economic requirements for integrating the various solar technologies into electric utility systems."

The Earth As a Solar Heat Engine

Useful amounts of electricity may be generated from many natural processes that are driven largely by energy from the sun: winds, waves, ocean-thermal gradients, and vegetable photosynthesis.



Vertical-axis machine responds to wind from any direction, but blade interference in its own wake reduces efficiency. Low-tower requirement and ground-level turbine installation are capital cost economies.

Weather phenomena, such as wind and rain, are obvious—though indirect—products of solar radiation on the surface of the earth. Ocean currents and thermal gradients are more subtle, as is the photosynthesis by which all firewood is grown. Carrying the thought further, hydropower is another indirect form; and from a historical perspective, so are fossil fuels. (Some have even proposed including tidal energy, though it is predominantly actuated by the moon, and nuclear energy, though its release depends on inherent physical properties of uranium and thorium.)

In the classification of new energy sources, a number of indirect solar sources have come to be accepted as belonging in the category of solar power. Among these are wind power, ocean wave power, ocean-thermal gradients (harnessing the temperature difference between deep layers and surface layers of the seas), and biomass conversion (burning vegetable crops, forest products, animal dung, or fuels made from them, for heat energy).

Wind power

Harvesting the wind, of course, is not new. Everyone has read about the windmills of Holland. In times past, Holland and the other countries ringing the North Sea—Belgium, France, England, Denmark, Germany—depended in large measure on the wind for milling grain. The old sail-vane-type windmills were displaced by the steam engine because they were no longer economical for grinding wheat and even less so for driving an electric generator. But these countries and others are now actively reinvestigating wind-power potential.

Although it's often forgotten that NASA is not concerned with space alone, the first *A* in NASA stands for Aeronautics, and NASA is the residence of the most advanced research on airfoils in the United States. Consequently, working with DOE, it is a lead agency on wind-power research. The huge airfoil blades on which modern wind-power machines are based are mounted with variable-pitch gears so that the blade angle of attack can be varied to obtain optimal aerodynamic efficiency over a range of wind speeds.

The grandfather of today's wind turbines was the Smith-Putnam machine on Grandpa's Knob, Vermont, a 1.25-megawatt unit that fed power into the lines of Central Vermont Public Service Corp. intermittently from 1941 through

1945. Its useful life ended when one of the 8-ton blades of its 53-meter (175-ft) diameter rotor failed while in operation.

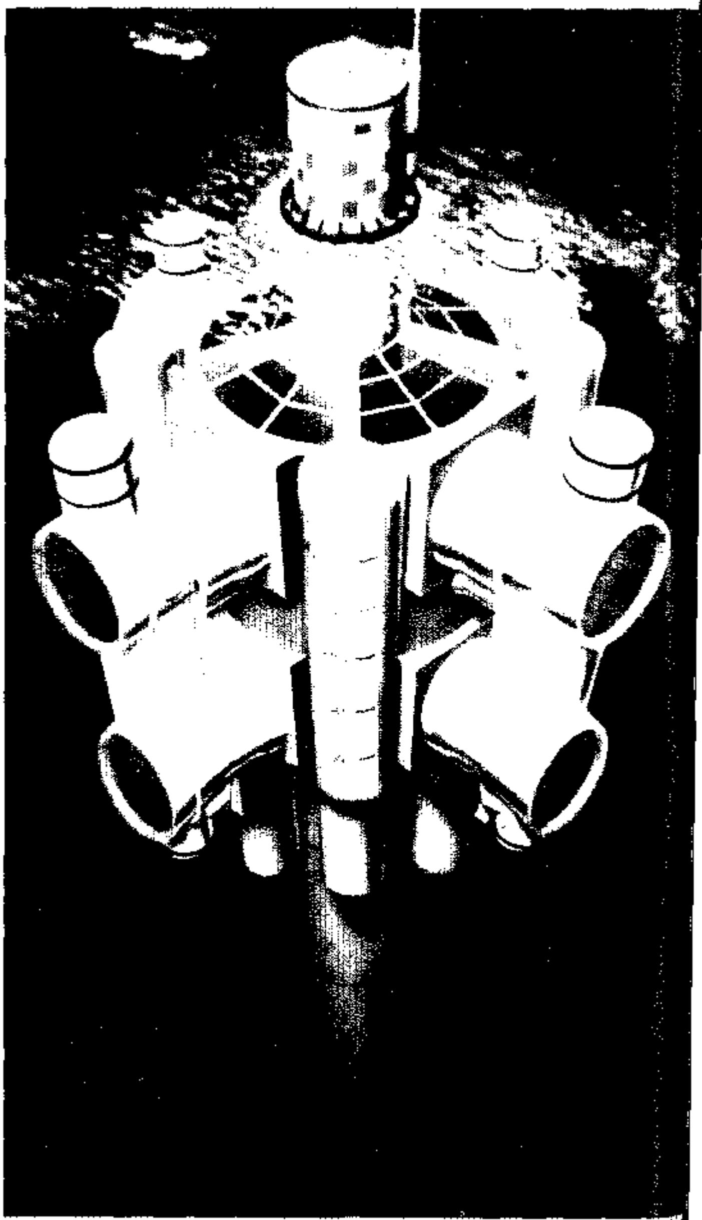
As of the end of 1977, the largest operating wind turbine generator (WTG) in the world was a 0.1-megawatt unit at NASA's Plum Brook Station at Sandusky, Ohio, operational since September 1975. Its 38-meter (125-ft) diameter twin-bladed single rotor is mounted at the downwind end of a streamlined nacelle, or housing, which contains a synchronous power generation system. The nacelle is atop a 30-meter (100-ft) tower, mounted on bearings so that it may rotate to keep it facing into the wind. The weight of the nacelle, its contents, and rotor is 20 tons.

Power is generated whenever the wind velocity attains or exceeds 3.6 meters per second (8 mi/h). A 6.3-meter per second (14-mi/h) wind develops an output of 50 kilowatts; rated output of 100 kilowatts is reached whenever the wind speed reaches 8.2 meters per second (18 mi/h). In winds greater than 27 meters per second (60 mi/h), the blades are feathered to protect the system, and no power is generated. The entire unit is designed to withstand wind velocities up to 68 meters per second (150 mi/h).

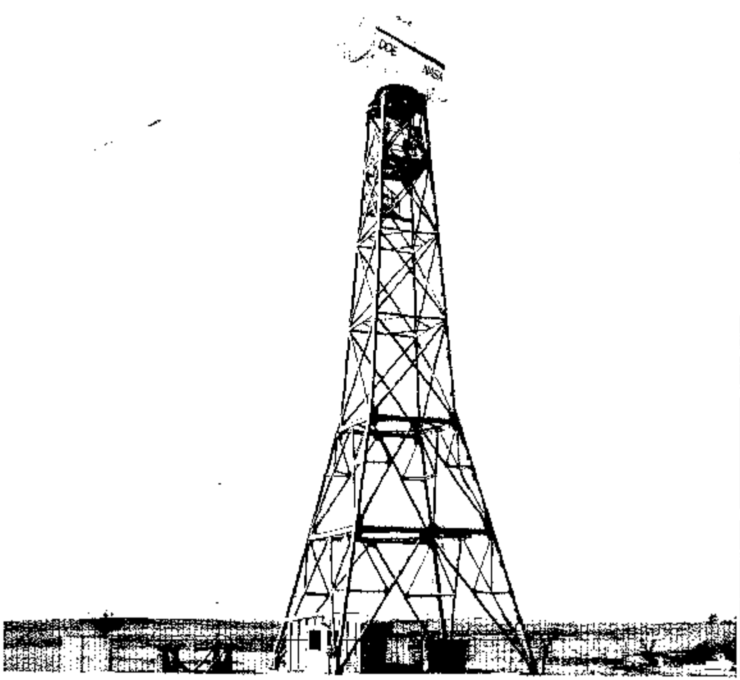
The power coefficient of the twin-bladed Plum Brook rotor is about 0.4, meaning that about 40% of the kinetic energy in the wind is converted to drive-shaft energy. A three-bladed rotor would raise the power coefficient slightly, but not enough to justify the $100,000 cost of the third blade. The theoretical maximum power coefficient of any wind generator is 0.593, for aerodynamic reasons.

The simplest way of increasing rotor power is to increase blade length, as power from a given wind velocity increases as the square of blade length. It

Floating power plant circulates warm surface water to boil a turbine working fluid. It also pumps cold water up through a half-mile-deep probe to condense the turbine exhaust. The thermal efficiency is low, but the "fuel" resource is immense.



Newest and most powerful wind machine in the DOE research program is this 0.2-MW turbine generator just completed at Clayton, New Mexico. Tip-to-tip diameter is 38 meters (125 ft).



has been reported that a 1.5-megawatt WTG being planned by DOE and NASA will have a rotor 61 meters (200 ft) in tip-to-tip length. Because of materials limitations it is not clear that rotors of this size with acceptable operating lifetimes can be built. This question is a major issue being addressed in the federal wind program.

There are totally different, innovative concepts being worked on (in Europe as well as in the United States) that get away from the classic windmill vane configuration. One is a rotor whose axis is vertical rather than horizontal. Vertical-axis WTGs can accept wind from any direction, obviating the need for mechanisms to turn the rotor into the wind and permitting the heavy power drive systems to be installed at ground level. Further, they do not necessarily require towers. These are advantages that could significantly reduce capital cost.

Some 70 U.S. utilities reported (in a 1976 DOE survey) they have "at least an open mind" on using wind power; a few have offered to provide sites, control rooms, and personnel to test DOE-developed WTGs. Some are engaged in studies to evaluate the potential wind power available in their service areas, either as part of a DOE wind resources effort or with their own funds. But it may be taken as axiomatic, as Theodore W. Black of Hammond Farrell, Inc., wrote recently in *Power Engineering,* that utilities will not invest in wind power until WTGs have demonstrated the ability to provide power of acceptable quality over long operating lifetimes and are able to be readily integrated into existing utility systems. Service lifetimes of 20–30 years without excessive maintenance are another utility prerequisite, as are reliable cost data. The capital cost for the Plum Brook WTG was $5500 per kilowatt of rated capacity, which Black characterizes as "probably a bargain for a first-of-a-kind, heavily instrumented, test-bed WTG with a computerized control room."

An improved Plum Brook machine with twice the capacity—0.2 megawatt—was dedicated January 28, 1978, at Clayton, New Mexico. Two identical WTGs under construction are also expected to be operational before the end of this year: one at Culebra Island off the east coast of Puerto Rico, the other on Block Island at the mouth of Long Island Sound. The three machines, although identical, will be evaluated in widely different environments: Clayton on the high plains, Culebra in the tropics, Block Island in the cold winter of northern latitudes. All are entirely federally financed and will be operated by utilities for two years with detailed test data going to DOE, after which the plants will be turned over to the utilities.

The Plum Brook WTG, designated Mod-0 by DOE, and the three Clayton-class WTGs, called Mod-0A, have 38-meter (125-ft) diameter rotors. A 61-meter (200-ft) rotor machine, called Mod-1, designed and built by General Electric Co., is being installed in Boone, North Carolina, and is also scheduled to be operating by the end of this year. Its capacity rating will not be determined until final design is completed, but will be between 1.5 and 2 megawatts. A contract for a Mod-2 WTG with a rotor diameter about 91 meters (300 ft) has recently been awarded to Boeing Aerospace Co. This will be rated between 2.5 and 3 megawatts. The site has not yet been determined; 16 sites are under consideration and more candidate sites may be solicited.

This is DOE's big-machine program, but it is not going only in the direction of bigness. DOE has several joint programs with the Department of Agriculture for evaluation of small machines and has a full-blown development effort to try to bring to commercialization improved machines in three size categories: 1, 8, and 40 kilowatts. A test facility has been established at Rocky Flats, Golden, Colorado, where off-the-shelf wind machines now being marketed for farm use can be evaluated under different wind characteristics, their performance capability measured, and data fed back to the manufacturers for use in improving their current models. The DOE program includes not only power generators but water pumpers as well and both horizontal-axis and vertical-axis machines.

The structure of the federal wind energy program, which has as its goal the acceleration of the development, commercialization, and utilization of economically viable wind energy systems, covers five areas:

- Program development and technology, including mission analysis; applications of wind energy; legal, social, and environmental issues; wind characteristics; technology development; and advanced systems
- Small machines (less than 100 kilowatts) for farm and rural use
- 100-kilowatt-scale systems
- Megawatt-scale systems
- Large multiunit systems

The federal budget for wind energy conversion has grown impressively from $200,000 in FY73 to $7.9 million in FY75, $14.3 million in FY76, $24.6 million in FY77, $35 million in FY78, and in the FY79 budget presented to Congress, it has been increased to $40 million.

Wind power problems

Of course even wind machines are not without their drawbacks. Most obvious is the erratic nature of the wind. A fundamental problem is the lack of wind data on a seasonal, daily, and hourly basis, not only regionally but locally, because wind patterns are fickle and differ greatly over small distances.

Moreover, there is no suitable storage system to smooth out the power delivery rate of WTGs; the consensus today is that the most cost-effective way to use wind power on a utility grid is to save fuel when the wind blows and not try to store the wind energy.

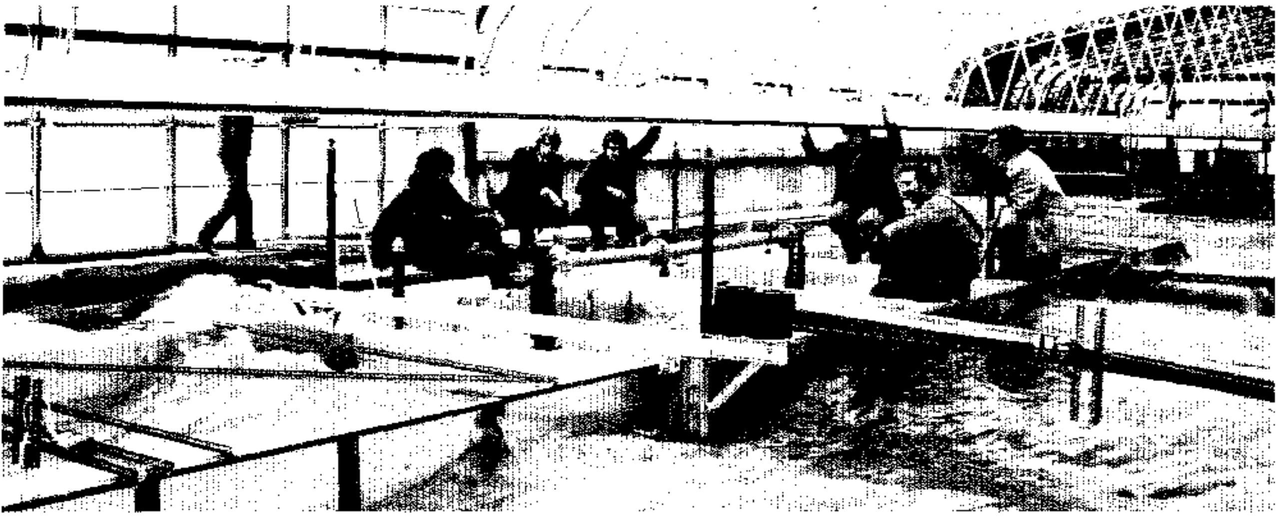
Potential problems in the environmental area include a possible noise nuisance, the "scenic pollution" of long lines of tall structures spread across a landscape, and the still-unstudied possible danger to migrating birds. These and other potential deficiencies will be addressed in the DOE program.

EPRI is addressing the potential and the problems of wind power plant integration into electric utility systems through an analytic study contracted to the General Electric Co. (RP740). In this study, established utility industry generation-planning techniques have been adapted to include wind power plants, allowing individual utilities to assess the value of wind generation in their systems. Value estimates and impact assessments have been obtained for several U.S. utility systems as part of this study.

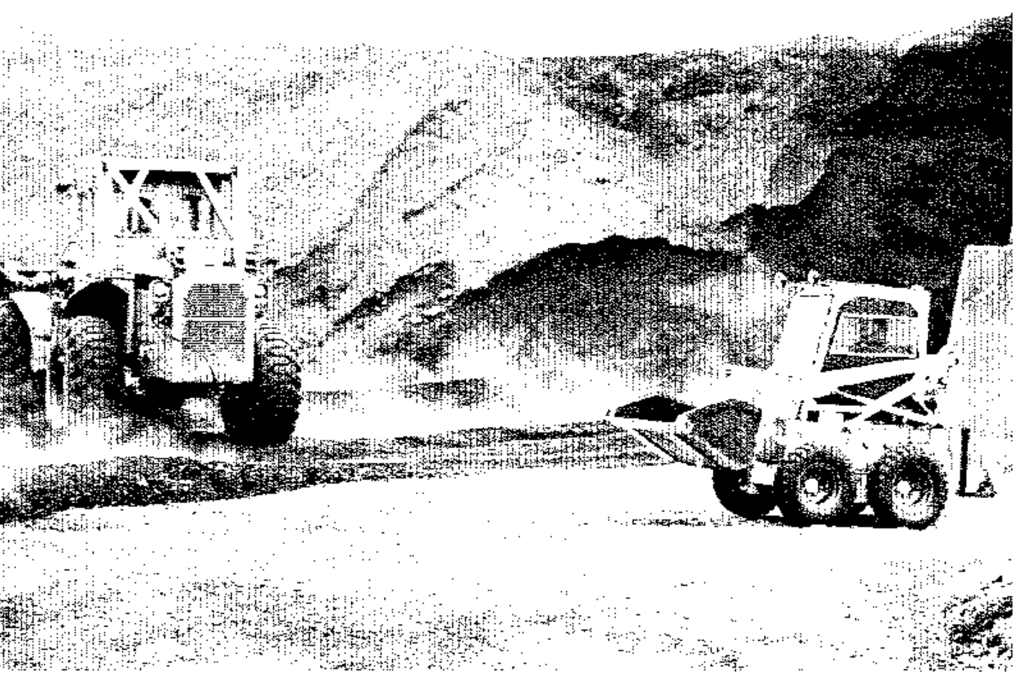
Wave power

Wave energy derives from wind energy and has an advantage over wind in that it has been naturally concentrated by accumulation over time and space. The major disadvantages of wave energy compared with wind—beyond the fact that we have no experience with any operating machine or system, not even one as rudimentary as the old windmill—are that the energy is available only on the ocean, and the extraction equipment must operate there, with consequent implications for construction cost, maintenance, lifetime, and reliability.

No major development program to harness wave energy has been carried through, except for small-scale power supplies for navigational buoys, and no prototype devices have been commercialized. The United States is doing very little in this area, and the federal energy R&D program does not allocate significant effort here. But Britain is very high



Wave power is modeled by Britain's Central Electricity Generating Board to evaluate various mechanisms whose oscillations can be made to generate electricity. Energy conversion efficiencies may average between 25% and 50% over a range of wave conditions.



Stockpiles of wood chips replace stockpiles of coal as biomass comes back into use as a direct combustion fuel. Wastes from forest product processes and certain agricultural harvests—notably sugarcane—are the most likely candidates for use by strategically located plants or utilities.

on wave energy. This is hardly surprising since the annual average power of waves off the Atlantic coast of Britain alone has been calculated at about 80 kilowatts per meter—or about 8000 megawatts from a 100-kilometer (62-mi) frontage. "A prodigious amount of power," comments D. J. Littler, controller of research for U. K. Central Electricity Generating Board (CEGB).

To be sure, as with direct solar and wind energy, waves do not provide firm power. Weather ships have recorded periods of up to a week in the spring with no significant wave action.

Basically, attempts to extract energy from the ocean waves fall into two categories: shoreside or offshore installations.

The shoreside schemes, which were actively studied in France and Britain in the 1940s, involve converging vertical walls that direct waves through flap valves into a reservoir from which the water returns to the sea through a turbine. In all cases, the achievable output was found too low, the capital cost too high, and the approach was abandoned.

Sea-based devices are more promising, despite the additional problem of transmitting power to shore. They can be sited as far as 20 kilometers (12 mi) from the coast in deep water where the energy is greater, and they can extract energy at higher efficiency.

The three most promising types of floating device, according to CEGB's Littler, are:

□ Flapping plates. A freely moving plate would transmit all the incident energy without absorbing any, while a heavily loaded plate would reflect most of the incident waves. To achieve a high extraction efficiency, the front surface of the plate should move with the water to minimize reflection while its rear surface effectively remains stationary to avoid transmitting energy by generating waves behind the plate.

□ Floating rafts. Energy can be extracted from variations in the surface profile of the sea by using the relative motion of adjacent elements of a series of coupled rafts to operate a pump at each joint.

□ Air bells. These extract energy by causing wave action in a floating buoy to displace air from one chamber to another through flap valves and an air turbine. This concept has been applied in Japan to develop a self-powered navigation buoy. A possible variation of the device would be to displace water through a water turbine.

It is still too early, Littler says, to determine which of these approaches will prove most promising. In tank tests, a flapping-plate device using a cam-shaped rocking float has achieved extraction efficiencies of 90% with waves of single frequency and with the loading of the device accurately tuned to match the frequency of the incident waves. However, a practical device would be exposed to waves over a frequency range of about 2 to 1, and from a range of directions.

Nevertheless it is probable, Littler contends, that large devices of all three types could achieve practical efficiencies in the 25–50% range, so that a unit 300 meters wide (comparable with the length of a large supertanker) could produce an annual average power output of about 10 megawatts in the North Atlantic.

CEGB considers wave power to be "the most promising of the alternative energy sources available, primarily because of the large amount of energy potentially available from around the British coasts," Littler reports. CEGB does not expect wave power to be competitive with nuclear power, but is spending about $100,000 a year on wave-power research —a small amount in absolute numbers but a large proportion of total world expenditures in this field.

Ocean-thermal energy

Another ocean-based indirect form of solar energy is ocean-thermal energy conversion (OTEC). This is a century-old concept based on the belief that there ought to be some way to harness the difference in temperature between the surface layers of ocean water that are warmed by the sun and the colder, deeper regions. A number of schemes for doing this have been put forward. The most generally favored systems use a closed cycle containing a working fluid, such as ammonia, propane, or freon. Warm, surface seawater is pumped through an evaporator where it vaporizes the working fluid; the vapor expands to drive a low-pressure turbine, generating electricity. Cold seawater is pumped up through a vertical pipe of about 450–920 meters (1500–3000 ft), extending down from the floating platform on which the evaporator and turbine are also mounted; the cold water condenses the working fluid, which then returns to the evaporator to repeat the cycle.

Considerable R&D is being carried out on OTEC systems. DOE is spending $35 million in FY78 on OTEC. Lockheed Missiles & Space Co., Inc., Westinghouse Electric Corp., and TRW, Inc., are working on studies of the power cycle, and two naval architects, Gibbs & Cox, Inc., and M. Rosenblatt & Sons, Inc., as well as Lockheed, are working on design of the hull for the floating platform. DOE wants to have a 25-megawatt demonstration module in operation by 1986 aboard a platform sized for four such modules, for a total of 100 megawatts.

There are major technical problems to be overcome, including reducing the cost of the evaporators and condensers, biofouling, lengthening the corrosion life of the power plant, the design and construction of the long cold water pipe, and the transmission of energy to shore. However, conceptual solutions are seen to all these problems, and those working in the field regard none of them as insurmountable. However, one inherent problem is that the maximum efficiency of the system is limited to about 3–4%, which imposes a very unforgiving set of design conditions.

OTEC developers believe most of the U.S. Gulf Coast has adequate warm water close to shore to provide the thermal resource needed. They envision a ring of OTEC plants perhaps 129 kilometers (80 mi) offshore around the Gulf of Mexico—a series of floating energy parks of perhaps 3000 megawatts total capacity and composed of from 6 to 20 hulls per park, transmitting power to shore by a single cable system per park. This would be baseload power, as the energy source is available 24 hours a day, 365 days a year, degraded only by the plant's availability factor. This gives OTEC a tremendous potential built-in advantage over wind and wave power.

Thinking further into the future, some have also suggested the possibility of manufacturing anhydrous ammonia or aluminum at an OTEC energy park, or hydrogen for the oft-touted hydrogen economy of the future. Another of the many long-range schemes mentioned is elimination of the submarine cable and the turbine, transmitting energy to shore as bulk heat in barges carrying molten salts heated to high temperatures as "heat batteries."

Tidal power

Another source of energy that is based on ocean dynamics—although, as noted, more lunar than solar in origin—is tidal power.

There are relatively very few suitable sites where the daily tidal range is great enough to warrant the staggering cost of building a dam with sluices. One of the best known is the Bay of Fundy between Nova Scotia and New Brunswick, Canada. Not even President Franklin D. Roosevelt's enthusiasm and determination for harnessing the tides in Passamaquoddy Bay (an arm of the Bay of Fundy between Maine and New Brunswick) sufficed to overcome the capital cost hurdle.

The only large-scale tidal plant is that built by France across the mouth of the Rance River in Brittany, where a dam supports 12 bulbs in the river stream, each containing a reversible turbine that can generate 240 megawatts whichever direction the tide is running. However, although it has been operating about 10 years and furnishes 500 gigawatthours annually, experience with that plant has not been encouraging. The utilization factor is poor, only about 2000 hours per year, or roughly 25%, resulting from the inherent drawback of systems having only one reservoir.

Biomass conversion

Bioconversion is a new word for an old process. Wood and organic wastes, now called biomass in the context of energy, were man's principal fuels until the industrial revolution at the beginning of the nineteenth century and the use of coal. Since the worldwide energy shortage began to loom in the past decade, some have been looking at bioconversion systems as a way of helping to piece out our total energy requirements.

The term *bioconversion* includes a number of processes beyond the one most frequently associated with it, namely, growing trees for firewood. It covers other fuel crops, such as sugarcane, silage corn, seaweed; agricultural wastes, such as wood chips from lumber and paper mills, and bagasse (the dry stalks of sugarcane or grapes after the juice has been extracted); combustible municipal solid wastes (discussed in the November 1977 issue of the *EPRI Journal*); fuel derived from sewage; and the burning of animal dung.

Only with firewood and dung has there been widespread experience. As recently as 1960, India obtained 11.2% of its energy from burning cow dung. As cows are sacred to the Hindu and allowed to roam freely, the distribution of gobar (cow dung) is universal in most of rural India, and it is the staple fuel in the villages. Today, use of this fuel has risen to 14% as the result of an effort by the Indian government to discourage open burning of gobar and replace it by methane-producing, closed burners. According to the Indian embassy in Washington, 40,000 "family-size" gobar-gas units have already been installed.

In the United States today, the major use of biomass conversion is in the pulp and paper industry, which depends on its own waste—burning wood chips and sawdust—for up to 40% of its internal energy needs for low-temperature process heat.

It must be stated that photosynthesis, the basic process by which plants grow, "is the least efficient of all solar conversion technologies, that high net yields of fuel crops is possible in theory but is speculative in practice, and that significant fuel crop production requires long-term research and major breakthroughs in cultivation technologies and plant breeding," according to an EPRI study on the potential of bioconversion. Transportation costs also are a key limitation to the scale of bioconversion systems.

Two likely fuel crops in the United States, the study showed, are eucalyptus in California and red alder in the Pacific Northwest, which might produce 9 and 12 tons, respectively, per acre per year. At 16 million Btu per dry ton, this works out to 600,000 tons to supply a 100-megawatt plant at 80% capacity—or 6 million tons and 2589 km^2 (1000 mi^2) of dedicated forest land (the size of the state of Rhode Island) to support one 1000-megawatt plant. Just for the sake of perspective, this compares with 171.4 tons of uranium per year to run a 1000-megawatt nuclear plant, also at 80% capacity factor. This forest production is 5–10 times more than we are now getting from our forests, although the present yield is without irrigation and fertilization, which would have to be done for a managed crop (and which would increase the cost). Again, it is dangerous to assume that water and fertilizer would even be available for forest crops.

Nevertheless there is a growing interest in growing plants to produce an intermediate, storable fuel.

Prospects

To sum up, it would appear that these long-shot indirect solar technologies have potential and promise, but all four have unsolved technical problems; all have, in greater or lesser measure, problems of environmental and social acceptability, and none can be counted on to provide more than a percent or two of total U.S. electric power needs by the year 2000, or even early in the next century.

At the Institute

Cox New RAC Chairman

Ellis T. Cox, executive vice president and chief operating officer of Potomac Electric Power Co., was recently named by the EPRI Board of Directors to be chairman of the EPRI Research Advisory Committee (RAC).

RAC, which is composed of utility engineering executives, advises the EPRI president, Board, and staff on R&D policy and program planning.

Cox, a member of RAC since January 1977, replaces Ludwig P. Lischer. Lischer, vice president in charge of engineering, research, and technical activities for Commonwealth Edison Co., served as chairman from the time RAC was organized in November 1973. He will continue work as a Committee member.

Cox joined Potomac Electric in 1972 and was appointed executive vice president and chief operating officer; in 1973 he was elected to Potomac Electric's board of directors.

Prior to his affiliation with Potomac Electric, Cox held several senior and top management positions, including vice president and general manager of the Power Generating Division, Babcock & Wilcox Co., and president of Allis-Chalmers Power Systems.

New EPRI Offices Nearing Completion

Three new office buildings to accommodate EPRI's growing staff in Palo Alto, California, are scheduled for completion in April 1978. Attached to the Institute's present headquarters in Palo Alto, the complex will provide office space for additional staff—expected to reach 538 by December 1978, compared with 424 in December 1977.

The three new buildings will cost slightly more than $3 million.

As part of the new complex, an innovative monitoring system for solar water-heating installations will be tested on a system attached to the third building.

EPRI also has a small Washington, D.C., office with about 10 professional staff members serving as representatives for several EPRI divisions.

The mailing address for EPRI in Palo Alto will remain the same: 3412 Hillview Avenue, P.O. Box 10412, Palo Alto, CA 94303.

Group Recognizes Solid Waste Benefits

The increasing value of energy and raw materials in solid waste, together with the spiraling cost of disposal and the lack of environmentally acceptable landfills, is spurring new interest in the field of resource recovery.

A discussion of ways to resolve many of the significant technical problems and political and economic issues associated with processing refuse to recover energy, steel, aluminum, and other valuable resources was the objective of a recent conference sponsored by EPRI and the Edison Electric Institute (EEI).

The conference was attended by about 45 utility executives, government officials, and consultants, who agreed that by using refuse as a fuel, utilities would perform an invaluable public service. (The energy content of the 150 million tons of refuse produced in the United States each year is equivalent to more than that of 200 million barrels of oil.) They also concurred that because the regions of greatest refuse production correspond to utility centers of power generation, electric utilities are in a position to serve as big customers of energy from processed solid waste.

The technology exists for recovering energy in the form of electricity, steam, and solid fuel and is being developed to produce liquid and gaseous fuels. But, as reported at the conference, there are technical problems that primarily revolve around the combustibility of the refuse-derived fuels and their effect on utility boilers. Those problems are the subjects of ongoing research and development sponsored by EPRI, the U.S. Environmental Protection Agency (EPA), and DOE.

Participants in a technical workshop identified several areas for further research and development, including impact of solid waste fuels on power plant operations, solid waste fuel specifications, and data collection on corrosion, pollution control, and operation and maintenance costs at power plants that use solid waste fuels.

They emphasized the need for R&D in fuels derived from solid waste in gas- and oil-fired power plants. One approach is to produce a gas or liquid fuel from solid waste by pyrolysis (heating in the absence of air). However, this approach is not yet economically feasible, nor has it been adequately demonstrated.

According to Robert Paladino, co-organizer of the conference and assistant to the president of EEI, political and economic problems associated with using fuels from refuse are more difficult to overcome than the technical ones, largely because of the diverse goals and interests of those concerned with resource recovery projects—local governments, the private company that builds and operates the facility, the investment community, the landfill operator, the electric utility, and the public.

During a workshop on institutional issues, participants discussed roles of utilities in resource recovery, financing alternatives for resource recovery projects, and interaction with public utility commissions. Also discussed were contracts among utilities, communities, and resource recovery facility operators and the extent to which both solid waste and political boundaries are obstacles to resource recovery projects.

Agreement was reached among the participants that all of these policy-related issues should be investigated by EEI.

Science and Technology Conference Planned

EPRI is planning a major international conference in the spring of 1979 to explore the role of science and technology in the development of modern society. This conference will be part of a year-long celebration of the centennial of Thomas Alva Edison's development of the carbon filament for incandescent lighting, which was the foundation of the electric power industry.

Science and technology and human potential is the theme of the conference scheduled for April 1–4, 1979, in San Francisco. It is expected to attract 1000 national and international delegates representing government, business, industry, educational institutions, research organizations, and other segments of society.

Formation of the conference plans is being guided by an advisory committee of leaders in the fields of education, business, industry, journalism, and government. Among the committee members are Philip H. Abelson, editor of *Science;* Harvey Brooks, Aiken Computation Laboratory, Harvard University; Arthur M. Bueche, vice president, research and technology, General Electric Co.; Melvin Kranzberg, Georgia Institute of Technology; Ernan McMullin, Department of Philosophy, University of Notre Dame; Michel Pecqueur, deputy general administrator, French Atomic Energy Commission; Simon Ramo, vice chairman of the board of directors, TRW, Inc.; Alvin Weinberg, director, Institute for Energy Analysis; and Colin W. Williams, dean, Divinity School, Yale University.

McCarroll Reappointed to EPA Advisory Board

EPRI Health Effects Program Manager James McCarroll, M.D., has been reappointed as consultant to the Science Advisory Board of EPA, his third such appointment since 1970.

The Science Advisory Board is composed of a group of independent scientists appointed by EPA to advise the agency on scientific policy. In addition to his EPRI activities, McCarroll is working with the board's subcommittee on the revised air quality criteria for photochemical oxidants.

The committee, he reports, is critically evaluating the criteria documents prepared by the EPA staff and is providing input and guidance to help EPA develop the best possible data base for ambient air standards in the United States.

According to McCarroll, coauthor of *Ozone and Other Photochemical Oxidants,* published by the National Academy of Sciences last year, current standards for photochemical oxidants are unrealistic. He explains that naturally occurring oxidants, as measured by ozone, frequently exceed the standards, even in rural areas where human influence is minimal.

McCarroll, who for 30 years has studied the effects of the physical environment on health, reports that of the six air pollutants regulated by EPA, photochemical oxidants are the only ones not emitted directly into the atmosphere. More than 50 compounds are formed when unburned hydrocarbons combine with oxides of nitrogen under the ultraviolet rays of the sun.

While hydrocarbons are created primarily by mobile sources, including automobiles, trucks, and buses, oxides of nitrogen come from both mobile and stationary sources, such as industrial and power-generating plants, home heating, and cooking.

Photochemical oxidants at high levels are known to cause eye irritation and irritation of the mucous membranes in the nose, throat, and chest. Beyond that, they can cause aggravation of existing illnesses, a decrease in athletic performance, and other health problems.

Project Highlights

Researchers Study Energy Storage

A $9 million government–utility industry research program now under way could lead to a reduction before 1990 in costly oil use by utilities.

The two-year project, sponsored by EPRI and the Department of Energy (DOE), is a study of two energy storage options, known as compressed-air storage (CAS) and underground pumped hydro (UPH). They are being considered as power sources for use in those periods of high electricity demand when many utilities are forced to rely on oil to fire combustion turbines.

If successful, the research will help utilities determine whether the capital and operational requirements of either or both of these technologies are attractive enough for the utilities to proceed with plant construction.

With CAS, the idea is to compress air during periods of low electricity demand by using low-cost nuclear or coal-derived energy and to store the air in underground reservoirs. Some oil would still be used and the compressed air would serve as a fuel supplement.

With UPH, water is pumped from a low reservoir to a high reservoir during slack periods of electricity use. During peak demand periods, the water is allowed to flow down through turbines to generate electricity, which is less expensive than using oil-fired combustion turbines. UPH is similar to existing pumped-hydro installations except that one or both reservoirs are underground.

Two major contracts were recently signed—one with Potomac Electric Power Co. (Pepco) of Washington, D.C., and one with Middle South Services, Inc. (MSS) of New Orleans, Louisiana. Each project is examining a specific type of energy storage reservoir. While Pepco is investigating the use of underground cavities in hard rock as storage reservoirs (for both CAS and UPH), MSS is examining the use of solution-mined salt caverns (created by pumping briny water out and fresh water in).

A third contract is being negotiated with a group of five utilities headed by Public Service Indiana. The group includes Commonwealth Edison Co., Illinois Power Co., Central Illinois Public Service Co., and Union Electric Co. The contract would result in the study of a third type of underground reservoir, called an aquifer. An aquifer is a porous rock formation that normally holds water in its pores. In CAS systems, the water is displaced by high-pressure air.

CAS and UPH compare favorably with other storage systems being investigated by EPRI, including electrochemical (battery) energy storage and thermal storage. Because they are extensions of well-developed technologies, CAS and UPH are nearer to commercial reality than these other systems, according to EPRI Program Manager Thomas Schneider.

In fact, the first CAS plant in the world will soon be completed in Germany by Nordwestdeutsch Kraftwerke AG. The project being undertaken with EPRI–DOE support will use the German experience in establishing a basis to help U.S. utilities decide whether to commit themselves to the construction of CAS plants.

Reducing Power Substation Costs

Efforts to reduce the cost and increase the reliability of electric utility substations are continuing through a new four-year research project announced recently by EPRI.

Specifically, researchers will work to develop compact capacitors that will be one-tenth the size of present-day capacitors. The capacitors being developed, called compact capacitor banks, and harmonic filters will help improve the efficiency of electric utility systems and filter out high frequencies often encountered on transmission lines. Such frequencies may cause interference on telephone lines and problems within the utility system itself, such as overheating power components.

The new research has been contracted to Consolidated Edison Company of New York, Inc., and Gould Inc. of Rolling Meadows, Illinois. Gould is developing the equipment, and Consolidated Edison will install and test it at its Astoria substation in the borough of Queens.

If the size of substations is reduced, land can be conserved for other uses, capital costs lowered, reliability of electricity service improved, and environmental impact lessened.

A major high-voltage substation can occupy 20 acres, but with new technology, that same substation can now be sited on less than 2 acres, according to EPRI's Richard Kennon, who will be monitoring the project.

The success experienced in reducing the size of substations has been attributed to new gas-insulated components, where the electrical conductors normally suspended in air are enclosed in a better insulating gas, such as sulfur hexafluoride.

The capacitors being developed in this project, for example, will be placed in an enclosed pressurized vessel, where temperatures are controlled. So the components are not only smaller but also more reliable because they are isolated from bad weather and other conditions that adversely affect reliability.

EPRI Negotiates 59 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP377-3	Gas-Cooled Central Receiver—Closed-Cycle 1-MW (thermal) Bench-Model Testing	9 months	165.0	Boeing Engineering & Construction *J. Bigger*
RP925-1	Commercial Solar-Augmented Heat Pump System	2 years	45.0	Southern California Edison Co. *J. Cummings*
RP980-5	Evaluation of Four Magnetic Desulfurization Concepts	5 months	59.7	Bechtel Corp. *B. Slaughter*
RP985-1	Partial Oxidation for Power Generation	2 years	2000.0	Texaco, Inc. *L. Bingham*
RP986-2	Coal Gasification System Analysis	7 months	59.8	United Technologies Corp. *M. Gluckman*
RP992-1	Ceramic Materials Application to Low-Activity Fusion Reactors	16 months	100.0	General Electric Co. *R. Richman* and *N. Amherd*
RP1031-1	Study of Alkali Scrubbing Chemistry	1 year	335.3	Combustion Engineering, Inc., Power Systems Group *T. Morasky*
RP1037-1	Steady-State Simulation of a Texaco Gasifier	13 months	180.8	Texaco, Inc. *G. Quentin*
RP1038-2	Dynamic Modeling of Hydrogen-Sulfide and Ammonia Absorption System	1 year	164.9	Systems, Science & Software *L. Atherton*
RP1041-2	Autothermal Reforming Process for Electric Utility Fuel Cells	9 months	99.0	NASA Jet Propulsion Laboratory *E. Gillis*
RP1077-1	Failure Cause Analysis —Fossil-Fired Boilers, Pressure Parts	1 year	99.8	Battelle, Columbus Laboratories *J. Dimmer*
RP1078-1	Commercialization of Coal Liquefaction for the Northeast Region	13 months	100.0	Stone & Webster Engineering Corp. *R. Wolk*
RP1080-1	Preliminary Capital Cost Estimates of SRC-Fired Power Plants	8 months	124.4	Bechtel Corp. *S. Vejtasa*
RP1082-1	Comparative Analysis of Utility Sensible-Heat-Storage Systems	9 months	83.0	General Electric Co. *T. Schneider*
RP1086-2	Economic Comparison of Hydrogen Production Using Sulfuric Acid Electrolysis and Sulfur Cycle Water Decomposition	4 months	36.2	Westinghouse Electric Corp. *A. P. Fickett*
RP1089-1	Cool Storage Instrumentation and Data Verification	28 months	371.3	Carrier Corp. *E. Ehlers*
RP1090-1	Heat Storage Instrumentation and Data Verification	23 months	435.5	Arthur D. Little, Inc. *E. Ehlers*
RP1130-1	Evaluation of a Fabric Filter on a Pulverized Coal-Fired Boiler	15 months	275.0	Meteorology Research, Inc. *R. Carr*
RP1134-1	Process Development of Improved SRC Options	7 months	159.8	Conoco Coal Development Co. *R. Wolk*
RP1135-1	Assessment of Dual Energy Use System (DEUS) Fuel Cell Applications	10 months	298.0	Mathtech, Inc. *A. Fickett* and *E. Gillis*
RP1182-1	Optimization-Simulation Methodology for Wet/Dry Cooling	15 months	79.4	Dynatech Corp. *J. Maulbetsch*
RP1200-1	Evaluation of Technology in Support of Phosphoric Acid Cathodes	1 year	74.6	Energy Research & Consultants Corp. *E. Gillis*
RP1235-3	Laboratory Analyses of Coal-Derived Synthetic Fuel Samples	1 year	20.0	Babcock & Wilcox Co. *R. Carr*
Nuclear Power Division				
RP122-1	Feasibility Study of Pipe Welding Using a Homopolar Generator	18 months	130.6	University of Texas at Austin *K. Stahlkopf*
S123-1	Evaluation of Steam Separators for Reduced Carryover and Improved Recirculation	8 months	86.2	Curtiss-Wright Corp. *J. Mundis*
RP311-5	Mass Spectrometric Assay of Grain Boundary Impurities in Iron-Nickel-Chromium Alloys	1 year	35.0	Rensselaer Polytechnic Institute *T. Passell*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP810-6	Soil Structure Interaction	11 months	78.0	Applied Nucleonics Co., Inc. *C. Chan*
RP885-3	Distribution and Maintenance of Nuclear Computer Codes	1 year	15.0	Science Applications, Inc. *B. Zolotar*
RP885-4	Distribution and Maintenance of Nuclear Computer Codes	6 months	24.7	Nuclear Services Corp. *B. Zolotar*
RP885-5	Procedures for EPRI Code Distribution	4 months	53.9	SRI International *B. Zolotar*
RP892-8	Ultrasonic System Optimization Study Project IV, UT of Dissimilar Metal Welds	4 months	51.0	Nuclear Energy Services, Inc. *E. Reinhart*
RP961-4	Validation of Real-Time Software Used in Nuclear Plant Safety Applications (Consultant Agreement)	2 years	12.0	Professor C. V. Ramamoorthy *A. Long*
RP965-3	Analysis of LOCA-Induced Fluid Structure	1 year	80.0	DOE *J. Carey*
RP1065-3	Asymmetric (Hydrodynamic) Loads During Hypothetical LOCA	3 years	147.2	Northwestern University, Office of Research and Sponsored Programs *R. Oehlberg*
RP1069-1	Development of an AC Probe Device to Detect and Measure Corrosion in PWR Steam Generators	1 year	121.9	Brookhaven National Laboratory *T. Passell*
RP1072-1	Basic Studies on the Variabilities of Fabrication-Related Sensitization Phenomena in Stainless Steels	2 years	200.0	General Electric Co. *R. Smith*
RP1074-1	Studies of Plutonium and Uranium Benchmark Experiments	1 year	77.4	Stanford University *O. Ozer*
RP1117-1	Transient Fuel Behavior During a Hypothetical LWR Accident	10 months	80.0	Combustion Engineering, Inc. *R. Oehlberg*
RP1117-2	Transient Fuel Behavior During a Hypothetical LWR Accident	9 months	30.0	Science Applications, Inc. *R. Oehlberg*
RP1118-1	Zircaloy Tube Bundle Thermal Hydraulics at Elevated Temperatures	1 year	54.9	University of California at Los Angeles *R. Duffey*
RP1123-1	Evaluation of Multiaxial Fatigue	2 years	232.5	Stanford University *K. Stahlkopf*
RP1124-5	Turbine Chemical Monitoring Planning	3 months	3.7	Babcock & Wilcox Co. *T. Passell*
RP1125-1	Application of Nonlinear Signal Processing to Pipe and Nozzle Inspection	27 months	1321.8	Adaptronics, Inc. *G. Dau*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Electrical Systems Division				
RP996-2	Compact Capacitors for AC–DC Transmission	41 months	500.0	Consolidated Edison Company of New York, Inc. *R. Kennon*
RP1024-1	Study of Distribution System Surge and Harmonic Characteristics	22 months	290.4	McGraw-Edison Co. *W. Blair*
RP1048-1	Improved Economic Operation of Power Systems—System Control Performance	31 months	323.4	Autocon Industries, Inc. *C. Frank*
RP1048-3	Improved Dispatch Methods	15 months	340.5	Philadelphia Electric Co. *C. Frank*
RP1097-1	A Study of Electrostatic DC Fields in Converter Stations	9 months	110.0	Ohio State University *S. Nilsson*
RP1137-1	Optical Temperature Sensors for Transformers	9 months	50.0	Sigma Research, Inc. *E. Norton*
RP1142-1	Improved Current Limiting Fuses	3 months	188.1	Phoenix Electric Corp. *E. Ballard*
RP7866-1	Air Cycle Cooling of Electrical Power Cables	18 months	213.0	AiResearch Manufacturing Company of California *T. Rodenbaugh*
RP7870-1	Improvement of Installation Techniques for Buried Transmission Cables	9 months	104.3	Bechtel Corp. *T. Rodenbaugh*
Energy Analysis and Environment Division				
RP862-5	Emission Inventory for the SURE Region	20 months	267.0	GCA Corp. *R. Perhac*
RP1052-1	Geochemistry of Uranium Deposits	2 years	37.0	University of Texas at Austin *J. Platt*
RP1112-1	Animal Toxicologic Studies on Fossil Fuel Combustion Products	30 months	596.6	University of California at Irvine *J. McCarroll*
RP1112-3	Animal Toxicologic Studies on Fossil Fuel Combustion Products	30 months	1050.0	Massachusetts Institute of Technology *J. McCarroll*
RP1145-1	A Model for Forecasting the Purchase and Use of Electric Automobiles	16 months	177.6	Charles River Associates Inc. *A. Lawrence*
RP1149-1	Development of a Compatible Computer System for Energy Supply Modeling	4 months	30.0	Social Systems, Inc. *A. Halter*
RP1154-1	The Measurement of Sulfur (IV) Species in Aerosols Produced by Fossil-Fuel-Burning Electricity Stations	27 months	175.0	Brigham Young University *R. Perhac*

Washington Report

Solar energy shines on Washington, D.C., as the most popular star in the galaxy of new energy resources. Congress registers strong support for it, and as a result, federal funding has increased dramatically—nearly tenfold from the $42 million of FY75 to the $411 million budget authority of FY78. (Budget authority is the funding that may be committed during a fiscal year.)

Public interest groups also champion solar energy, but in many voices that do not always agree with the objectives of federal solar policy. In particular, Washington is the headquarters for Solar Action, Inc., now planning a nationwide Sun Day celebration of solar energy—and other renewable resources—on May 3. Its organizers welcome solar technologies but frequently deplore the apparent concentration of federal R&D funds on large-scale systems. Sun Day therefore promises to be localized in its appeals and its events, beginning at sunrise on Cadillac Mountain in Maine and moving across the country in a dawn-to-dusk parade of tours, fairs, rallies, films, concerts, lectures, teach-ins, and other demonstrations reminiscent of Earth Day in 1970.

Still, if solar energy has a Number One fan in Washington, it would have to be the U.S. Congress. This was clearly evident in January's hearings on DOE budget requests for FY79 (which begins October 1, 1978). The president's requested budget authority for solar energy (including biomass conversion) totaled $400 million, down slightly from the current year. Mike McCormack (chairman of the Senate Subcommittee on Advanced Energy Technologies and Conservation Research, Development, and Demonstration) echoed the concerns of his fellow subcommittee members that the nation should be "moving aggressively forward in solar energy R&D," not leveling off.

DOE's Eric Willis, acting deputy assistant secretary for Energy Technology, explained the reduction as a function of several factors, among them the winding down of the solar heating and cooling demonstration program, and a larger FY78 budget than had been expected when planning was under way for the FY79 requests (Congress increased funding in the conference report), and he added an important note of caution:

"We are at a critical junction in the development of solar energy," he told the subcommittee members. "Although we want to move with deliberate haste to where the technology shows promise . . . we don't want to be in the position of translating great expectations into 'much ado about nothing.'"

Two solar offices

Responsibility for moving ahead with solar programs in DOE is divided between two offices headed by assistant secretaries: the Office of Energy Technology and the Office of Conservation and Solar Applications. The split reflects DOE's basic organizational philosophy that new technologies be grouped by their stage of development rather than by resource type. Solar technologies considered to be commercial or nearly so are grouped within the Office of Conservation and Solar Applications. Those still in technical development fall under the jurisdiction of the Office of Energy Technology.

The most visible program in the former area has been the solar heating and cooling (SHAC) demonstration program mandated by the Solar Heating and Cooling Demonstration Act of 1974. In carrying out provisions of the act, DOE has worked with a number of other federal agencies: the Department of Housing and Urban Development (HUD), the National Aeronautics and Space Administration (NASA), the National Bureau of Standards (NBS), the General Services Administration (GSA), the Department of Defense (DOD), and the Department of Health, Education, and Welfare (HEW).

DOE and HUD are conducting the SHAC residential demonstration program in the private sector; DOE shares this responsibility with GSA for federal buildings and with DOD for its installations. Nonfederal commercial building demonstrations are being managed solely by DOE. NASA is providing both development and management support; NBS is developing standards and performance criteria for SHAC systems and equipment and is also establishing a program for accrediting laboratories to test solar equipment; and HEW is conducting a program for demonstrating SHAC systems in private hospitals and other health care facilities.

Donald A. Beattie, acting assistant secretary for Conservation and Solar Applications, told January's Senate subcommittee hearing about the national data collection network established to integrate evaluation efforts throughout the federal SHAC program. In total, he said, there are 106 operational projects involving 1300 units, with data coming from 40 different demonstration sites.

DOE's budget request for the SHAC demonstration program in FY79 reflects a decrease of nearly $30 million from FY78 funding. At least in the heating area, that program is winding down. The original legislation called for demonstration of solar heating by 1977 and according to Beattie, "All forces tell me we have achieved the goal." Solar cooling is a different story, however. Beattie told the senators that the solar cooling demonstration program will have to continue beyond the 1979 limit called for in the act. Beattie reported that few of the multi- and single-family residential projects (only 3% and 5%, respectively) have included solar cooling to date. About 30% of the commercial projects have included cooling, but Beattie admitted that cost-effectiveness is still a problem.

The other major program considered near-enough commercial to be included in the Conservation and Solar Applications office is the study of agricultural and industrial process heat uses. DOE has about 50 experiments under way for heating rural greenhouse-residence combinations and livestock shelters, drying crops and grains, and processing food. Industrial experiments include process hot water and steam, dehydration, and commercial greenhouses.

DOE SOLAR BUDGET AUTHORITY
($ million)

	FY 1978	*FY 1979 (requested)*
Technology Development		
Thermal applications	$ 40	$ 45
Technical support and utilization	9	14
Solar electric applications		
Solar-thermal	104	100
Photovoltaic	77	76
Wind energy	37	41
Ocean-thermal	36	33
Biomass	21	27
Total Technology Development	324	336
Demonstration		
Heating and cooling demonstration	66	36
Federal buildings	20	25
Commercialization	1	3
Total Demonstration	87	64
Total	$411	$400

Source: DOE "Budget Highlights," January 23, 1978

Solar electricity generation

The Office of Energy Technology administers programs for solar options not yet considered ready for commercial introduction. Among these "adolescent" technologies today are solar-thermal and photovoltaic electricity generation, wind and ocean-thermal energy conversion, biomass conversion, and (under technical feasibility evaluation by NASA) solar satellite power systems.

"The key uncertainty in the development of solar electricity is not technical," Eric Willis told McCormack's Advanced Technologies subcommittee, "but lies in proving that it can be economically competitive with other sources." Each of the programs in the Energy Technology office is focused on "improving the economics of a safe, reliable system."

DOE's efforts to develop solar-thermal power systems fall into two categories: a central receiver, or power tower, and distributed receivers, combined with individual focusing mirrors.

The main thrust of the former is development of a 10-megawatt pilot power plant near Barstow, California. Although this program was threatened by federal deferral, Willis said it is now proceeding, with construction of the plant scheduled to be completed by FY81. According to Willis, the plant will "establish the technical and economic data base needed by utilities to make investment decisions in the early 1980s on retrofit applications to existing power plants now fueled with natural gas, and decisions in the mid-1980s regarding storage-coupled generation systems. In addition," he said, "it will be the first opportunity for industry and the utilities to gain actual experience integrating solar hardware into an existing power system." He noted that the most promising near-term use for this technology appears to be in the Southwest, where there is about 40 gigawatts of fossil-fired utility capacity (and an equal amount of industrial process energy use), some portion of which could be displaced by solar-thermal retrofit.

DOE has now completed construction of a 5-megawatt solar-thermal test facility in Albuquerque, New Mexico, where receiver testing is being emphasized during FY78. EPRI-developed receivers are among those being tested.

The solar-thermal program also includes work in distributed receiver systems, both "total energy systems" that generate electricity and produce heat for buildings or industrial processes and small community-scale power systems for such purposes as irrigation.

For photovoltaics, Willis noted that DOE is getting "increasingly optimistic" about the technology, but with special reference to dispersed (localized) systems, he said that not enough is yet known of their interface with electric utilities, load management implications, and socioeconomic factors. One of DOE's goals for solar cells is to lower the cost (now about $11 per peak watt, according to Willis) to $2 by 1982 and to less than $0.50 per peak watt by 1986, the level at which the agency believes market penetration can occur. DOE is working on such techniques as thin films (cadmium sulfide and gallium arsenide) as alternatives to silicon for flat plate arrays and on concentrating systems that use lenses to focus sunlight on a smaller cell area. In fact, DOE anticipates that concentrators will be the first to reach the level of $1–$2 per peak watt.

All in all, the federal solar energy program has grown by leaps and bounds in both scope and funding from its lean and narrow days less than 10 years ago. It has found an ardent promoter in Congress and has drawn strong—even if sometimes discordant—support from a chorus of consumer, environmental, and industry voices. Although federal funding requested for the next fiscal year seemed in January to reflect a leveling of solar's meteoric budgetary rise, all indications point to a strong program. With so many solar supporters in the nation's capital, not to mention a sun that comes up pretty much on schedule (despite record February blizzards), it is clear that solar energy is here to stay.

New Technical Reports

Each issue of the JOURNAL includes summaries of EPRI's recently published reports.

Inquiries on technical content may be directed to the EPRI project manager named at the end of each summary: P.O. Box 10412, Palo Alto, California 94303; (415) 855-2000.

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ELECTRICAL SYSTEMS

Study of gas dielectrics for cable insulation

EL-220 Final Report (RP7802)

Gas-insulated transmission cables have been in commercial use in the United States since 1971. The first commercial installation was at a rating of 345 kV. However, data from work at this voltage level gave no firm indication that the systems could be scaled up to UHV levels. As a result of work done by Massachusetts Institute of Technology, it is concluded that SF_6 gas can, given proper attention to equipment design details, serve as a dielectric for the highest voltages contemplated by the electric utility industry.

An integral part of the program was the successful design, construction, and operation of test facilities for studies of the highest voltage gas dielectric cable at UHV levels. The results of the research at these levels demonstrated that SF_6 can be used as a dielectric to insulate the required withstand voltages for UHV apparatus. This work indicates that there is no total voltage effect that could impose a limit to the design levels attainable with this gas. The SF_6 behaved well in the sense that its dielectric strength was predictable over a broad range of conditions. In addition, SF_6 was found to maintain a substantial dielectric superiority over both air and nitrogen in the larger systems studied. Some alternative gases and mixtures were also assessed, though not to the same extent as SF_6.

The project also achieved the fundamental goal of determining the critical properties of compressed SF_6 gas insulation for electric power cables. Both qualitative and quantitative data, including specific design criteria, were established for EHV and UHV apparatus. *EPRI Project Manager: R. Samm*

Development of dynamic equivalents for transient stability studies

EL-456 Final Report, Vols. 2 and 3 (RP763)

The second volume of R&D results of system dynamic equivalents for transient stability studies performed by Systems Control, Inc. (SCI) is a guide for users of the computer programs developed during this project. This guide enables a utility to implement the programs.

The third volume presents a version of the SCI computer programs that was adapted for use with the IBM 370/168 machine. This version was adapted and tested at Pacific Gas and Electric Co. *EPRI Project Manager: T. S. Yau*

Modeling of arc discharges in power circuit breakers

EL-482 Final Report (RP378-1)

Power system growth increases performance requirements for power circuit breakers. A more detailed understanding of arc interruption is needed to develop these breakers. One approach to obtaining this understanding is arc modeling.

Previous mathematical studies of arc have been mainly of two types: either extremely simple, to allow mathematical manipulations to proceed, or highly complex, to attempt to represent the arc as accurately as possible. In the former case the models are often neither realistic nor mathematically rigorous, whereas in the latter case they are so complicated that insight into physical properties is lost. The approach in this study by the University of Pennsylvania is similar to that of the first category, although an attempt is made to be as realistic as possible and to ensure that the mathematical reasoning is rigorous.

This model is designed to determine the effect that electrode geometry has on an electric arc. The problem is attacked in a quantitative way in terms of the curvature of the electrodes. The next question is whether, after a given interruption attempt, the fault will be cleared. A new type of mathematical attack on this problem was initiated with the model, and it shows that an interruption criterion can be obtained in a rigorous and physically meaningful way. The analysis is based on the stability of the mathematical model. The results show how much any interruption depends on arc characteristics and circuit parameters. *EPRI Project Managers: N. G. Hingorani and G. Bates*

Resistive cryogenic cable: phase III

EL-503 Final Report (RP7806)

The objective of this project by General Electric Co was to design, fabricate, and test components of an ac resistive-cryogenic cable system. Fiber-reinforced plastic was considered to be the most promising pipe material. After extensive dielectric tests, cellulose paper was selected for use as the dielectric in the cable samples tested. Instead of the more complex and expensive vacuum-multilayered thermal barrier around the liquid nitrogen containment pipe, a thermal insulation of closed-cell polyurethane foam was chosen as a more desirable envelope.

After extensive fabrication and testing efforts, a half-scale sample of pipe with adhesive joints passed all permeation, thermal cycling, and pressure cycling tests. However. General Electric recommends further testing before a development effort for a full-scale system is initiated. *EPRI Project Manager: T. Rodenbaugh*

Backfill materials for underground power cables: phase I

EL-506 Interim Report (RP7841-1)

Because the allowable current loading of buried electric transmission cables is frequently limited by the maximum permissible temperature of the cable or of the surrounding ground, there is a need for cable backfill materials that can maintain a low thermal resistivity even while subjected to high temperatures for prolonged periods. This report describes the results of studies by the University of California at Berkeley for developing improved methods for placing backfill around underground power cable systems and special treatments to reduce the thermal resistivity and increase the thermal stability of the backfill materials.

The thermal needle method has been selected as the simplest, fastest, and most reliable method for measuring the thermal resistivity of backfill materials in the laboratory. A special thermal needle design has been developed for this project. *EPRI Project Manager T. Rodenbaugh*

Transformer noise abatement, using tuned sound enclosures

EL-529 Final Report (RP579-1)

The objective of this project by Allis-Chalmers Corp. was to reduce the noise emitted from power transformers by using a close-fitting, integrally mounted noise shell. The noise shell consists of a series of panels attached to the tank by means of rubber insulators. Theoretically, this approach should yield noise reductions of 20 dBa or more. Theoretical reductions in excess of this have been achieved in laboratory models, and sound-absorptive materials are not required. However, this technique is entirely theoretical and has not been applied to a practical situation. Accordingly, the overall objectives of this project were to test the noise shell theory and to adapt the theory to a practical application.

The project was divided into two phases: Phase 1 for development and Phase 2 for commercial production design and demonstration. This document reports the work performed under Phase 1

Transformer noise originates almost entirely in the core and is produced by the magnetostrictive effects of steel, which cause the core to vibrate. Core vibrations are transmitted to the transformer walls, support members, radiators, and accessory equipment in two ways—through the core support structure and through the highly incompressible insulating oil. The most significant sound frequencies are in the lower region, between 120 and 600 Hz. Radiators, which are an important source of noise, must be treated to significantly reduce overall noise level. All sides of a transformer need to be enclosed, including the reinforcing ribs. With pier-mounted transformers, the bottom is a significant source of noise and must be treated.

In this project. a noise reduction of 8 dBa was achieved. While this reduction was somewhat lower than the goal of 15 dBa, the work showed that the theory is adaptable to a practical application and that continued development is warranted. *EPRI Project Manager. E. Norton*

Investigation of feasibility of vacuum arc fault-current-limiting device

EL-538 Final Report (RP476-1)

The feasibility of developing a vacuum arc fault current limiter (FCL) was investigated in this project. This work is an outgrowth of studies on the interruption of dc vacuum arcs that have been under way for several years at the State University of New York at Buffalo. In those studies a magnetic field has been used to interrupt or control the current flow in a vacuum arc device. The configuration of the device is such that electron current is forced to flow primarily radially outward from the end of a relatively small, rod-shaped cathode to a ring-shaped anode. Control is achieved through the application of an axial magnetic field.

Operation at current levels in the 5–10-kA range has been demonstrated for periods up to about 8 ms. The voltage of operation that has been demonstrated is smaller than required because of discharge paths that develop within the device in parallel with the desired path from the cathode to the anode. Significant progress has been made in eliminating these discharge paths by using insulating shields between the anode and the cathode support structure. The occurrence of a 30-kHz relaxation-type oscillation undoubtedly aggravates the breakdown problem because of the induced voltage surges that occur.

In the process of developing design criteria for vacuum arc FCLs, several other studies were performed. A brief study of FCL commutation voltage requirements showed that the voltage appearing across a commutation device can be limited to a very reasonable value if the commutation current waveform is properly controlled. A study of magnetic flux concentration that used the anode in a vacuum arc switch showed experimentally and theoretically that concentration times up to about 1 ms are practical with a copper anode. Another study dealt with an investigation of the phenomena occurring during the ignition of arcs on both gold and copper cathodes. The temperature distribution in the anode of a vacuum arc FCL was analyzed. A spectrograph was used for plasma studies in vacuum arc FCLs. Finally, a streak-and-framing camera was used to study cathode spots in vacuum arcs. *EPRI Project Manager: R. Kennon*

Transformer hot spot detector

EL-573 Final Report (RP752-1)

The desirability of measuring transformer hot spots is dictated by economics. Utility operations require that all components be operated at the maximum ratings consistent with satisfactory lifetime. At present, no practical hot spot measurement technique exists.

The system proposed here by Nucleonic Data Systems, Inc., involves the transfer of hot spot temperature data to an external monitor via acoustic transmission. Special acoustic detectors were constructed to monitor transformer-generated noise up to 300 kHz. Spectral analysis of a 20-MVA low-noise transformer indicated the existence of an adequate frequency range for acoustic data transmission Hot spot transmitting and receiving equipment was designed. The space limitations of existing transformer designs, however, prevent easy removal of the electronic sensor leads from local hot spots. In addition, the microelectronics in the transmitter cannot withstand existing maximum hot spot temperatures. These shortcomings make implementation of the acoustic transmitter package impractical at this time. *EPRI Project Manager: E. Norton*

Guide to the design and general use of the Waltz Mill forced-cooling research facility

EL-575 Final Report (RP7823)

The goal of forced cooling of underground cables is to increase their current-carrying capacity, particularly during peak load periods. This report by Jerome Underground Transmission Equipment, Inc., describes in detail the 138-kV forced-cooling test facility now installed at the Waltz Mill cable-testing facility (Pennsylvania). Design information both for system components and for operational and maintenance procedures are given. Of significant interest are the design and construction of the cable itself, which represent a major stride forward in the ability to instrument high-voltage cables.

Results of preliminary tests that characterize thermal-hydraulic behavior are presented. Data on forced-cooling friction loss for a known cable configuration have been successfully correlated with model studies. Cable characteristics such as insulation thermal resistivity and ac loss are also supplied.

This report also serves as a guide to proper use of the test facility and includes information on how to operate it, perform preventive maintenance, and establish system equilibrium conditions that will guarantee consistent results for various tests. *EPRI Project Manager: T. Rodenbaugh*

The use of two-phase heat transfer for improved transformer cooling

EL-588 Final Report (RP479-1)

Transformers are an integral part of any transmission and distribution system, and reliable, efficient operation of these units is therefore essential. Traditionally, transformers have been sized to provide sufficient excess capacity for peak loads to be met without severely overloading the transformers. With rapidly escalating costs of power class transformers, the trend has been toward higher loading, a condition that can cause a rise in transformer temperature and result in decreased insulation life.

Primarily because of a change in transformer siting policy, higher operating temperatures are now common for smaller transformers as well. Whereas residential distribution units were formerly pole-mounted, modern underground distribution systems often require direct burial or vault-mounting of the transformers, and both of these methods are restrictive in terms of the thermal environment. This has often led to the derating of transformers for underground service or to a shortened transformer life.

In view of this situation, it appeared that substantial benefits could be gained through the use of two-phase systems. In particular, the application of efficient two-phase heat transfer techniques such as boiling, condensation, and thin-film evaporation appeared promising in light of the present use of single-phase cooling systems. Since it was recognized that the requirements and limitations are different for power class transformers and for underground distribution transformers, separate consideration was given to each type.

Sigma Research, Inc., was the contractor. *EPRI Project Manager: E. Norton*

Cable neutral corrosion, phase I

EL-619 Final Report (RP671)

This report presents the results of a project conducted by General Cable Corp. pertaining to the selection and evaluation of semiconducting thermoplastic compounds for use as a corrosion-protective overall jacket on concentric neutral underground residential distribution primary cables.

Prior investigation indicated the likelihood that a semiconducting thermoplastic jacket would protect a concentric copper neutral conductor from corrosion in both duct and direct earth burial installations. If such a jacket possessed radial impedance comparable to that of the earth and if the radial impedance remained essentially stable in service, such a jacketed cable under accidental dig-in conditions should yield step-and-touch voltages approaching those of a cable with an exposed neutral conductor.

The project consisted of compound screening and a six-month accelerated-aging test program of full-size 15-kV cables. Eleven semiconducting thermoplastic compounds, received from six manufacturers, were subjected to the screening test program. Six compounds were accepted for further testing. Accelerated aging of full-size 15-kV cables jacketed with each of the six approved compounds took place under the following conditions: exposure in a 100°C air oven; exposure in 75°C tap water; and burial in three soils, with and without ac test voltage applied between the copper concentric neutral conductor and ground.

Measurements of physical properties and of radial resistance and capacitance of the semiconducting jacket compounds were performed initially and at regular intervals during the course of the test program. *EPRI Project Manager: W. E. Shula*

Cable neutral corrosion, phase II

EL-622 Final Report (RP671)

Severe deterioration of the concentric neutral conductor as a result of corrosion presents a problem of serious concern to power and communication companies, as well as to other utilities using direct-buried metallic facilities. Loss of or discontinuity in the power cable neutral can cause improper operation of protective devices, unbalanced line voltages, and improper operation of (and possible damage to) buried communication facilities. It can also create safety problems.

Corrosion of the bare copper concentric neutral wires of cables installed underground has been reported since the early 1960s. Such instances were considered to be isolated and to result from unusual circumstances. In recent years, incidences of corrosion have increased, and the occurrences have been widespread geographically. Corrosion of the bare copper wires is now attributed to soil conditions, galvanic action, concentration cells, and stray currents. In a number of cases, the cause of corrosion has not been identified with any degree of certainty.

A number of electric power utilities have employed an insulating-type or semiconducting jacket over the concentric copper neutral conductor as corrosion protection in locations where corrosion is known to occur. The National Electrical Safety Code does not presently recognize the use of a jacketed concentric neutral cable in joint-random installation with communication cable unless agreed to by the parties involved and unless a separate bare neutral conductor, of adequate size, is provided close to the power cable. Hence the use of jacketed cable has been restricted to cable buried in a separate trench or in a common trench with specified minimum spacing from the communication cable maintained.

The objective of this General Cable Corp. project was therefore to establish the performance of insulating-type and semiconducting jacketed concentric neutral cables in comparison with bare copper concentric neutral cable under fault conditions from the standpoint of transient voltage gradients developed in the earth. It was considered that data generated in this project could be employed as evidence for the acceptability of a change in the National Electrical Safety Code to permit the use of jacketed concentric neutral cable in joint-random installation with communication cable in environments corrosive to bare copper. *EPRI Project Manager: W. E. Shula*

ENERGY ANALYSIS AND ENVIRONMENT

Oxidant measurements in western power plant plumes

EA-421 Final Report, Vols. 1 and 2 (RP861-1)

This report presents the results of one of two interrelated projects that measured photochemical oxidants in western power plant plumes. The research described in this report was conducted by Meteorology Research, Inc. (MRI) to support a University of Maryland effort involving the first airborne measurements of the photochemically important hydroxyl (OH) species in ambient air. The results of the University of Maryland study will be discussed in a later EPRI report.

The MRI studies involved extensive airborne air quality and meteorological monitoring in the plumes of two southwestern coal-fired power plants. Parameters measured included ozone, NO, NO_x, SO_2, sulfates, hydrocarbons, humidity, winds, and temperature, both in the plumes and in background air.

The results of the research project are presented as Volume 1, Technical Analysis, and Volume 2, Data. In addition, an IBM-compatible computer tape containing all collected data is available. *EPRI Project Manager: C. Hakkarinen*

OH radical measurements: impact on power plant plume chemistry

EA-465 Final Report (RP676)

This report by the Georgia Institute of Technology presents the first direct airborne measurements of the hydroxyl (OH) radical in ambient air near a power plant plume. Theoretical modeling studies have indicated that OH is a key species for the photochemical conversion of SO_2 to sulfates and of NO_x to nitrates. The overall photochemical conversion rate of SO_2 was calculated from the measured "high noon" concentration of OH on July 16, 1976 ($9.5 \times 10^6/cm^3$) and from theoretical computations of the diurnal OH cycle. The resultant value of about 0.7%/h is somewhat higher than measurements of conversion reported by other investigators in the Four Corners area. However, it should be noted that neither the theory nor the practice of OH measurement has been perfected, and there remains a substantial need for additional research in the future. *EPRI Project Manager: C. Hakkarinen*

The identification and analysis of urban air quality patterns

EA-487 Final Report (RP438-1)

Research for the sampling, analysis, and evaluation of atmospheric trace components was undertaken by the University of Arizona in and around Tucson in order to identify relationships between atmospheric parameters (both physical and chemical) and air quality conditions.

Large-particle airborne soil or crustal materials were found to dominate the particulate population in both the urban and rural southern Arizona atmosphere, with over a dozen of the measured species directly attributable to these sources. Nonsoil species in general appear to be well mixed and contained predominantly in the small-particle population. This suggests that these species are generated by gas-to-particle conversion processes and distant or diffuse anthropogenic and natural sources. The acid-base nature of airborne gases and particles appears to control the gas and particle distribution of several volatile species (HCl, HBr, HNO, NH_3) and to largely define the particulate sulfate speciation, primarily $(NH_4)_2SO_4$. Large seasonal fluctuations, consistent with the climatology and meteorology of the area under investigation, were observed.

Multivariate statistical techniques were used to significantly enhance the capabilities for data evaluation. Cluster analysis was shown to be valuable for data examination and presentation, as well as for pattern identification. Factor analysis was used to separate the variance of the data into a smaller number of components. Examination of these derived factors makes it possible to assess their chemical and physical significance in terms of sources and atmospheric chemical and physical processes. These data evaluation techniques show great potential for helping to explain the complicated relationships associated with atmospheric chemistry and air quality investigations. *EPRI Project Manager: C. Hakkarinen*

Coal price formation

EA-497 Final Report (RP666-1)

The Supply Program of EPRI's Energy Analysis and Environment Division has undertaken an extensive effort to develop analyses of coal supply that can be used in long-range planning and technology assessment. The present study of the history of coal prices and supply in the period from 1940 to 1975 is part of that effort and was carried out by Charles River Associates Inc. Though the future behavior of coal markets will occur in an environment of unique economics, technology, and government policy, the historical patterns analyzed in this study provide clues for understanding the process of coal price formation and supply in the future.

In this study a framework for price and supply determination is developed for the individual producer and for coal market regions over short-, intermediate-, and long-run forecasting periods. The framework is based on analyses of industry structure and market conventions, coal mining cost formation, the role of transportation in interregional coal competition, and the spatial pattern of coal prices. Coal mining cost formation is derived from historical analyses of coal mining technology, input factor markets, and impacts of government regulation. *EPRI Project Manager: T. Browne*

Uranium price formation

EA-498 Final Report (RP666-1)

This study by Charles River Associates Inc. examines the response of the supply of U_3O_8 to incentives offered first by AEC and later by the utilities in the context of new and developing market conventions. The methodology used is microeconomic analysis, qualitatively applied to the history of price formation in the market. The history of production techniques and factor price changes is studied for exploration, mining, and milling. The impact of government policy, both during the AEC stockpiling period and in the commercial-market era, is analyzed. Demand factors are briefly examined to provide a context for supply and price behavior, and the structural characteristics of the industry are briefly described. The history of prices and contract conditions is discussed in detail.

Because the study emphasizes the implications of the history of uranium price formation for forecasting supply response, the study presents many different kinds of data and evaluates their quality and appropriateness for forecasting. A simple, very useful framework for analyzing the history of the market for U_3O_8 was developed and used to describe supply responses in selected important periods of the industry's development.

The study concludes that the response of the supply of U_3O_8 to rising prices and to expectations of demand growth has been impressively strong. The potential reserve inventory is large enough to meet the needs for nuclear power generation through the end of this century. The price that is necessary to induce producers to find and produce these reserves is uncertain, partly because of problems inherent in estimating long-run supply curves and partly because recent inflation has created major uncertainties about the cost of future supplies. The history of the industry suggests that moderate increases in the real price from experienced levels will be sufficient. More precise conclusions can only come from future work on this market; suggestions for additional research are included in the final chapter. *EPRI Project Manager: T. Browne*

Forecasting and modeling time-of-day and seasonal electricity demands

EA-578-SR Special Report

The papers published in these proceedings were presented at the Workshop on Methodologies for Forecasting Time-of-Day and Seasonal Electricity Loads, sponsored by EPRI. The workshop was held at the Aspen Institute for Humanistic Studies from March 30 through April 1, 1977. The workshop provided a forum for the presentation of empirical results from several new econometric models of electricity demand. Also discussed were new research on and theoretical analyses of issues relevant to measuring, forecasting, and modeling the demand for electricity by time of day and by season.

Three of the empirical studies on the Connecticut peak-load-pricing experiment were sponsored by EPRI to develop better methods for modeling and forecasting residential electricity loads. The fourth empirical paper on the Connecticut experiment was done in-house at EPRI. In addition to the EPRI-supported research, the workshop included several contributed papers on the theoretical and empirical problems of modeling electricity demand. Two papers were contributed by FEA staff economists, three by economists from Bell Telephone Laboratories, Inc., one by staff members of The Rand Corporation, and the remainder by several university researchers.

The papers have been sorted into three main categories: econometric papers that deal with modeling and forecasting the demands of individual households for electricity under time-of-day pricing; econometric and statistical time-series papers that deal with forecasting the peak loads of utility systems; and papers that provide insights into previous experience with peak load pricing, cost-benefit analysis. model specification, and experimental design related to load forecasting and load control. *EPRI Project Manager: A. Lawrence*

ETA–MACRO: a model of energy-economy interactions

EA-592 Key Phase Report (RP1014)

This study by Stanford University resulted in the development of ETA–MACRO, a model for integrating long-term supply and demand projections. The model is designed to compare the options that are realistically available to the United States as we move away from our present heavy dependence on oil and gas resources toward a more diversified future energy economy.

Future markets are simulated through a dynamic nonlinear optimization procedure. To describe the production, savings, and investment relationships, two dynamic submodels are combined: ETA, a process analysis for energy technology assessment; and MACRO, a macroeconomic growth model that provides for substitution among capital, labor, and energy inputs. The model allows explicitly for energy-economy interactions, cost-effective conservation, interfuel substitution, and new supply technologies.

A variety of energy sector scenarios may be explored through this model, but this report has focused on a single issue—the proposal that additional civilian nuclear power plants be banned in the United States. Under assumptions similar to those adopted by the CONAES Modeling Resource Group, ETA–MACRO predicts that a "no nuclear" policy would have negligible macroeconomic effects before the year 2000 but that it could lead to an *annual* loss of $100 billion by the year 2010. Other numerical assumptions would of course lead to very different conclusions. *EPRI Project Manager: S. C. Peck*

Methodology for predicting the demand for new electricity-using goods

EA-593 Final Report (RP488-1)

Consumers are frequently faced with the problem of choosing among a variety of similar goods. When new goods are being introduced or the characteristics of existing goods are changing, conventional demand functions do not adequately handle the analysis. This study by Charles River Associates Inc. exposits a model that was developed (along with an algorithm for its estimation) to analyze such cases. The report considers the potential and requirements for applying this model to the market for home temperature conditioning alternatives in order to predict the future demand for heat pumps with specified characteristics.

To model the market adequately for a group of similar goods, one must allow for the possibility of variation in personal tastes. To accomplish this, the weights of the various characteristics in the utility function are assumed to be drawn from parametrically specified distributions. The estimation procedure consists of finding the maximum likelihood value of these parameters. After the development of the model its estimation technique is described, and a small artificial example is given to illustrate its forecasting properties. These properties are discussed in terms of their desirability and their relation to the basic properties of the model. Also, for a new-goods scenario, a comparison is made with the logit model.

The applicability of the model to studying the demand for heat pumps is discussed, and the specifics of such a study are illustrated. The results and a discussion of a previous application of the model to the demand for new automobiles are then presented. The final chapter points out connections to other literature and some areas with potential for further research. *EPRI Project Manager: R. T. Crow*

FOSSIL FUEL AND ADVANCED SYSTEMS

Upgrading of coal liquids for use as power generation fuels

AF-444 Annual Report (RP361-2)

This report by Mobil Research and Development Corp. describes the results from the first year of a two-year program on upgrading coal liquids for use as gas turbine fuels. The hydroprocessing of coal liquids (derived from the H–Coal and solvent-refined coal [SRC] processes) in fixed-bed pilot units using commercially available catalysts is described.

Distillate coal liquids can be upgraded to the quality levels of existing petroleum-derived turbine fuels. Hydrogen consumption and processing severity are dependent upon the hydrogen and nitrogen contents of the feed. Product quality (e.g., heteroatom and aromatic content) is quantified in terms of process conditions by a kinetic reaction model. The distillate coal liquids are compatible with petroleum-derived fuels. Hydroprocessing of blends of nondistillable SRC product and process solvent removes up to 90 wt% of the heteroatoms and converts large quantities of the SRC to lower-boiling, less aromatic material suitable for use as turbine fuel. Severe hydroprocessing is required to significantly improve the compatibility of SRC with heavy petroleum fuel.

During the first year, a bench-scale hydroprocessing unit was extensively modified to process high-melting, low-fluidity coal liquids. This unit will be used during the second year for additional hydroprocessing studies (using both commercial and Mobil proprietary catalysts) on more refractory coal liquids: H–Coal 400°F+ fuel oil, more concentrated blends of SRC and process solvent, and SRC produced at short contact times. In addition, small-scale turbine combustor tests using raw and hydrotreated distillate coal liquids from the SRC and H–Coal processes will be completed during the second year under a subcontract with Westinghouse Electric Corp. *EPRI Project Manager: W. C. Rovesti*

Engineering review and evaluation of Combustion Engineering, Inc., coal gasification process development unit

AF-558 Final Report (RP244-2)

EPRI is cofunder with DOE of a Combustion Engineering, Inc., project to design, construct, and test a process development unit for coal gasification that makes low-Btu fuel gas for electric power applications.

The process under investigation is an air-blown, two-stage, atmospheric-pressure, entrainment-type gasification system using a gasifier that is in many details similar to established commercial boiler designs. This report, prepared by Bechtel Corp., is an engineering evaluation of the process, facility, and test program. *EPRI Project Managers: H. Gilman and L. Bingham*

The panel bed filter

AF-560 Final Report (RP257-2)

Studies were undertaken by the City College of the City University of New York to test the filtration performance of the panel bed filter at 300°F in a laboratory unit; to test puffback cleaning of the filter in a tall panel representing a single element of a commercial design; to study filtration performance of a coherent surface deposit of fly ash resting upon sand or other granular solid: and to develop mathematical models for application of the panel bed filter as a gas-solid reactor or heat exchanger. *EPRI Project Manager: S. B. Alpert*

Assessment of fuel-processing alternatives for fuel cell power generation

EM-570 Final Report (RP919-1)

The hydrogen fuel cell power plant is expected to become a commercial reality in the near future. The fuel processor that converts hydrocarbon feedstocks to hydrogen is an integral part of this system. Fuel cell power systems being developed are capable of using methane through light naphthas for this purpose; however, a reasonable fuel cell market will require the use of a number of fuels, ranging from synthesis gas to distillate oils. In this context, No. 2 fuel oil is of particular interest.

The present study by Catalytica Associates, Inc., focuses on hydrogen production technologies for dispersed fuel cell power stations, using a feedstock of No. 2 fuel oil. The primary objective is to provide a perspective for the feasibility of efficiently converting this feed to hydrogen in a fuel processor that is integrated with the dispersed power station. The approach involves a comprehensive review and analysis of existing, emerging, and conceptual hydrogen production technologies. Of the processes considered, high-temperature steam reforming (using both fixed and fluidized catalytic beds) and autothermal reforming are the most promising fuel-processing alternatives. They are expected to convert No. 2 fuel oil to hydrogen with minimal problems from carbon deposition and sulfur poisoning; they should also have high thermal efficiencies because of the low steam-to-carbon ratios required for their operation.

Specific recommendations are outlined for further study of the more promising fuel-processing approaches and for identifying the most effective means for integrating them with a dispersed fuel cell plant. *EPRI Project Manager: E. A. Gillis*

Catalyst development for coal liquefaction

AF-574 Annual Report (RP408-1)

The objective of this project by Amoco Oil Co. was to develop an improved catalyst for the hydroliquefaction of coal to a clean-burning fuel for power generation.

A batch screening reactor was used to test over 150 catalysts. Both experimental and commercially available catalysts were investigated; they represent a wide variety of support types, catalytic metals, and surface properties. The relation between initial performance and various catalyst properties was established. The main conclusions are the following: (1) alumina and silica-alumina are the preferred catalytic supports; (2) cobalt-molybdenum and nickel-molybdenum metal combinations give the best overall performance; (3) optimum metals loading for CoO-MoO_3 is 3–15%; and (4) a more open pore structure is preferred for coal liquefaction.

Promising catalysts were tested further in the continuous pilot plant to define their short-term aging behavior. Four commercial catalysts and one experimental catalyst were evaluated. For boiler fuel production, all the catalysts gave a small increase over the thermal baseline. The more important function of the catalyst is for product-quality upgrading, which includes hydrocracking and saturation of polycyclic aromatics plus heteroatom removal. The H–Coal catalyst, HDS-1442, exhibited the slowest decline in benzene-soluble conversion. Its unique surface property (namely, a bimodal pore-size distribution) may be responsible for this desirable aging behavior. Pore-size distribution data on fresh and spent catalysts show that macro feeder pores have less tendency to plug and will continue to transport material to the micro pores of the catalyst interior. *EPRI Project Manager: W. C. Rovesti*

Advanced technology fuel cell program
EM-576 Interim Report (RP114-2)

Early fuel cell power plants are expected to find significant application in small municipal and rural systems and in spinning reserve duty. This report by United Technologies Corp. describes results of the effort to extend the application of fuel cell power plants by improving the heat rate, cost, and fuel flexibility of dispersed generators and by identifying the best approach to the use of coal and coal products in central station and dispersed fuel cell power plants.

The goal of the three-year effort is to demonstrate that technology concepts promising these improvements are ready for engineering development. The study is complemented by an effort to identify materials, configurations, processes, and designs consistent with improved fuel cell power plants. *EPRI Project Manager: A. P. Fickett*

Exploratory studies of high-efficiency advanced-fuel fusion reactors
ER-581 Annual Report (RP645)

This report was prepared by the University of Illinois, Brookhaven National Laboratory, and Lawrence Livermore Laboratories. The objective of the study was to examine the potential advantages and feasibility of using deuterium and D–^{3}He fusion fuels rather than D–T. The report describes the first part of the study, which was concerned with the use of tokamak reactors to burn such fuels. The choice of reactor type was made with the expectation that (because of the emphasis on such systems in the national R&D program) tokamaks will form the basis for the first generation of fusion power plants. The key question is whether tokamaks can be extended to burn fuels other than D–T and thus take advantage of features such as the following: unique blanket designs possible with the elimination of tritium breeding; increased plant lifetimes possible with reduced neutron fluxes and new blanket designs; and improved energy conversion efficiencies associated with the increased fusion energy carried by charged particles.

While achievement of necessary plasma conditions for deuterium and D–^{3}He plants is demanding, no insurmountable obstacles have been found. Indeed, difficulties associated with the plasma may be more than offset by the much greater simplicity of blanket technology. Further, the extended lifetime, easier maintenance, reduced tritium-containment requirements, and efficient thermal cycles afforded with nonbreeding blankets could represent an important economic advantage. *EPRI Project Manager: F. R. Scott*

Fusion reactor first-wall/blanket systems analysis: tokamak concepts
ER-582 Interim Report (RP472-1)

The first-wall/blanket, one of the most critical design challenges of controlled thermonuclear reactor (CTR) components, will have a significant influence on the economy of fusion power. Many interrelated factors influence the choice of materials and design for the first-wall/blanket component. These factors include high temperatures, cyclic loads, tritium containment, high coolant pressures, intense magnetic fields, maintenance of hard-vacuum conditions, and exposure to high-energy neutron radiation.

This report, prepared by McDonnell Douglas Astronautics Co.—East, includes discussions of major features of D–T tokamak fusion reactors, Tocomo program development, wall loading trade study, wall life determination, peak coolant temperature trade study, and design complexity study.

An assessment was made of two titanium alloys for use as structural materials for a first-wall/blanket. The results of this assessment are contained in a separate report, *Assessment of Titanium for Use in the First-Wall/Blanket Structure of CTRs* (EPRI ER-386) *EPRI Project Managers: N. A. Amherd and R. A. Richman*

Availability patterns in fossil-fired steam power plants
FP-583-SR Special Report

This report compares the availability of fossil-fired units over 600 MW with that of units of 200–389 MW and 390–599 MW during the five-year period between 1970 and 1974.

Baseload cyclic, coal, oil, mixed-fuel, once-through boiler, drum-type boiler, mature, and immature units are examined separately to show the effects of design and operating variables. The reasons for the observed differences are discussed. The conclusions lead to recommendations for collecting and utilizing outage data and for research to improve availability. *Prepared by D. Anson. EPRI Project Manager: D. Poole*

Application of scrubbing systems to low-sulfur, alkaline-ash coals
FP-595 Final Report (RP785-1)

The objectives of this study by Arthur D. Little, Inc., were to collect and evaluate available information on low-sulfur western coals, which produce alkaline fly ash, and the behavior of such fly ash in scrubbing systems; and to determine whether sufficient data are available to develop guidelines and specifications for future scrubbing systems on the basis of fuel and ash analyses and boiler design information. Data were reviewed and summarized from 5 pilot plant operations and 19 full-scale operating systems on about 4100 MW of boiler generating capacity fired with low-sulfur western coals.

Data analysis performed as part of the study concentrated on unique aspects of fly ash alkaline scrubbing systems (i.e., the behavior of alkaline fly ash in scrubbing systems and approaches to predicting ash behavior on the basis of fuel and ash characteristics). Scrubbing system performance characteristics that were investigated include particulate removal, SO_2 removal, ash alkali and supplementary alkali utilization, oxidation, scaling, water balance, waste properties, and performance of materials. Additional data and procedures are required in the following areas in order to predict scrubbing system performance: prediction of ash reactivity and alkalinity without pilot plant operations, chemical and physical properties of waste solids, and performance of materials of construction in scrubbing service (with particular emphasis on plastic linings). *EPRI Project Manager: T. M. Morasky*

Evaluation of coal devolatilization concept
AF-608 Final Report (RP523-1)

The objective of this test program by Babcock & Wilcox Co. was to evaluate the concept of increasing make-gas heating value from an air-blown entrained gasifier by feeding some or all of the coal to a devolatilizer vessel downstream from the gasifier. It was further required that the increase in heating value be accomplished without the production of tar or soot.

A pilot plant was constructed, consisting of a gasifier 0.3 m (1 ft) in diameter and a devolatilizer 2.4 m (8 ft) high with an inside diameter of 0.46 m (18 in). A total of 43 test runs were conducted, using an eastern bituminous coal and a western subbituminous coal. Three modes of operation were employed: all coal fed to the gasifier, all coal fed to the devolatilizer, and half the coal fed to each.

Analysis of the pilot plant data yielded the following general results: (1) the gases with highest heating value were generated when all of the coal was fed to the gasifier; (2) unacceptably large tar quantities were generated when half or all of the coal was fed to the devolatilizer; and (3) tar content of the make gas was negligibly small when all the coal was fed to the gasifier.

Data analysis also showed that heat losses were considerably higher than those anticipated. A detailed analysis of the pilot apparatus has shown that without modification there appears to be no method of operation that will significantly lower heat losses. *EPRI Project Manager: M. Gluckman*

NUCLEAR POWER

One-third-scale air-water pump program: test program and pump performance
NP-135 Key Phase Report (RP598-1)

The need for reactor coolant pump two-phase data to be used in transient LWR LOCA calculations was discussed in meetings between AEC and the reactor vendors early in 1973. At this time the vendors were calculating pump performance and overspeed with analytic models based on very little available data. Subsequently, Babcock & Wilcox Co. conducted a pump two-phase air-water–flow test program at the Bingham-Willamette Co. on an available one-third-scale model reactor coolant (RC) pump. A horizontal, air-water flow test loop sized specifically for the one-third-scale, 10-in-diam RC pump was constructed.

The successfully completed objectives of the program were to (1) obtain steady-state pump performance data for various air-water mixtures at several pump speeds and system pressures while operating in the first three of the four quadrants of the pump performance map; (2) obtain sufficient single-phase, steady-state pump performance data to verify the pump performance map for the one-third-scale model pump; (3) obtain continuously recorded data on the transient spinup characteristics of an unpowered pump accelerating from zero speed for selected constant flow rates of various air-water mixtures;

and (4) determine the variation in homologous pump head and torque for selected values of pump inlet void fraction over a range of pump operating conditions. *EPRI Project Manager: K. A. Nilsson*

One-third-scale air-water pump program: analytic pump performance model and pump performance data
NP-160 Key Phase Report, Vols. 1 and 2 (RP598-1)

A major consideration in the design of engineered safety systems and licensing of LWRs is that sufficient cooling capability be provided to keep clad temperature of reactor core fuel elements below specified values, even for a postulated break in principal coolant loop components, such as the main recirculation loop pipe. Therefore, it is necessary to be able to predict reactor system performance in such a LOCA and to take steps toward the prevention and/or mitigation of accidents when designing the system.

Analyses of a postulated LOCA include predicted core flow and broken-loop pump overspeed, both of which are dependent on the performance characteristics of the reactor coolant pumps. The pump in the broken leg pipe directly affects the rate of system depressurization by retarding blowdown flow, and the remaining pumps affect the flow rates and distribution throughout the system. Analytic pump models generally in use for LOCA calculations employ homologous flow relationships to derive head and torque behavior in the two-phase flow regimes, and an empirical head degradation factor based on limited experimental information is commonly used.

The first volume presents the analytic pump model developed by Babcock & Wilcox Co. as part of the one-third-scale air-water pump studies, using the entire set of collected steady-state air-water test data.

The second volume is a supplement to the first and consists of a computer printout of data on pump performance, which was measured on a one-third-scale model reactor coolant pump in a test loop using air-water as test medium. Testing was carried out by Babcock & Wilcox Co.

Homologous pump performance data were calculated with a digital computer code, WAPMP, which is listed ahead of the test data. *EPRI Project Manager: K. A. Nilsson*

Analytic models and experimental studies of centrifugal pump performance in two-phase flow
NP-170 Key Phase Report (RP493)

As part of EPRI's research on the performance characteristics of reactor coolant pumps, work was performed by the Massachusetts Institute of Technology (MIT) to evaluate existing analytic models describing centrifugal pump performance in two-phase flow. A new method to predict pump two-phase performance is proposed in this report and is evaluated using existing pump performance data from all four quadrants. Fourth-quadrant data taken at MIT on some simple pump geometries are also presented. *EPRI Project Manager: K. A. Nilsson*

1/20-scale model pump test program facility description
NP-293 Key Phase Report (RP347)

Part of EPRI's continuing effort to improve and advance LWR safety technology is a task being performed at Creare Inc. on pump modeling. The objectives are to provide a physical understanding of the fluid dynamics of multiphase fluid flow through centrifugal pumps, to define those fluid-dynamic and mechanical characteristics of LWR primary coolant pumps that are important to reactor safety analysis, to determine the adequacy of scale model testing for obtaining data on pump fluid-dynamic performance under conditions of a hypothetical LOCA, and to develop models of the pump–primary-coolant-loop system LOCA characteristics that are appropriate for computer code development. These objectives are being addressed by both analytic and experimental work.

Considerable effort has gone into the design of a scale model pump facility, in which both low-pressure air-water tests and higher-pressure steam-water tests of two 1/20-scale reactor model pumps will be performed. This report describes the experimental test facility used for the scale model testing. The model pump is described, as well as instrumentation and measuring techniques. *EPRI Project Manager: K. A. Nilsson*

Recirculation pump seal investigation
NP-351 Final Report, Vol. 1 (TPS76-635)

This report by MPR Associates, Inc., presents the results of a review of experience with reactor coolant and recirculation pump seal designs and with pump seal auxiliary systems. The scope of this review includes all operating commercial LWRs over 400 MW (e) in the United States.

Problems that have been encountered with seals and seal auxiliary systems are discussed, the principal causes of seal failure are identified, and recommendations for improving reliability and reducing maintenance of the seals are given. The action that utilities can take to improve seal performance and increase seal life is presented in the form of technical requirements that can be incorporated in technical procurement specifications for pump seal systems and seal auxiliary systems. *EPRI Project Manager: J. Mundis*

Recirculation pump seal investigation
NP-351 Final Report, Vol. 2 (TPS76-626)

A review of BWR recirculation pump seals was conducted by General Electric Co. as the first step in the possible development of a new pump seal with improved sealing capability and service life. The first task of this study was the identification of the major seal failure mechanisms. A new seal specification was written, and existing seal designs were then investigated. The fourth task was the conception of a combination seal based on results of the three previous tasks.

Unknown causes were the leading reasons for seal failure, followed by crud in the seal, incorrect manufacturing, and design errors. The new seal specification established design goals for a low-leakage, long-life dynamic recirculation pump seal. Existing seal designs, including the present face seal configurations, ferrofluidic, visco, hydrostatic face, hydrodynamic face, and bushing seals, were investigated in the third task. The hydrodynamic spiral-groove face seal was judged to be the best replacement for the present face seal design. *EPRI Project Manager: J. Mundis*

One-third-scale air-water pump program: alternate pump performance data
NP-385 Key Phase Report, Vol. 2 (RP598-1)

This report presents an alternative version of an analytic pump model developed by Babcock & Wilcox Co. for predicting reactor coolant pump behavior during two-phase flow conditions. This new version was based on a revised reduction of the steady-state data collected during the testing of a one-third-scale reactor coolant pump using air-water mixtures. Like the original model, the alternative version relates the single-phase homologous characteristics of the pump to the corresponding two-phase parameters through multiplier functions of the average void fraction. Several assumptions and definitions of pump and flow parameters were modified in developing the new model. *EPRI Project Manager: K. A. Nilsson*

One-third-scale air-water pump program: LOCA and pump overspeed analyses
NP-474 Final Report (RP598-1)

Babcock & Wilcox Co. (B&W), in conjunction with the Bingham-Willamette Co., conducted a test program to investigate the performance of a one-third-scale model reactor coolant (RC) pump using air-water mixtures. A pump model was developed from air-water test data reduced to homologous form for use in predicting RC pump response to two-phase flow conditions during a LOCA.

The effect of using the B&W air-water pump model to calculate pump overspeed and peak cladding temperatures expected to occur during a LOCA were investigated. Calculations were performed for several different conditions, using the B&W air-water pump model. *EPRI Project Manager: K. A. Nilsson*

Gamma scan measurements at Zion Station Unit 2 following cycle 1
NP-509 Final Report (RP130)

An extensive gamma scan measurement of irradiated fuel was performed by General Electric Co. following Cycle 1 at Zion Station Unit 2. These measurements were to provide power distribution benchmark data for verification of those methods used for predictive calculations and in-core monitoring of core power distributions.

Combination of the benchmark data reported here and the design details and operating history of the core allows evaluation of the accuracy of power distribution calculations. These measurements constitute a detailed benchmark for power distribution in a PWR, addressing the questions of gross core shape, detailed axial shape, core symmetry, and power sharing among assemblies of differing enrichments. Successful completion of a project of this magnitude is the result of excellent cooperation among Commonwealth Edison Co., EPRI, and General Electric. EPRI-sponsored projects such as this will provide the users and manufacturers of nuclear supply systems with valuable benchmark data to improve performance and availability and to increase margin, by reducing uncertainties in the design and operation of plants. *EPRI Project Manager: R. N. Whitesel*

Zircaloy cladding ID/OD oxidation studies
NP-525 Final Report (RP251-1)

The objective of the EPRI/Metal Properties Council (MPC) Zircaloy LOCA project was to systematically investigate the oxidation and deformation rate behavior of Zircaloy cladding under simulated LOCA conditions to obtain quantitative data for use in LOCA evaluation codes. Such data can help to reduce the uncertainties in these calculations and minimize the potential for derating of units, which has occurred in the past. The jointly sponsored research was conducted by Battelle, Pacific Northwest Laboratories for EPRI and MPC.

The project consisted of four research tasks. The ID/OD oxidation task, which is the subject of this report, provides the reference experimental data to characterize the relative ID/OD oxidation that could realistically occur near the rupture area during a LOCA. Five nuclear fuel suppliers (Babcock & Wilcox Co., Combustion Engineering, Inc., Exxon Nuclear Co., Inc., General Electric Co., and Westinghouse Electric Corp.) provided additional funding to MPC. *EPRI Project Manager: J. T. A. Roberts*

Long-term performance of charcoal absorbers removing radioiodine in ventilation exhaust air
NP-534 Final Report (RP274-1)

Filtering effluent gases through charcoal filters is one method of reducing radioiodine discharges from nuclear power plants. With the establishment of the criterion of keeping exposure to radioactive materials as low as possible and the movement toward multiunit sites and discontinuation of tall stacks, airborne waste treatment systems become an important part of effluent control.

Most data concerning removal of iodine are from studies applying large concentrations of iodine under laboratory-controlled conditions. Only limited data are available for trace concentrations under actual operating conditions. This study was undertaken by Science Applications, Inc., to collect data under actual operating conditions over a relatively long period of time. *EPRI Project Manager: H. Till*

Special tip detector measurements at Edwin I. Hatch Nuclear Plant Unit 1 prior to end of cycle 1
NP-540 Final Report (RP130-3)

This report by General Electric Co. presents results, conclusions, and discussion of a special traversing in-core probe (TIP) test performed at the Hatch 1 reactor. The purpose of the test was to provide power distribution data to support resolution of the apparent thermal neutron TIP asymmetry problem and to provide detailed qualification data for process computer programs and BWR core analysis methods.

Full-core power distribution data were obtained using three General Electric test detectors—a thermal neutron TIP (standard production TIP), a gamma TIP, and a fast neutron TIP. Apparent asymmetries measured with the gamma TIP were a factor of 2 lower than asymmetries indicated by the thermal neutron TIP. Although the data analysis, including gamma scan evaluation, is not complete, the gamma detector appears to be a suitable replacement for the thermal neutron detector.

Data obtained for the fast neutron detector were extremely noisy and of limited usefulness in the analysis of this detector's performance. However, the fast neutron data did indicate both a higher asymmetry and a higher dependency on void fraction than the gamma TIP. *EPRI Project Manager: R. N. Whitesel*

Optimization of reliability data system
NP-543 Interim Report (RP826)

Reliability engineering is receiving increased attention by the electric power industry as a means of improving the availability of its generating units. Reliability engineering applies the knowledge gained at operating units to improve equipment, systems, and methods of operation and maintenance. The effective application of reliability engineering depends on a good information feedback system.

There are now several data-information feedback systems that report on various items of unit and equipment reliability, maintainability, or availability. These systems are very specialized and collectively report on only a small portion of the total experience from operating nuclear and fossil units. This study by Holmes & Narver, Inc., determines what the industry's need for data is and what kind of information feedback system could satisfy the product-improvement needs of utilities, consultants, and manufacturers. *EPRI Project Manager: W. Lavallee*

Improvement of reference nuclear data for commercial power reactor analysis and design
NP-556 Final Report (RP708-1)

The National Neutron Cross Section Center (NNCSC), Brookhaven National Laboratory, is participating with EPRI in an effort to improve the nuclear data base used as input for commercial power reactor analysis and design.

NNCSC is responsible for making available sets of evaluated neutron cross-section data that can be used for reactor applications. To fulfill these requirements, NNCSC coordinates not only a national data evaluation effort but also a data testing program to verify data and establish priorities for the improvement of the reference data base.

Although the primary objectives were the performance of definitive benchmark calculations using Monte Carlo methods and the evaluation of nuclear data for gadolinium isotopes, in 1976 NNCSC participated in many other activities that had an impact on EPRI programs. These are summarized briefly before the detailed discussion of NNCSC data testing and data evaluation projects. *EPRI Project Manager: O. Ozer*

Development of the materials code, MATMOD (constitutive equations for Zircaloy)
NP-567 Final Report (RP456-1)

Structural elements of the modern LWR core are composed primarily of the zirconium alloys Zircaloy 2 and Zircaloy 4. When diagnosing faults in the core region and designing improved core components, it often becomes desirable to predict the mechanical response of these components to the duty cycle imposed in service. Continuing developments in the field of computer-oriented structural analysis methods are making it increasingly possible to predict core component behavior accurately under the complex loading conditions encountered in service.

The results of this project by Stanford University represent a significant improvement on previously available methods for describing the material behavior in the form of mathematical equations and for solving the equations in a structural analysis computer program.

The work at Stanford University has been part of a coordinated effort with General Electric Co. and Massachusetts Institute of Technology. Stanford's task was to mathematically describe the non-direction-dependent behavior of the metal. General Electric was charged with producing a mathematical description of the directional dependency (anisotropy) of the mechanical behavior of zirconium and with reducing the analysis method of the coordinated project for practical use.

Results of the project are being used for the specific purpose of developing an advanced model of nuclear fuel rod reliability. More widespread use of this potentially powerful methodology in design and analysis of power plant components awaits the development of efficient general-purpose computer methods for solving the complex set of equations at low cost. *EPRI Project Manager: T. Oldberg*

Rewetting model using a generalized boiling curve
NP-571 Topical Report
(RP228-1 and RP248-1)

Considerable interest has recently been generated in the problem of surface rewetting, because of its role in LWR safety. Following a postulated LOCA, the reactor core might be uncovered, resulting in a deterioration of heat transfer and a consequent temperature excursion of the fuel cladding. To safeguard the integrity of the fuel rods, the core is cooled either by top-spraying of coolant (typical of BWRs) or by bottom-flooding (PWRs and BWRs). With either type of cooling, a task of the emergency core cooling system is to rewet the hot cladding of the fuel rods by means of falling or rising liquid flow.

An analytic one-dimensional conduction model was developed by the University of California for the rewetting of a hot surface. A generalized boiling curve was applied to account for the various heat transfer regimes involved in the quenching phenomenon. A nondimensional velocity was defined, which played the role of an eigenvalue in the solution of the governing equation, and this was shown to generalize the applicability of the predicted results for a wide range of experimental conditions. The method is applicable for an arbitrary distribution of heat flux in the sputtering region and does not require the conventional a priori definition of a rewetting temperature. *EPRI Project Manager: K. H. Sun*

Defining document for a design-operation evaluation model for BWR power plants
NP-587 Final Report (RP686-1)

Power plants are designed primarily on the basis of steady-state performance analyses of their components and, in the case of nuclear plants, detailed safety analyses of postulated accidents. In general, neither of these design analyses focuses on the reliable performance of plants during periods of anticipated dynamic operation, such as load following, cyclical on-off duty, unit trips, or equipment failure. This report by Philadelphia Electric Co. documents the requirements for a design-operation evaluation model, which could help to increase plant productivity and reduce startup problems by providing (1) improved subsystems integration and control system design to ensure that major components are maintained within operating limits during normal transients; (2) verification of desired operational capabilities for different modes of plant operation; and (3) prestartup simulation capability for the development of operational procedures and the resolution of operational problems.

The need for such a model is discussed in the report, and the model's capabilities (which are based in part on the results of a survey of 33 utilities that own BWR power plants) are described. Examples are also presented of a number of simulation studies that have been used successfully to solve specific plant design and control problems. Within this context, the philosophy of modeling and the plant simulation process are reviewed, and the requirement and scope of a BWR model are presented. In general, the U.S. utility industry has had very little experience with design-operation evaluation modeling. The report concludes with the recommendation that a modeling tool that is simple, flexible, and economical should be developed for the utility industry. *EPRI Project Manager. A. B. Long*

Validity and design of environmental surveillance systems for operating nuclear power plants

NP-604 Final Report (RP405-1)

The composition and procedures of environmental surveillance programs at completed and operating nuclear power plants have been examined by Georgia Institute of Technology with respect to their validity, continuing significance, and cost. It was found that many programs contain components that are mainly extensions of preoperational baseline measurements that need not be continued indefinitely; other programs lack the statistical validity to make their continued application meaningful.

For the planning of programs that will extend over the 30–40-year routine operation of the plant, criteria are proposed for selecting only those samples and analyses that are of sufficient continuing importance to justify their indefinite retention. Other program elements of local importance may be added, including a flexible response for occasions when radioactive release levels from the plant rise for any reason. *EPRI Project Manager: M. H. Kirkpatrick*

Calculations of neutron flux levels in the pressure vessel of an LWR

NP-617 Final Report (RP827-2)

A knowledge of the effects of radiation in nuclear reactors is of importance for their safety and reliability. To assess radiation-induced degradation of performance for nuclear components, it is necessary to have a complete description of the neutron fields around these components, particularly the pressure vessel, which is one of the primary containment boundaries in nuclear systems.

This study by Radiation Research Associates, Inc., is directed toward the continued assurance of the safety of LWR pressure boundaries and the ability of new and existing plants in the United States to meet licensing and technical specification requirements.

The calculations presented in this report compose a critical part of EPRI's program of analytic calculations related to verification of pressure vessel integrity. *EPRI Project Manager. F. J. Rahn*

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