Programs In Renewable Energy

Fiscal Year 1989

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Federal involvement in renewable energy research and development (R&D) focuses on long-term needs to achieve national policy goals. Private-sector industry tends to focus on short-term rather than long-term activities and is generally reluctant to invest in projects that do not produce tangible benefits in the near term. The federal government, on the other hand, sets long-term R&D priorities for energy security and fills the gaps in the early phases of high priority R&D that industry is not willing or able to perform.

The U.S. Department of Energy's Renewable Energy Program provides for industry involvement in determining long-term research needs, sponsors the research needed to address these priorities in collaboration with industry, and disseminates research results.

This publication describes the specific research activities that will be undertaken during FY 1989 in each individual program along with the results expected from those activities.

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Introduction

A "commodity-based energy economy" can be defined as one in which the majority of the life-cycle cost for producing the energy is the cost of the raw material fuel input (commodity). Because the overwhelming majority (approximately 85%) of U.S. energy is produced by the straightforward combustion of fossil fuels, this country can be viewed as having a commodity-based energy economy. An energy economy that includes a large component of commodity-based energy supplies can be subject to volatility and a large degree of uncertainty in response to international economic and political forces. Although research is under way to prolong the availability of commodity fuels (e.g., research on new enhanced oil recovery techniques and technologies), the volatility and uncertainty of the supply will tend to increase as the domestic commodity base moves toward eventual depletion.

Energy-intensive economies over time will likely proceed to the increased use of indigenous, abundant resources by utilizing advanced technology. Notable examples of "technology-based" energy supply options (for which the

Amorphous silicon thin-film modules.

primary life-cycle cost of producing the energy resides in the capital cost of the plant rather than the fuel cost) include fusion, for which the energy source will be the hydrogen isotope deuterium abundantly present in the world's oceans, and renewable energy based on solar, wind, ocean, biomass, hydropower, and geothermal resources. Advanced technology will also be crucial to energy conservation techniques and nuclear fission systems.

Technology-based energy systems use a technology that is both capital intensive and complex, to collect and concentrate the natural resources and to convert them into the energy forms (e.g., heat, light, electricity, or liquid/gaseous fuels) required by developed economies. An increasing reliance on a broad array of technology-based energy systems will additionally require the development of advanced energy storage and distribution technologies to provide economically optimal and reliable interfaces with the nation's existing energy distribution infrastructure. However, technology-based energy supplies in general rely on very plentiful indigenous resources.

The Department of Energy (DOE) sponsors research in each of the technology-based energy supply options. This document describes the research to be undertaken by DOE in renewable energy technologies, electric energy systems, and energy storage during fiscal year 1989 (FY 1989). For each of these programs, more detailed information about FY 1989 activities is contained in individual annual operating plans; more information about future plans is contained in multiyear plans for each technology.

Renewable Energy Technologies

Renewable energy technologies currently contribute to this nation's energy security, stability, and strength objectives as stated in the DOE report to the President of the United States, *Energy Security* (DOE/S-0057), March 1987. Renewable resources contribute to energy security because they are indigenous, nondepletable, and enormously abundant, and hence not subject to supply interruption or control from outside the United States. They are a source of energy stability because they offer a diversification of supply that can satisfy energy demands directly in all the common forms of energy used by the United States energy infrastructure: electricity; heat; and gaseous, liquid, and solid fuels.

Renewable energy technologies increasingly contribute to energy and economic strength through the emergence and establishment of viable domestic energy industries and through the development of national scientific and engineering capability. Continued advances in research can be expected to further enhance their economic viability and contribution to the nation's energy supply mix and competitiveness in world energy markets.

Renewable energy supplies are by far the most plentiful energy resources to the national economy. Current estimates indicate that the solar and geothermal resource base (i.e., the known and hypothesized amount of resource available in total) accounts for as much as 75% of the total U.S. energy resource base. It is no surprise then that the usage of renewable energy in the United States is growing steadily. The Energy Security review estimates that renewable energy's contribution to the total U.S. energy production will increase from the present 9% (largely from hydropower, biofuels, and geothermal sources) to 12% within two decades. The International Energy Agency publication entitled *Renewable Sources of Energy* (OECD/IEA, Paris 1987) noted that renewable energy sources are making progress internationally as well.

Today's research lays a foundation for an even larger role for renewables in the nation's longer term energy supply system. Renewable energy technologies such as photovoltaics, wind, geothermal, and solar thermal appear poised to make a vital contribution to the electric power generating sector. Important opportunities also exist for renewable energy supplies to meet requirements for industrial process heat, liquid and gaseous fuels, and the cooling, lighting, and heating of buildings. Biofuels, solar, and geothermal energy can provide for the direct replacement of heat-producing technologies or on-site electricity generation alternatives. Biofuels, geopressured geothermal, and municipal solid waste options provide the potential for production of liquid and gaseous fuels. Advances in electric energy systems and in energy storage will provide the basis for greatly improved utilization of renewable resources. The DOE program undertakes research in each of these technology areas.

Program Goal

DOE's Renewable Energy Program is working toward the goal of producing a technology base on which the private sector can build to provide the economy with a broader selection of competitive energy supply choices. The federal research and development (R&D) program is intended to act as a catalyst to stimulate private sector development of renewable technologies. The DOE research program addresses key, high-risk technical issues that lead to a scientific and engineering knowledge base on which industry can develop renewable energy systems with greater efficiencies, longer system lifetimes, and lower system costs.

The multiyear plans for each technology within the DOE research program describe specific cost and performance goals to be achieved in the near and long term. Research goals vary for each technology because each particular renewable resource and its most useful applications vary across the United States. Nevertheless, in order to realize their large potential contribution to the nation's energy supply, renewable technologies will have to be competitive in the energy market and be compatible with the existing supply system.

For this reason, renewables technologies that are in near-term developmental stages have established goals related to economic competitiveness. Those renewable energy technologies that produce electricity have established long-range cost goals (for the middle to end of the next decade) ranging from 3¢ per kilowatt-hour (kWh) to 10¢ per kWh to be competitive with conventional electric generating costs across base-load, intermediate, and peaking plants. For renewable energy technologies that directly produce liquid and gaseous fuels, long-range cost goals include $1.00 per gallon for gasoline or ethanol and $3.00 to $4.00 per million Btu (MBtu) for methane or thermgas gaseous fuels.

Some renewables technologies produce heat for direct application (e.g., for industrial process heat or building space conditioning); these use a long-range cost goal of $9.00 to $10.00 per MBtu. Finally, research is under way to develop improved technologies for the storage of energy. Research goals for these technologies vary widely because the intended applications range from electric utilities to individual residences or vehicular transportation. As an example, advanced battery concepts are expected to provide residences with storage of solar electric power at a cost of 3¢ per kWh of energy delivered.

A number of renewables technologies under investigation in the DOE research program (such as geothermal-magma, hydrogen, or advanced fundamental electrochemical materials research) are long-range concepts whose

Experimental wind turbine at SERI.

technical viability remains to be established. Goals for these programs are established in terms of gaining sufficient scientific understanding that engineering development and goals can be set in the future. Further details on technology program goals and objectives in these and other areas of research may be found in the previously mentioned program multiyear plans.

Program Strategy

To contribute to the nation's energy security goal, the strategy of the Renewable Energy Program is to develop, in cooperation with the private sector, a range of potentially viable energy technologies. The approach is to concentrate federal resources on scientific and engineering research to achieve a better understanding of the characteristics of renewable energy sources, of the technologies for collecting and converting these sources to useful forms, and of the generic materials sciences to support industrial development of reliable and efficient systems.

DOE's research emphasizes basic and applied research and exploratory development that supply the scientific and technical basis for increasing cost-effective use of the renewable energy resource base. Federal funds will continue to support university and national laboratory research while encouraging increased cooperative R&D activities with industry, to bring emergent technologies from the laboratory to the point of technical understanding that will allow each participant to develop its own product-specific technology.

Program Management

DOE Headquarters. The DOE Headquarters staff provides the centralized leadership necessary to ensure that program activities are consistent with national energy policy, priorities, and directives. Headquarters is ultimately responsible for the achievement of program goals and milestones. Manage-

DOE Renewable Energy Research Programs

- Solar Buildings - the use of solar energy to heat, cool, light, and ventilate buildings.
- Solar Thermal - the use of concentrated sunlight for industrial processes and for thermal production of electricity.
- Photovoltaics - the direct conversion of sunlight into electricity using semiconductors.
- Ocean Energy - the use of the temperature differential within oceans to produce electricity or an energy-intensive product.
- Wind Energy - the use of wind power to produce electricity.
- Biofuels - the production and processing of biological or municipal and other organic waste feedstocks as fuels, or the conversion of such materials into liquid or gaseous fuels.
- Geothermal - the use of the high temperatures and fluids within the earth as a thermal source for electricity production and direct heat applications.
- Electric Energy Systems - the integration of innovative technologies (including superconducting cables) into the nation's utility network and improved technology to provide flexibility and control over large grids.
- Energy Storage - the development of thermal, chemical, and electrochemical technologies to store energy, allowing the use of renewable supplies despite their intermittent nature.
- Supporting Activities - activities necessary to support research, including measurement of the solar radiation resource, maintenance of research facilities, and transfer of research data and results to industry.

ment of technical activities is decentralized among various DOE Field Offices, the Solar Energy Research Institute (SERI), and national laboratories to ensure that specialized technical expertise is available to supervise the research. Under the administrative oversight of the appropriate technology office within the Office of the Deputy Assistant Secretary for Renewable Energy, each technology division implements DOE policy at the program level and allocates the necessary technical and budgetary resources for the program activities. The divisions establish research program objectives and priorities for SERI, the national laboratories, and other contractors, and approve annual plans for performing assigned activities. They also monitor and evaluate technical progress and redirect program operations as necessary. Headquarters staff represents the United States in international R&D programs, and responds to requests from DOE authorities, Congress, federal agencies, and the public for program information.

DOE Laboratories. The DOE Laboratories, including national laboratories and SERI, provide management and technical support for each renewable energy program's technical activities. The laboratories are responsible for the day-to-day implementation of research activities, including projects performed in house and contracted work in areas assigned to them by Headquarters. They encompass skills and facilities not available or affordable in private industry; these facilities are used directly and are also made available on a cost-reimbursable basis to private researchers as necessary to accomplish joint objectives. For example, User's Facilities at SERI include the Photovoltaics Devices and Measurements Laboratory and the Wind Energy Test Center.

In addition, to ensure the success of federal partnerships, the DOE laboratories allocate a significant part of their resources to projects performed directly by universities, private companies, and research institutions. They support a significant level of scientific educational training through postdoctoral appointments, graduate student research, and other educational programs. The remaining resources are used for activities performed within the laboratories. They select program participants and provide specific technical management. Finally, disseminating information to DOE Headquarters, other DOE laboratories, and contractors (including private industry and universities) is an important function of the laboratories.

Program Funding

The federal investment in renewable energy research and development is appropriate in light of the large contribution renewable technologies can make toward achieving improved energy security and the extent of the remaining basic scientific and technical issues needed to be resolved. The renewable energy budget is formulated to sustain highest priority research and maintain a balanced program to provide for private sector decision-making, while minimizing federal program outlay requirements. A substantial additional level of research is conducted in related program areas or in cooperative efforts with DOE, by the renewable energy industry, states, and user communities such as the Gas Research Institute (GRI), the Electric Power Research Institute (EPRI), and individual utilities. The DOE Renewable Energy Program, including the various renewable energy technologies, electric energy systems, and storage, is funding nearly $150 million for activities in FY 1989.

Federal Laboratories Involved in Renewable Energy R&D

- Argonne National Laboratory (ANL)
- Brookhaven National Laboratory (BNL)
- Jet Propulsion Laboratory (JPL)
- Lawrence Berkeley Laboratory (LBL)
- Los Alamos National Laboratory (LANL)
- National Institute of Standards and Technology (NIST: formerly the National Bureau of Standards or NBS)
- Oak Ridge National Laboratory (ORNL)
- Pacific Northwest Laboratory (PNL)
- Sandia National Laboratories (SNL)
- Solar Energy Research Institute (SERI)

Summary

Federal involvement in renewable energy R&D focuses on long-term needs to achieve national policy goals. Private-sector industry tends to focus on short-term rather than long-term activities and is generally reluctant to invest in projects that do not produce tangible benefits in the near term. The federal government, on the other hand, sets long-term R&D priorities for energy security and fills the gaps in the early phases of high priority R&D that industry is not willing or able to undertake. The continuum of DOE-funded research — from basic, to applied, to proof of concept — is maintained through multiyear commitments, with the DOE role varying along the continuum. The DOE program provides for industry involvement in determining long-term research needs, sponsors the research needed to address these priorities in collaboration with industry, and disseminates research results. The energy marketplace and private industry are best suited to develop and produce near-term renewable energy technologies at a rate consistent with their market viability and suitability.

The following sections described the specific research activities that will be undertaken during FY 1989 in each individual program, and the results expected from those activities.

DOE Solar and Other Renewables Funding
(millions of dollars)

	FY 1989 Appropriation
Solar Buildings	5.4
Photovoltaic Energy	35.5
Solar Thermal Energy	15.0
Biofuels	13.4
Wind Energy	8.8
Ocean Energy	4.1
International	1.0
Technology Transfer	2.4
Solar Energy Research Institute	0.6
Program Support	1.0
Resource Assessment	0.8
Program Direction	4.2
Subtotal, Solar	92.2
Geothermal Energy	19.6
Hydropower	0
Electric Energy Systems	23.6
Energy Storage	13.5
Total Renewable Energy Funding	148.9

Solar Thermal Energy

Solar thermal energy systems concentrate the sun's radiation to generate electricity, produce high-temperature process heat, and provide high radiant flux for use in various chemical reactions and production of transportable fuels. The goal of the program is to improve solar thermal performance and to provide cost-effective energy options that are strategically secure and environmentally benign. Major research activities include collection, conversion, and systems and applications technologies for both central receiver (CR) and distributed receiver (DR) systems. This research is being conducted through a network of national laboratories in close coordination with the solar thermal industry, utility companies, and universities.

Research Needs

During the 1980s, both the capital and energy costs of solar thermal systems have been reduced by 80%. Current system designs have an annual efficiency of about 15% and a capital cost of about $3000 per kilowatt-electric (kW_e) for CRs, and 20% and $3000 per kW_e (peak) for DRs. In addition, further cost reductions are possible to potentially make solar thermal technology cost-competitive, including reductions for peak and intermediate load generation for CRs, and for peak, intermediate, and remote applications for DRs. Long-term goals call for system capital costs below $1200 per kW_e and system energy costs below 5¢ per kilowatt-hour (kWh). To reach these goals, components and systems with lower cost and higher efficiency, performance, and reliability are being developed. This development follows two basic paths:

- For CR systems, critical components include stretched-membrane heliostats, direct absorption receivers (DARs), and transport systems for molten salt heat transfer fluids.
- For DR systems, critical components include stretched-membrane dishes, reflux receivers, and Stirling engines.

Currently, the major thrust of the program is to provide electric power. However, there is an increasing emphasis being given to applications such as detoxifying hazardous wastes and developing high-value transportable fuels. These potential uses of solar thermal technology are still in the research stage, mostly exploring concept feasibility.

The Solar Thermal Program is divided into three areas: collection technology, conversion technology, and systems and applications technology.

Research Activities

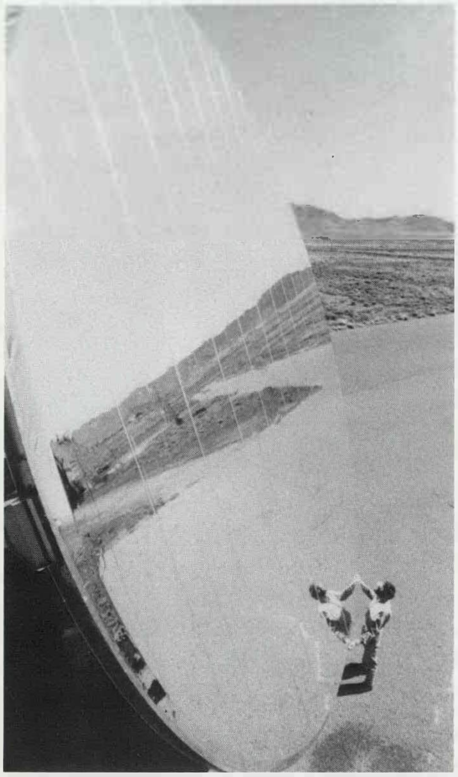
Collection Technology

Optical Materials. The objective of optical materials research is to obtain improved reflectors that achieve a specular reflectance greater than 90% at costs approaching \$10 per square meter (m^2) (\$20 per m^2 currently), and satisfactorily operate in the solar environment over periods of at least five years. Research in FY 1989 is focused on the development of silver/polymer surfaces and thin-foil silver steel reflectors with these characteristics. In addition, abrasion-resistant coatings will be tested and evaluated.

The problem of efficiency losses of large area heliostats and dishes because of soiling will be addressed through the development of materials that resist such soiling, such as polymeric hard coats added to the reflective surface.

Concentrators. The objective of the concentrator research is to develop low-cost, high-performance concentrators that will be able to meet long-term cost goals of \$40 per m^2 for heliostats and \$130 per m^2 for dishes (\$120 per m^2 and \$250 per m^2 now). Analyses have indicated that advanced membrane concentrators are the most promising configuration. In FY 1989, researchers will continue to develop stretched-membrane heliostats with evaluation of the second generation 50-m^2 prototypes developed under contract with Solar Kinetics, Inc. (SKI), and Science Applications International Corporation (SAIC). The early assessment of these units indicates overall optical performance equal to glass/metal heliostats and superior surface control in wind gusts. The Stretched Membrane Dish Concentrator Development Project will continue with the goal of developing a large membrane dish based on designs being developed by SKI.

The structural response, optical performance, and thermal efficiency characteristics of membrane/frame/support structure configurations for membrane concentrators under wind and other loadings will be evaluated. In addition, low-cost drive systems tests and sol-gel reflective section and semiautomatic concentrator controls will be evaluated.



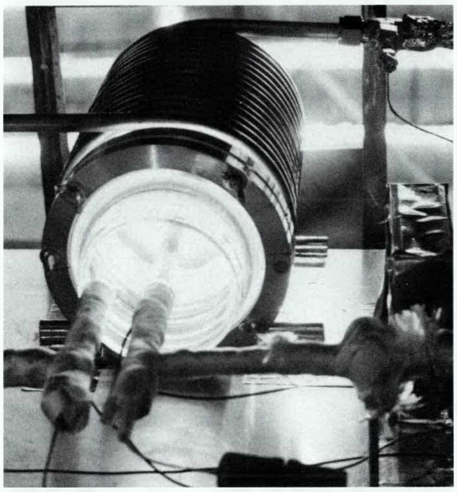
Prototype stretched-membrane mirror module built by Solar Kinetics, Inc.

Receivers. The focus of receiver R&D is the continued development of molten-salt receivers for near-term CR systems, the development of advanced receiver concepts such as the DAR for central receivers, and the development of the reflux receiver configuration for parabolic dish systems. The DAR offers levelized energy cost gains of 14%-18% and shows potential for reaching the long-term CR cost goal of \$30 per m^2. CR systems using a molten nitrate salt DAR are the preferred configuration for applications up to 600°C. Testing using the new 2-megawatt-thermal (MW_t) DAR test apparatus at Sandia National Laboratories will take place during FY 1989, in addition to analysis of a conceptual commercial design.

Research will continue on the flow of molten salt down a simulated DAR panel, as will research on the ability of the salt (with blackener added) to absorb high levels (1000 suns) of concentrated solar energy.

A reflux receiver designed for use with the STM4-120 kinematic Stirling engine will be tested at the Distributed Receiver Test Facility (DRTF) in Albuquerque, N. Mex. The reflux receiver concept uses a boiling metal and a heat pipe approach to decouple solar energy absorption from heat input to a dish-mounted heat engine; this allows for independent optimization of the receiver and engine heat load functions. Evaluations will be conducted for reflux receivers being developed in conjunction with the Free-Piston Stirling Engine (FPSE) Design Program.

Conversion Technology



Reactor used in the experimental solar detoxification of hazardous waste.

Heat Engines. The primary focus of heat engine R&D involves the dish-electric concept using Stirling engine cycles that have high reliability with design lifetime over 50,000 hours and engine efficiencies over 35%. In FY 1989, a variable swashplate kinematic Stirling engine, the STM4-120, will be tested at the DRTF. Work will continue on the development of highly reliable, long-lived engines of both the swashplate Stirling concept for near-term applications and FPSE concepts for the mid-term. The conceptual designs of a solar-driven FPSE will be evaluated by NASA/Lewis Research Center and Sandia National Laboratories, and a competitive contract will be awarded for detailed design and fabrication during FY 1989.

Direct Conversion. Research at SERI and the University of Dayton has shown that a beam of concentrated solar energy can break down hazardous chemicals more efficiently and at lower temperatures than can standard incineration methods. The advantages of using concentrated solar energy for the detoxification process include reduction of incomplete combustion products; the ability to incinerate in a nonoxidizing environment under better control of thermal input conditions; and on-site destruction, which eliminates the need for accumulation and transportation of hazardous wastes to disposal sites. Tests were run at the White Sands Solar Furnace (WSSF) in White Sands, N. Mex., in which a beam concentrated to 1000 suns provided the energy for a solar detoxification reactor to destroy 99.9999% of a dioxin, a particularly hazardous industrial waste. The solar beam provided high energy photons that broke chemical bonds within the dioxin and photons that added a thermal component to accelerate the chemical reaction.

During FY 1989, tests will be conducted on a variety of other hazardous chemicals. Effort will also focus on a better understanding of the process that takes place when the stream of photons interacts with chemicals. As a complement to the destruction of chemicals, researchers at the University of Houston have shown experimentally that it is possible to use the solar beam to enhance chemical reactions. They have shown a 50-fold photoenhancement of the conversion of propanol to propylene, compared to a thermal reaction. Their effort in FY 1989 will turn toward reactions in which inexpensive chemical feedstocks can be turned into high-value fuel additives through the photocatalytic process.

Through tests in their solar furnace, Georgia Tech researchers have shown that carbon fibers heat treated with a solar beam (concentrated up to 7000 suns) show increased oxidation resistance. Additional tests and analysis will be conducted in FY 1989 to determine if the strength of carbon fibers can be increased while maintaining the increased oxidation resistance.

In FY 1988, each of these tasks showed a significant effect caused by a beam of concentrated solar energy. Research in FY 1989 will expand on these results to better understand the fundamental phenomena taking place and to develop photochemical processes that would lead to new applications for the solar thermal technology. In addition, basic research in direct conversion activities will continue during FY 1989 along with initial testing and evaluation of a 10-W regenerative thermoelectrochemical converter (RTEC) system, which has a potential for as much as 40% heat-to-electric conversion efficiency.

Transport and Storage. Primary emphasis of this area of research is the development of molten-salt transport and storage systems for CR systems. In FY 1989, the most significant activities include the evaluation of commercial scale salt pumps and low-cost valves under molten-salt operating environments. These tests include cyclical operation of the components to evaluate lifetime and performance.

Systems and Applications Technology

SBIR Innovative Concepts. The solar thermal program will support innovative concepts through participation in the DOE Small Business Innovative Research (SBIR) program.

Central Receiver Systems. Major activities are planned to research systems integration issues for CR technology, including a utility study conducted by a group of western utilities. The study will continue to address details of the conceptual design of a CR power plant, identify technical uncertainties, and define the preferred next steps along the path to commercialize the CR concept. Other systems studies that deal with DAR systems, stretched-membrane heliostats, and advanced control and plant automation system designs will be conducted.

Distributed Receiver Systems. The main emphasis of this research during FY 1989 is to continue the analysis, design, and evaluation of dish electric systems using advanced Stirling engines. In addition, researchers will continue to design and evaluate advanced dish subsystems and systems, including thermochemical transport systems.

Program Participants

Research Area	SERI	SNL
Fundamental Research	•	
Central Receiver Systems		•
Distributed Receiver Systems		•

Solar Buildings

Solar buildings technologies capture and convert sunlight into useful heat by using discrete collection, storage, and distribution elements (active systems), or by using the building structure itself (passive systems). They also make direct use of sunlight for interior lighting (daylighting systems). The Solar Buildings Technology Program conducts research activities to provide the solar industry with the technology base needed to develop reliable solar systems that can contribute significantly to a building's space heating, hot water, cooling, and lighting requirements at competitive costs. Major research activities are aimed at improving the overall effectiveness of active solar water and space heating systems, increasing solar cooling system thermal performance, increasing daylighting system contributions, and enhancing solar energy supplied to seasonal and annual buildings requirements by means of practical systems integration. These activities are planned and executed in close cooperation with the solar and buildings industries to ensure that the results of program efforts can readily be adopted by the private sector.

Research Needs

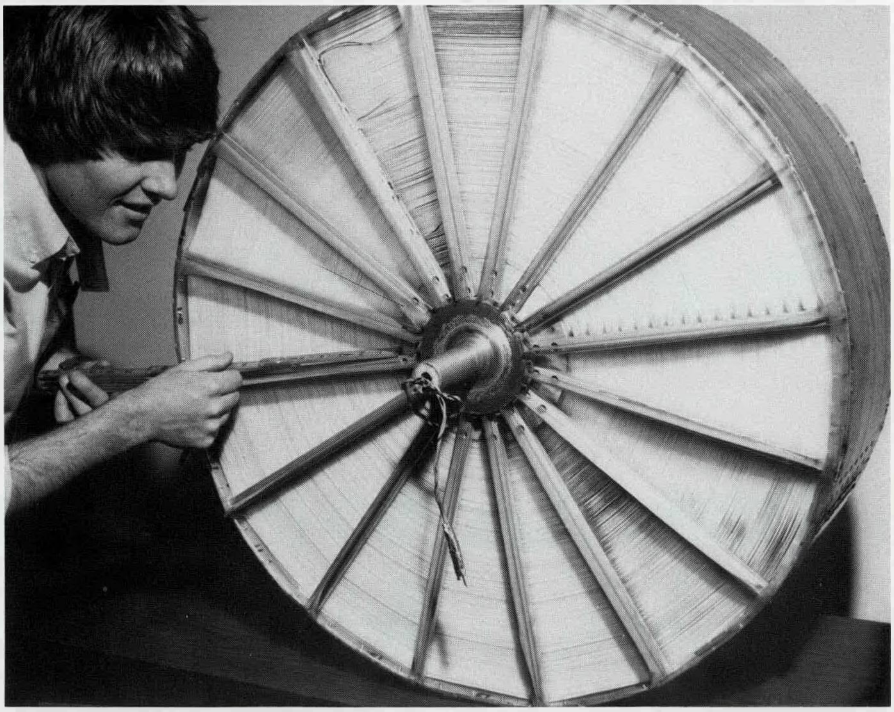
Solar buildings technologies have made significant advances in the research laboratory and in the marketplace since the early 1970s. The efficiencies of flat-plate collectors used in active systems have increased by 35% and reliability has improved substantially. Passive systems that are now available can provide as much as 40% of the heating needs of a typical residential building and a similar percentage of the combined heating, cooling, and lighting requirements of small nonresidential buildings. In selected markets, solar water heaters and passive solar heating systems have proven economically competitive; more than 1 million active systems and 225,000 passive systems have been installed. However, current technologies have yet to achieve widespread competitiveness or approach their technical potential in terms of efficiencies or energy contributions. Analyses have indicated that innovative concepts incorporating new materials and system designs could yield technologies that competitively meet as much as 80% of a building's heating, cooling, and lighting requirements in many regions of the United States.

For active solar water and space heating technologies, realizing this potential will require that system level improvements, based on the results of research and data gathered from well-designed systems, be incorporated in general practice. Working closely with the solar industry, the program strategy is to identify generic systems with the broadest applicability and to develop procedures for the design and testing of these systems. Rather than relying primarily on improvements at the component level, such as the use of low-cost thin-film collectors in place of standard metal-glass collectors, the focus is on improving control strategies and integrated system designs.

The principal impediments to increasing the solar contributions of passive solar heating systems beyond the 30%-40% level are the limitations of current glazing and thermal storage materials. Traditional storage materials such as brick or concrete must be used in relatively large quantities to minimize daily temperature fluctuations and to provide the required thermal storage capacity for storing solar heat. The use of phase change materials (PCMs) with several times the heat capacity of conventional building materials per unit weight could enhance the energy impact of a solar system. Recent efforts have focused on several PCMs that could be combined with conventional materials, such as composite lightweight PCM wallboard or masonry, tailored to store and release heat at the appropriate temperature for comfort conditions.

Active solar cooling systems need substantial improvements in performance, as well as cost reductions before they can compete effectively with conventional electric driven systems. Improvements are needed in the cyclic performance of advanced chillers and dehumidifiers, as well as reductions in collector array costs to deliver the required energy. Current efforts emphasize materials research on new desiccant materials and improved heat and mass transfer desiccant dehumidifier designs to increase the overall coefficient of performance (COP) by 50%. In hot, humid climates where dehumidification is a major concern, there is a need for efficient, low energy techniques for moisture removal. Passive building dehumidification strategies, including the use of desiccants in conjunction with conventional building materials, are objectives of current research.

In the daylighting area, current materials and design/control strategies can provide energy contributions of as much as 30% from sunlight. However, these contributions are confined primarily to building perimeter spaces. To



Experimental desiccant wheel for a dehumidifier cooling system.

increase these contributions, the efficiencies of perimeter systems must be increased, and new daylighting systems that can effectively illuminate spaces at the building core must be developed. For perimeter systems, the research emphasis is on materials that can dynamically control the intensity and direction of sunlight in response to building lighting requirements and thermal comfort conditions. Such systems will provide much greater occupant comfort than current systems, as well as reduce requirements for cooling. For core systems, the emphasis is on light guides that can direct light over distances up to 100 feet with less than a 50% loss in light intensity. The overall research objective is to increase daylighting contributions to 50% of the total lighting requirements in nonresidential buildings.

At the total building level, combining solar systems with conventional heating, cooling, and lighting technologies to permit maximum solar contribution at competitive costs remains a major challenge. Systems integration research activities are currently under way, in concert with industry, with the objective of translating performance and design data into technical guidelines that can be easily used by building designers and homebuilders.

Research Activities

Solar Heating

Heating Subsystems. Activities will encompass systems analyses, systems effectiveness research, and the development of low-cost system test procedures. Analyses of generic active domestic hot water and residential space heating systems suitable for widespread application will begin in FY 1989. Component substitution methodologies for each generic system will be developed and incorporated in simplified test procedures. Work on acceptance test procedures for installed systems will start in FY 1989. Research activities will include applying improved control strategies, such as microcomputer controlled seasonal variations, and incorporating design data from laboratory and field tests, in order to increase system performance by 15% to 25%. System effectiveness research will focus on reliability testing of materials in various system configurations. Methods to predict the long-term thermal performance of systems from short-term tests will be undertaken. Models of advanced solar heating subsystems will be developed and validated. Evaluations of the performance impacts of thermal storage materials incorporated in conventional building materials will be conducted.

Solar Cooling and Dehumidification

Desiccant Materials and Concepts. Research will continue on improved liquid and solid desiccant materials. FY 1988 efforts identified several polymer desiccant materials with potentially superior performance over more commonly used silica gels for desiccant cooling systems. The FY 1989 effort will characterize these materials experimentally in terms of moisture capacity, cyclic durability, and suitability for regeneration with solar heat. Studies will begin on the impacts of airborne contaminants on solid desiccant systems performance. The objective of the FY 1989 effort is to identify desiccant materials and concepts capable of achieving a COP of 1.5. Current desiccant cooling systems have COPs of about 1.0.

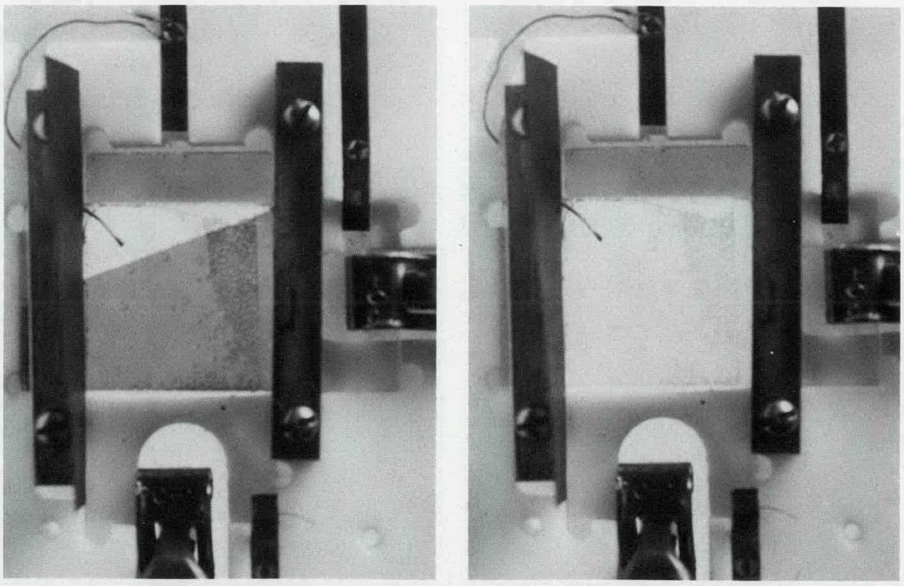
Cooling and Dehumidification Subsystems. Researchers will develop and test solar collector-regenerators, and conduct open-cycle absorption system experiments. A potentially low-cost experimental open-cycle absorption system has been constructed with the potential of providing as much as 70% of the cooling requirements of residential buildings in many locations in the United States. The FY 1989 work will focus on improving the heat and mass transfer effectiveness of the collector-regenerator by changing the design and developing methods to minimize the performance effects of contaminants. Passive building dehumidification strategies will continue to be explored at the Southeast Solar Cooling Test Facility, where a moisture measurement chamber will record and analyze moisture transport and equilibrium data of common building materials. Algorithms describing moisture absorption-desorption in residential buildings will be developed and validated.

Daylighting

Aperture Materials. Research in FY 1989 will continue to emphasize optically switching electrochromic films for controlling daylight and solar heat gains and losses through windows. Laboratory-scale electrochromic film assemblies have demonstrated their ability to switch reversibly over 100,000 cycles in response to an applied voltage. The objective is to develop an assembly that can switch from a light transmittance of greater than 80% to less than 10%, with a life exceeding one million switching cycles. The focus of current efforts is to optimize the individual films in the multilayer assembly and to progress from polymeric materials to all solid-state thin-film coatings with total thicknesses of less than 1 micron.

Daylighting Concepts. FY 1989 efforts will continue to emphasize concepts for increasing daylighting contributions to building interiors. This will involve research on light guides and holographic devices. The objective is to develop an interior light transport system that will illuminate 5 square feet of interior floor area for every square foot of sunlight collection area. Holographic devices have been under investigation as a means of directing light at a fixed angle over extended distances regardless of the position of the sun.

Daylighting Subsystems. Increased emphasis in FY 1989 will be placed on atria and other core daylighting systems. Atria have become a widely used architectural strategy for commercial buildings, but their daylighting and thermal performance are not well understood. The objective



Experimental electrochromic switching film in switched (left) and unswitched (right) states.

of the current effort is to improve the overall effectiveness of atria in terms of increased daylighting contributions and reduced heating and cooling requirements. With the objective of increasing the understanding of core daylighting, research will involve analytical studies, using advanced simulation tools, and the development of technical design guidelines.

Solar Systems Integration

Analysis. In collaboration with countries that belong to the International Energy Agency, studies required to establish the desired performance parameters for advanced solar building materials will be undertaken during FY 1989. Other studies needed to guide research leading to solar low-energy buildings will be undertaken. The feasibility of developing and validating analysis tools required for advanced technologies through international collaboration will be investigated. In cooperation with the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), work will begin on establishing a procedure for comparing and testing design tools.

Design Tools. The design guidelines for passive solar residential buildings developed with the Passive Solar Industries Council (PSIC) and National Association of Home Builders (NAHB) will be made available to builders by industry-based organizations. In addition, a computerized version of the guidelines and a spreadsheet version of the worksheets will be developed. Work will begin on a cooling calculation supplement to the ASHRAE publication entitled *Passive Solar Heating Analysis: A Design Manual.*

During FY 1989, SERI will establish a technical extension center to facilitate the transfer of research results emerging from the solar buildings program to industry. The center's activities will be cost-shared with industry.

Performance Measurement. During FY 1989, validation of the short-term test procedure developed for predicting the long-term thermal performance of solar residential buildings will be completed and the procedure adapted to field use, in collaboration with the NAHB National Research Center. The procedure will be documented and the software made ready for transfer to industry. In addition, modification of the procedure for application to nonresidential buildings will begin.

Program Participants

Research Area	SERI	LBL
Solar Heating	•	
Solar Cooling and Dehumidification	•	
Daylighting	•	•
Solar Systems Integration	•	

Photovoltaic Energy

Photovoltaic (PV) systems convert sunlight directly into electricity using solid state materials and technology. The National Photovoltaic Program, planned and managed by DOE, supports R&D to improve the conversion efficiency, cost-effectiveness, and reliability (durability) of terrestial photovoltaic systems. The major research activities are carried out under four categories: (1) thin-film polycrystalline and amorphous semiconductor materials research; (2) high-efficiency crystalline materials research; (3) fundamental and supporting research; and (4) collector and system research. This research is conducted by subcontract with industry and university research laboratories and to a lesser extent by in-house research at DOE's supporting laboratories at SERI and Sandia National Laboratories, both of which also provide management functions for the subcontracted research projects.

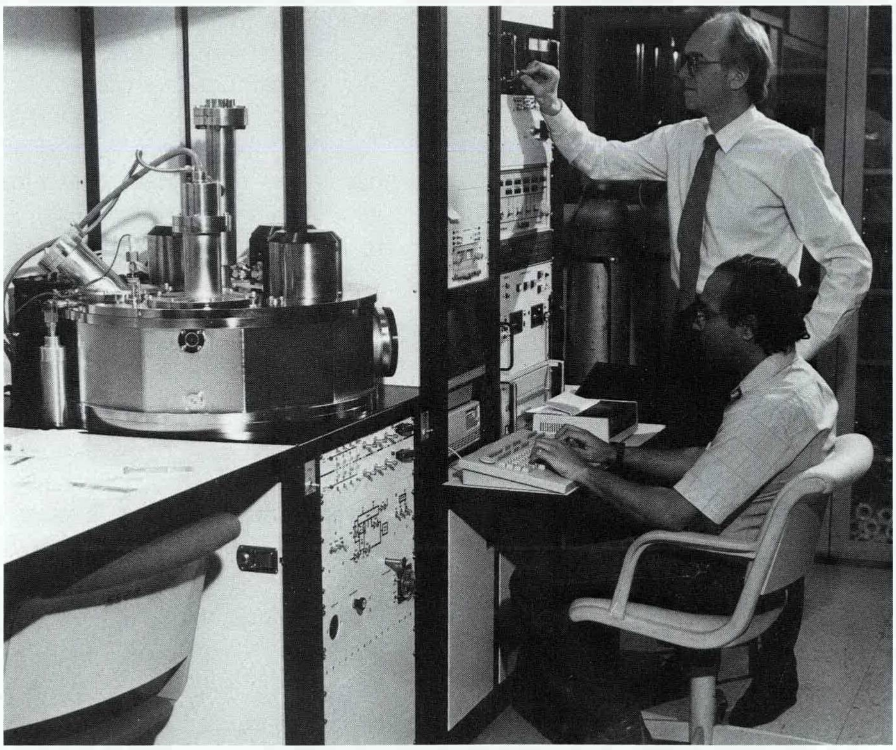
Research Needs

FY 1988 was a banner year for progress in photovoltaic technology and for progress toward the five-year-plan objectives of the National Photovoltaic Program. In the technology area, there has been unprecedented progress in both the R&D laboratories and in the development of industrial capabilities, products, applications, and markets.

In terms of the conversion efficiencies of flat-plate and concentrator cells and modules, a large number of world records have been achieved during the past year. Some of the notable records in cell efficiency are as follows: single-crystal silicon — 22%, gallium arsenide — 24%, and amorphous silicon — 12%. In addition, a number of tandem cells (two or three stacked single-junction cells) reached efficiencies of 31% for stacked crystalline concentrator cells and 13-14.5% for stacked, thin-film, flat-plate cells.

The past year marks the commercial delivery of crystalline silicon modules with sunlight-to-electricity conversion efficiencies that are 15% or higher — a performance goal that was targeted for the early 1990s. This industrial accomplishment results from a decade of DOE-supported collaborative research with many industries, along with FY 1988 breakthroughs in modeling and advanced cell designs accomplished at several university laboratories supported in DOE's fundamental research activities. However, further increases in commercial module efficiency and/or reductions in manufacturing costs are necessary to achieve DOE's cost goals for utility systems.

Industrial progress in expanding production facilities for and marketing of amorphous silicon modules (particularly for consumer products) continues to be outstanding. Thin-film amorphous silicon is a potentially lower-cost approach for power systems than the crystalline silicon modules previously



Precision sputtering equipment used to produce large-area thin films.

cited. Currently, the best efficiencies for commercial amorphous silicon modules are in the range of 5% to 7%.

Based on present and projected research results and scale-up in manufacturing capabilities, thin-film module efficiencies are expected to match today's 15% single-crystal efficiency by the mid-1990s. At least six producers of amorphous silicon cells and modules have announced plans to build more megawatt-sized production facilities in the next two years. In addition, several other companies are showing near-term interest in announcing new commercial module products based on cadmium telluride and copper indium diselenide, materials that have been developed through the DOE program's R&D projects with industry and universities as well as within DOE laboratories.

Two major strategies are in place in the DOE National Photovoltaic Program to achieve the delivery of economic electric power for electric utility grids. Cost goals in the five-year plan require flat-plate module manufacturing costs of $45 to $80 per square meter for module efficiencies of 15% to 20%, respectively; and for concentrator systems, costs of $60 to $100 for efficiencies of 25% to 30%, respectively. These translate to goals of 12¢ per kilowatt-hour (kWh) in 1992 and 6¢ per kWh in 2000, versus approximately 35¢ per kWh today.

The first strategy involves the development of flat-plate and concentrator PV systems based on a number of very high-efficiency crystalline cell and module concepts to obtain overall high system efficiencies at acceptable material and processing costs. The second strategy involves the development of flat-plate systems based on a number of thin-film cell and module technologies that emphasize low material and processing costs and acceptable system efficiencies to meet utility needs.

In addition to the two principal strategic thrusts, the PV program's fundamental research task provides supporting research activities to enhance the scientific and technical knowledge base needed by the PV industry to make informed choices in its R&D activities and commercial product development. This task includes directed research on particular generic problems and needs, including measurement instrumentation and methods for characterizing PV materials and devices, theoretical studies of the electronic structure of materials, modeling and analytical optimization studies of PV device designs, exploration of new materials and devices (new ideas), assessment and characterization of the solar radiation resource, and training of graduate students.

Research Activities

Advanced Thin-Film Materials

Amorphous Silicon Research Project. In FY 1989, the program continues four, cost-shared (50/50), integrated amorphous silicon research contracts with industry. A previous three-year set of industrial, cost-shared (about 30% by industry) contracts achieved 8% efficient single-junction modules.

This second three-year set of research contracts is aimed at achieving efficiencies of 10% and 13% for single-junction and multijunction power modules, respectively. In addition, the project in FY 1989 includes a substantial number of research contracts performed by university and industrial laboratories. The contracts are directed to specific technical problems areas (e.g., alloy materials and their electro-optical characteristics, light-induced degradation in cell performance, new deposition processes, plasma diagnosis, and cell design and modeling) and to basic materials and processing technology.

Polycrystalline Thin Films. Material and cell R&D projects are being carried out by industrial and university research groups on a range of thin-film PV materials and cells with PV systems potential, including polycrystalline silicon, cadmium telluride, and copper indium diselenide-based materials. Most of the contracts with industry involve cost-sharing (about 25% by industry). A principal goal of this task is to increase the performance (efficiency) of single and multijunction cells and modules for use in PV systems, from 10% efficient to 15% efficient. Objectives in FY 1989 include research to investigate new materials and cells, develop new deposition technologies, characterize electro-optical properties of materials as a function of deposition parameters, evaluate the effects of defects and impurities on bulk material characteristics, achieve a better understanding of film surface and interface effects, and demonstrate improved device efficiencies.

High-Efficiency Materials

Research in FY 1989 is directed to improving the understanding, performance, and reliability of high-efficiency, crystalline, single-junction and multijunction cells and modules leading to concentrator cell efficiencies of greater than 28% for single-junction devices and greater than 35% for multijunction devices. The principal PV materials to be studied are crystalline compounds, such as gallium arsenide and silicon. Objectives in FY 1989 include research on new compounds (alloys of three or four elements), film-growth and deposition processes, tunnel junctions for electrically interconnecting, monolithic (two or more cells fabricated directly on top of each other) tandem devices; passivation of film and interface surfaces; characterization of defects in film growth on less expensive substrates; and demonstration of improved conversion efficiencies in devices. For silicon, the objectives include an improved understanding of the effects of bulk and surface impurities, design and modeling of advanced cell structures, effects of cell processing on its performance (efficiency and stability), design and testing of cell structures for use in concentrator collectors, and demonstration of improved performance.

Fundamental and Supporting Research

University Participation. This program's objective is to attract highly qualified university research teams to the DOE PV program to promote creative, basic research that will enhance fundamental understanding and develop new ideas. Its relatively unique feature is a DOE commitment (based upon year-to-year appropriations) to support a professor and his or her associates (including postdoctoral and graduate persons) in an area of university and DOE interest for a minimum of three years. Research investigations can be widely diversified and include work in basic electronic processes in thin films, new semiconductor materials with PV potential, new methods of film growth or material fabrication, advanced PV cell designs, modeling of materials and devices, and new approaches to the characterization of semiconductor materials.

Solid State Theory. This research is aimed at improving the theoretical understanding of the electronic and chemical properties of compound semiconductor materials and their interaction with light. Through complex analytical procedures (mathematical methods), a hypothetical compound semiconductor can be examined analytically to predict its potential value and characteristics as a PV material. Several unknown compounds have been examined in the past, grown in crystalline form in the laboratory, and characterized. In FY 1989, other compounds will be examined, and several of the most interesting PV materials will be grown and characterized.

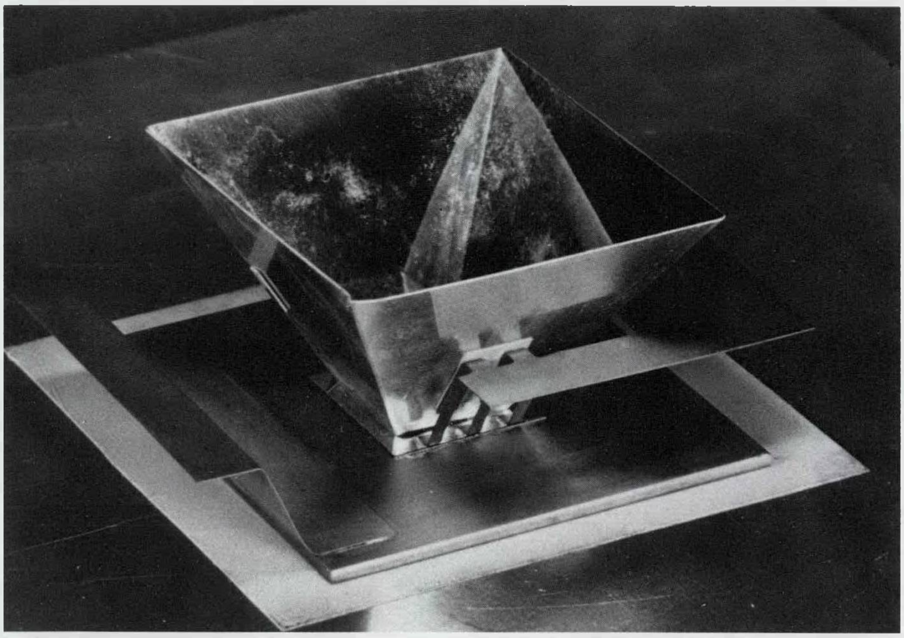
Measurement and Performance of Materials and Devices. This research involves the development and operation of a wide range of complex, analytical instruments and methods (including electronic detectors, particle beams, high-vacuum systems, and computer diagnostics and data-handling systems) for characterizing the electronic and structural properties of semiconductor materials and cells. About 10,000 materials and devices are analyzed annually for contractor and in-house research needs at SERI. The latest measurement technique developed and now in use at SERI is a scanning tunneling microscope that can visualize and identify individual atoms on the surface of a semiconductor film. This state-of-the-art capability, along with a wide range of other sophisticated measurements technology, has played a vital role in understanding and characterizing PV materials, surfaces, and interfaces; locating defects and junctions; and identifying impurities. In FY 1989, additional measurement equipment and methods will be developed in conjunction with continued research.

Collectors and Systems

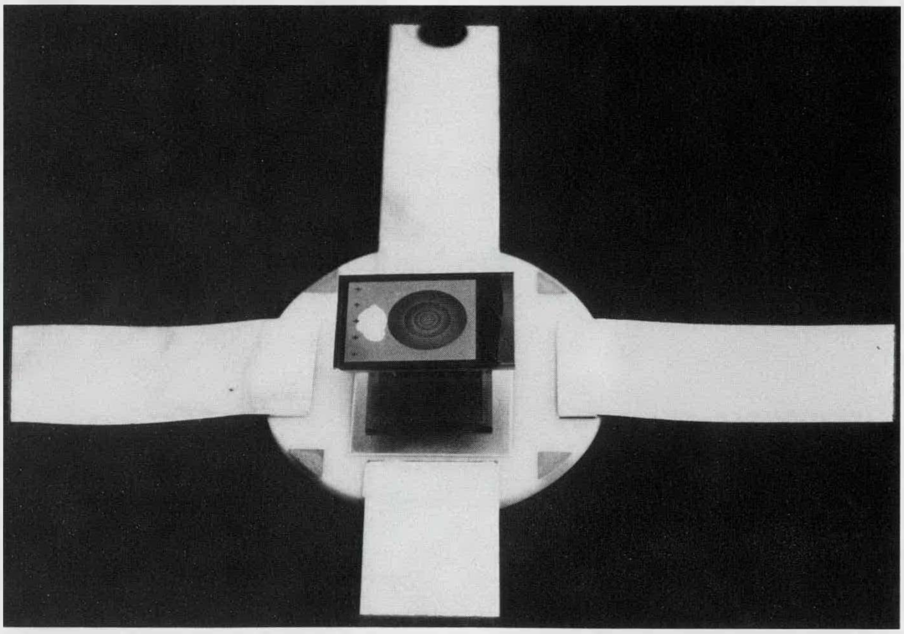
Flat-Plate Modules. Research on module-encapsulation materials and designs and assessments of the durability, stability, reliability, and lifetime of commercial modules will be continued on thin-film modules and devices. FY 1989 activities include the development and application of thin-film module qualification test procedures and specifications to support the PVUSA (Photovoltaics for Utility-Scale Applications) project to ensure reliable modules with expected lifetimes of more than 10 years.

Concentrator Modules. Component research will be continued to improve the performance and reliability of concentrator modules and to reduce the cost of module-ready cell assemblies and optical components. Activities in FY 1989 are to include development and testing of prototype point-focus concentrator modules with overall conversion efficiencies greater than 20%, line-focus modules with efficiencies greater than 16%, and module-ready cell assemblies with efficiencies greater than 30%.

Systems Development. The impact of new collector technologies on system design and performance will be assessed by operating and testing four



Light is concentrated onto a cell at the bottom of this cell assembly unit in Sandia National Laboratories' concentrator module.



Using a gallium arsenide cell (top) and a silicon cell (bottom) mechanically stacked together, SNL measured a record 31% efficiency for this advanced concentrator cell.

prototype thin-film arrays (about 4 kilowatts [kW] each) purchased from major amorphous silicon module manufacturers. Research activities in FY 1989 will also include the application of innovative power electronics technology to improve power conditioning of PV systems. The Design Assistance Center (DAC) will continue to assist a wide range of those implementing and using PV applications through its system technology transfer activity.

Systems Evaluation. The development of a comprehensive systems information data base will be continued and used to improve the design, performance, operations and maintenance costs, and reliability of all categories of PV systems, including stand-alone and grid-interactive systems. This data base is formulated to aid industry in developing new-generation systems, evaluating and costing new installations, and identifying design and hardware problems.

PVUSA. Phase I of the PVUSA project involves the construction and testing of five 20-kW systems employing emerging technologies; it will be located at the Pacific Gas and Electric Company test site near Davis, Calif. At least four of the systems will be installed and operating in the first half of FY 1989.

Capital Equipment

Funds will be used to maintain and improve instrumentation and research capabilities in support of in-house PV research at SERI and Sandia National Laboratories (SNL).

Program Participants

Research Area	SERI	SNL
Advanced Thin-Film Materials	•	
High-Efficiency Materials	•	•
Fundamental Materials	•	
Collectors	•	•
Systems		•
Capital Equipment	•	•

Wind Energy

Wind energy systems convert the energy in moving air into electricity using rotating wind turbines. These deceptively simple-looking, but actually quite sophisticated, devices are the subject of the research and development done under the Federal Wind Energy Program, which is aimed at improving their conversion efficiency, cost-effectiveness, reliability, and lifetime. Major research activities are investigating atmospheric fluid dynamics that affect wind flow; developing a better understanding of low-speed aerodynamics and structural design; and improving turbine airfoils, blade materials, and other advanced concepts. This research is conducted in close cooperation with wind turbine manufacturers, wind farm developers, and electric utilities to evaluate new concepts and theories, field test new components, and provide effective transfer of the new technology to industry.

Research Needs

The use of wind power has grown dramatically during the last decade — costs have dropped by a factor of 10 and machine reliability has doubled. Today there are more than 15,000 wind turbines operating on wind farms in California and Hawaii at several exceptionally good wind sites. The combined power rating of these turbines is 1500 megawatts (MW), which is equal to that of a large, conventional power plant, and they produce 1.8 billion kilowatt-hours (kWh) of electricity annually. Had this electricity been produced by oil-fired plants, more than three million barrels of oil each year would have been consumed. Initially, reliability was below expectations, but performance has been improving steadily; many of the newer machines have greater than 95% operational availability.

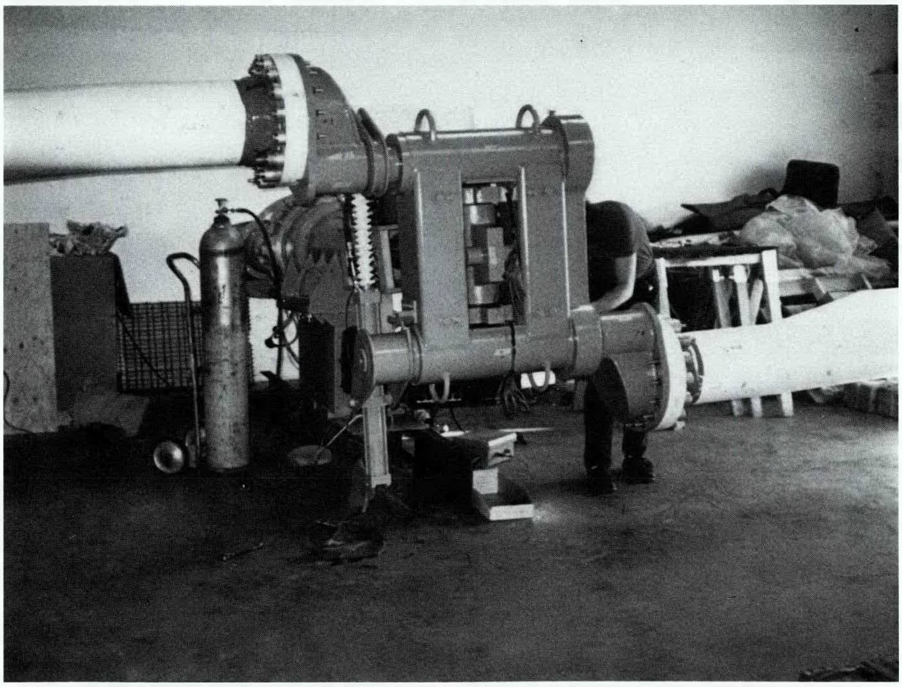
In addition, DOE successfully completed the development, installation, and testing of the MOD-5B, the latest in a series of large, multimegawatt wind turbines. In January 1988, this machine was sold to Hawaiian Electric Industries and put into routine operation, producing power for Hawaii. Since that time, the turbine has generated 5000 megawatt-hours (MWh) during 4500 hours of operation through August 1988.

In spite of these successes, major improvements are needed in wind systems technology in order to make them competitive in broader electric utility markets at typical wind sites (14-mph average) throughout the country. Today's systems produce power at a cost of 8¢ to 15¢ per kWh. To be competitive in broad markets, the cost of electricity must be reduced to 4¢ or less. This can be done through three avenues: better and more efficient airfoils, improved control systems and siting techniques resulting from a better understanding of the complex interaction between atmospheric turbulence and turbine structural response, and improved blade materials and design life-prediction capabilities. These approaches will allow industry to develop turbines that are less complex, at lower manufacturing costs, and that capture more energy from the wind. Future machines are expected to move toward specially designed and more efficient airfoils, variable-speed operation, and lightweight designs with ultrahigh material fatigue life.

Airfoil shapes used on wind turbines today are based on aircraft designs that are normally operated outside the turbulent atmospheric boundary layer and are intended to avoid stall. Because neither mode is true for wind machines, improved energy output can be anticipated from new rotor technology. Wind-tunnel testing has produced promising candidates for improved performance. These high-lift, low-drag, laminar-flow designs, combined with better operational control strategies, could improve annual energy capture by 20%, while extending the blade fatigue life by a factor of two.

Energy production and structural life of wind turbines can be dramatically affected by the complex, turbulent flow in the atmosphere near the ground where they must operate. Three major issues are involved in this research area, called atmospheric fluid dynamics. The first is to develop improved models of the wind encountered by the rotor, including turbulence. The second and third activities are aimed at developing improved models of atmospheric flow across a site; the second activity addresses the effects of complex terrain and the third activity addresses wakes — how the wake of a turbine affects the wind flow reaching a turbine located downwind of the first. Wake and array losses are estimated to account for an average 15% revenue loss in existing wind farms.

The ultimate challenge is to produce a turbine with an assured lifetime of 20 to 30 years for major components. Wind turbines are rotating objects that vibrate, and this complicates the design of structures that can achieve the required 30-year life. Loads or stress on the components of a wind system are caused by both predictable (deterministic) and random (stochastic) forces. The deterministic sources of loads include gravity, centrifugal forces, average wind



Northern Power Systems rotor hub, featuring innovative hinges that relieve fatigue loads, which reduce wind turbine life.

inputs, and startup/shutdown cycles. They are relatively well understood and have been taken into account in the design of more recent machines. Stochastic sources of loads include turbulence and eddies in the wind and the wakes from upwind turbines in a wind farm. These loads and their relationship to turbine design life are poorly characterized. Therefore, the goal of structural dynamics research is to develop better models of structural response and fatigue lifetime so that turbine components can be lighter and less costly, but more important, so that the fatigue life of critical components can be extended by a factor of two to five to achieve the required lifetime.

Testing and evaluating advanced wind turbine components and concepts are difficult and time-consuming processes because the wind is a diffuse, variable, and somewhat unpredictable energy source. Two approaches are taken in solving this problem. First, where possible, new ideas are evaluated in wind tunnels or on DOE-owned research turbines such as the 34-meter-diameter, vertical-axis turbine recently built by Sandia National Laboratories. This kind of testing allows the control of experimental variables and can provide precise results, but it is sometimes costly. A second approach has been used to complement traditional testing: conducting cooperative, cost-shared research using existing or modified turbines in commercial wind farms. This type of research testing produces valuable "real-world" results at a fraction of the normal costs. It also maximizes the transfer of new technology information to industry. These system concept tests range from evaluation of the fuel-saving potential of wind/diesel systems to operational testing of advanced airfoils.

Research Activities

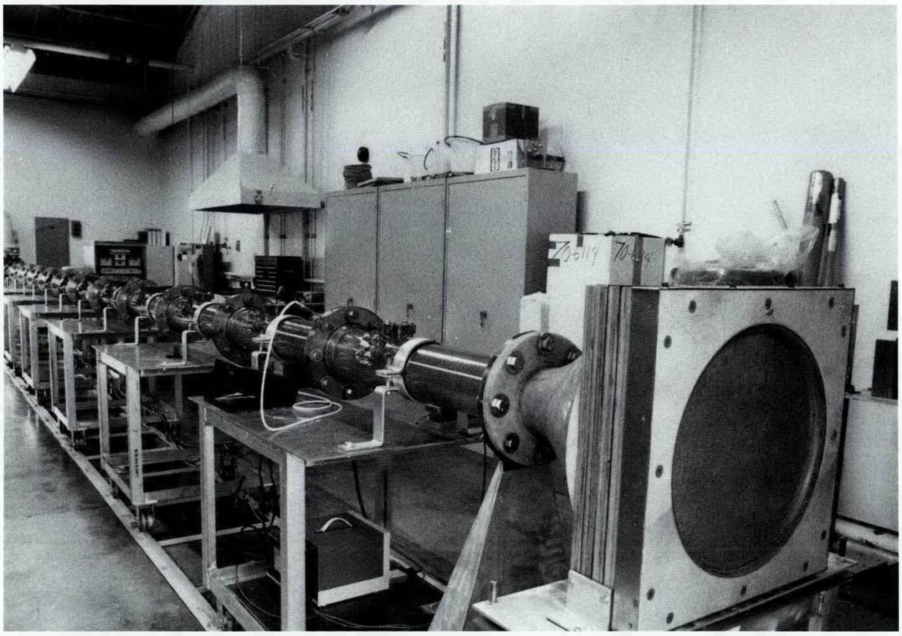
Atmospheric Fluid Dynamics

Turbulence and other variations in the wind inflow are the principal sources of fatigue loads and resulting stresses for a wind turbine of any size. Field evidence suggests that different scales of turbulence affect various turbines differently. In FY 1989, the major parameters describing turbulence at typical sites will be investigated through field measurements using multiple towers or anemometer arrays and other sensing equipment. Recent work has demonstrated that turbulence and eddy inflow are coherent, but they have complicated spatial and temporal structures. The goal of this activity is to establish a predictive capability that machine designers need to define component stress and lifetime.

Recent analyses of wind-farm performance data indicate that array performance losses caused by wakes and inefficient micrositing result in 10% to 30% lost energy. Thus, the area of wakes and performance remains an important element of the program. Planned FY 1989 activities build on previous work done in the cooperative research program, federal research, and international activities to produce a validated micrositing tool to account for wake losses, wake turbulence, the influence of terrain on flow, and climatology.

Aerodynamics

Aerodynamics describes the physical process through which the turbulent wind encounters the airfoil and produces unsteady pressures. These pressures are converted to useful mechanical work, as well as fatigue-inducing damage. Understanding the relevant phenomena is key to improving the performance of, and reducing stress on, wind turbines. The major research



Airflow boundary layer sensor calibration apparatus at Sandia National Laboratories.

effort in this area involves the use of advanced pressure transducers and other sensors under carefully controlled laboratory and field tests. Cross-laboratory efforts will continue, with additional testing of a fully instrumented, 10-meter turbine at SERI and research turbines at SNL.

A major thrust in external research is cooperative research with industry. A high priority is placed on taking advantage of wind-farm data to expedite an improved understanding of key processes and problems. These projects support industry directly through focused attention on high-priority problems and technology transfer and support the research program through the acquisition of research data at a relatively low cost.

Structural Dynamics

The goal of this activity is to predict turbine stresses and fatigue damage with sufficient confidence for a 20- to 30-year service life. The major unknowns in structural models are the uncertainty in the wind input, especially turbulence and shear, and the resulting impacts of unsteady loading on structural integrity and fatigue lifetime. Fatigue damage and the assurance of satisfactory lifetimes remain potential barriers for wind energy. Major structural problems have occurred in all the turbines used in wind farms, including even the heavier European designs, with any significant operating time. The problem is not just limited to blades, which provide the visible manifestation, but also occurs with blade attachments, hubs, yaw bearings, gearboxes, and towers. Fatigue research will receive greater emphasis in FY 1989. Activities include laboratory testing to document the properties of popular blade materials such as fiberglass; field testing to document fatigue damage; and limited, full-scale joint testing with industry in commercial systems. This program draws heavily on the experience of the aircraft industry.

In addition, research tests on several industry turbines will be continued to establish the correlation of wind turbulence with blade pressures and resulting structural stresses in order to identify both the fatigue-damaging loads and significant parameters in the wind flow that result in damage. Research will also be continued from FY 1988 on a single, more heavily instrumented turbine in the combined experiment.

Advanced Components

Efforts on proof-of-concept technology development in airfoils and variable-speed wind turbine systems will be continued. Payoffs are already seen in first-generation airfoils for horizontal- and vertical-axis systems that demonstrate improved energy capture; a reduced susceptibility to bug and dirt fouling; easier fabrication; and, possibly, reduced loads. It is anticipated that thousands of 10- to 15-meter, foreign-made turbines, whose initial fiberglass blades have delaminated, could be retrofitted with improved airfoils by U.S. manufacturers. Other benefits being pursued include improved post-stall characteristics. Tests of two families of fixed-pitch, horizontal-axis airfoils and one family of variable-chord, vertical-axis airfoils will be initiated or continued in FY 1989.

The second major thrust in this activity is a variable-rotor-speed wind turbine system. The objective of the DOE effort is to evaluate the benefits and costs of this advanced concept in order to permit industry to determine its applicability. The variable-speed technology promises to improve energy production, potentially reduce structural loads, and tailor the turbine to the characteristics at a site. FY 1989 activities will support industry in systems and scale-up studies to commercial-size systems.

Supporting Research

The supporting research includes activities that relate to the attainment of goals in the multiyear plan but do not appear explicitly in another category. Planned activities in FY 1989 would continue the characterization of wind/hybrid power systems and array power quality studies.

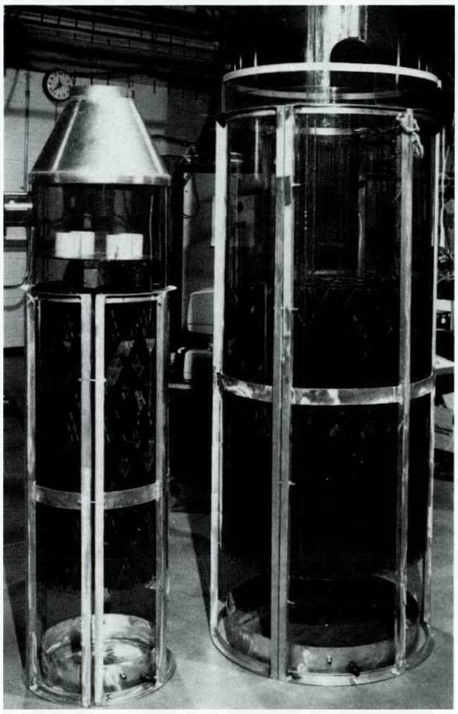
Program Participants

Research Area	SERI	SNL	PNL
Atmospheric Fluids Dynamics	•		•
Aerodynamics	•	•	
Structural Dynamics	•	•	
Advanced Components	•	•	
Supporting Research	•		

Ocean Energy

DOE's Ocean Energy Technology Program is seeking cost-effective ways to harness ocean energy. Federally sponsored researchers are studying methods that can transform the solar heat stored in the ocean's water into electricity through a process called Ocean Thermal Energy Conversion (OTEC). Thermodynamic research and analysis will provide a better understanding of the underlying physical effects that constitute the OTEC process. Researchers also perform experimental verification and testing in seawater, which will confirm the analytical projections and empirical relationships of thermodynamics established in fresh water studies. To a lesser extent, OTEC investigators carry out materials and structural research, which will lead to a better understanding of the various materials used in the ocean environment.

Research Needs

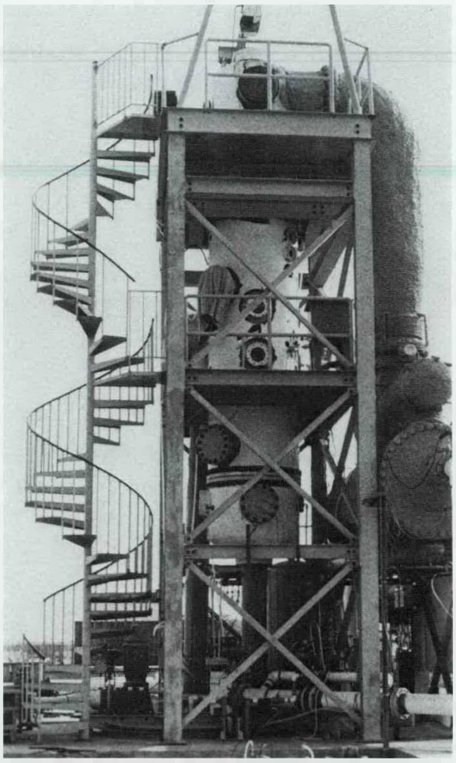


Direct-contact condenser side-by-side configuration in the Heat and Mass Transfer Scoping Test Apparatus.

Within the past 10 years the Ocean Energy Technology Program has improved the performance of OTEC heat exchangers by a factor of three, reduced the projected overall system cost by more than 30%, and established a working method of biofouling control. Researchers have determined that relatively inexpensive aluminum alloys can be used in place of more expensive titanium for making closed-cycle OTEC heat exchangers. The cost for this component dropped from an estimated $2500 per kilowatt-electric (kW_e) to about $1200 per kW_e.

Experimental data have shown that biofouling does not appear to be a problem in cold seawater and can be controlled by intermittent chlorination in warm seawater systems. A 20% reduction of the fouling coefficient, a measure of the overall heat exchanger performance, has improved the performance by about 12%. A further 20%-40% reduction of this coefficient has been shown in experiments to be achievable. Cost goals of $600 to $900 per kW_e for OTEC heat exchangers and achievement of a low fouling coefficient appear to be within reach with about two years of additional effort.

The major high-risk element of OTEC systems is the development and cost-effective acquisition of the cold water resource. Studies and physical models that use a conduit or pipe from the surface to the deep cold water have shown that this technique is feasible. Small pipes (12-inch and 15-inch diameter) were deployed at the Seacoast Test Facility (STF) in Hawaii in past years. An alternative technique, drilling-tunneling, may offer a cost-effective method for acquisition of the cold water for diameters of 10 feet or larger under some favorable geological conditions. A highly significant accomplishment in 1988 was the completion of acceptance testing for the upgraded seawater supply system at the STF. The newly deployed 40-inch-diameter cold water pipe, which extends to a depth of 2100 feet and is capable of transporting 13,300 gallons per minute (gpm) of cold seawater, is now



DOE's Heat and Mass Transfer Scoping Test Apparatus at the Pacific International Center for High Technology Research.

operational. The project, cost-shared by DOE, the State of Hawaii, and the Pacific International Center for High Technology Research (PICHTR), is considered a major technological breakthrough because fabrication, deployment, and operation were conducted without accident in a difficult ocean environment.

Because there is a limited quantity of experimental data, a strong emphasis is placed on the development of design and predictive methodologies for OTEC heat and mass transfer processes with seawater. Comparable heat and mass transfer data from private sector or other research do not exist. Researchers are examining technologies to improve the effectiveness of OTEC systems. In turn, this can lead to design criteria based on validated models and test data for future near-shore or land-based OTEC systems in the 5- to 15-megawatt-electric (MW_e) size range. The objective is to provide data that can be extrapolated, which will permit industry to design small but high-power-output plants that use fewer materials and lower water volumes for cost-effectiveness.

The program focuses on open-cycle OTEC. Open-cycle OTEC offers the projected advantages of the complete or partial elimination of conventionally constructed heat exchangers (i.e., elimination of high-cost material-intensive construction). Simple containers with inexpensive spouts for the evaporator and similarly inexpensive packings for the condenser are used in the cycle's open design.

Open-cycle processes of heat and mass transfer, extremely low pressure turbines for energy conversion, and compression and purge of noncondensable gases all contribute to system efficiency. Modifications to the Heat and Mass Transfer Scoping Test Apparatus (HMTSTA) at the STF have begun to allow for the testing of a direct-contact condenser that condenses the steam by mixing it directly with seawater. Analyses completed to date support the hypothesis that power conversion systems based on the open cycle can be cost effective. This effectiveness could be further enhanced in applications where potable water and electric power are both useful products.

Research Activities

Thermodynamic Research and Analysis

Using component and system performance models, this activity will analyze open-cycle OTEC experiments and evaluate designs and scaling requirements for proposed open-cycle component and system-level tests.

A performance specification and a conceptual design of a turbine test article to be used in the open-cycle system experiment (165 kW_e gross output) will be developed. System performance models to generate apparatus designs for heat and mass transfer test hardware and plans for experiments relevant to the system-level open-cycle experiment will be implemented. A conceptual design of an experimental open-cycle turbine converter and test component will be developed. Models that predict performance of open-cycle evaporators, direct contact condensers, and sorption processes will be developed and validated, in addition to analytical models of surface condensers appropriate for open-cycle applications.

Component and system performance models for analyzing hybrid systems will be implemented, and performance and cost projections for the concept will be evaluated, leading to the preparation of a conceptual design.

Materials and Structural Research

This activity will develop engineering correlations of open-cycle turbine and heat exchanger materials by organizing data on fouling, corrosion, and erosion.

Experimental Verification and Testing

This activity is the experimental complement to the related research tasks in the thermodynamic research and analysis activity. The main objective is to perform seawater experiments on sorption processes on key open-cycle components including direct-contact and surface condensers, the flash evaporator, and the mist eliminator. System level tests will be performed on the open-cycle OTEC power system to investigate interrelated heat and mass transfer processes and determine performance characteristics.

Design activities will be accelerated on the 165-kW_e turbine and the heat and mass transfer experimental apparatus subsystems.

Program Participants

Research Area	SERI	ANL
Thermodynamic Research & Analysis	•	•
Materials and Structural Research		•
Experimental Verification & Testing	•	•

Biofuels and Municipal Waste

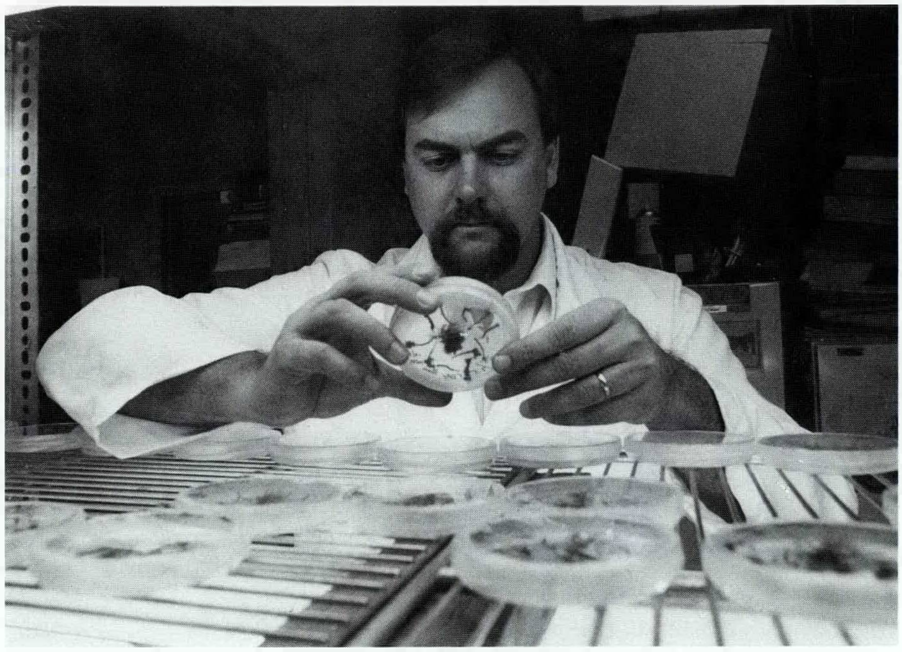
Biofuels are versatile, reliable, and renewable contributors to the U.S. energy supply, currently providing about 3 quads of energy annually, mostly in the form of heat and electricity. Biofuels also have the potential to supply significant quantities of the liquid and gaseous fuels that are high-priority energy products for this nation. Liquid and gaseous biofuels (such as ethanol from grains and low-Btu gas) are already being produced, but at only a small fraction of their potential. DOE's Biofuels and Municipal Waste Technology Division is conducting research aimed at unlocking that potential to produce safe, secure, and renewable fuels that can compete in conventional energy markets.

Biofuels technologies now being investigated combine a feedstock (either conventional wood, innovative energy crops, or agricultural, forestry, and municipal wastes) with a thermochemical or biochemical conversion process to produce liquid and gaseous fuels. Researchers are applying biotechnology and genetic engineering techniques to improve the growth, productivity, and energy characteristics of feedstocks. Advances in thermochemical (i.e., gasification and pyrolysis) and biochemical (i.e., fermentation and anaerobic digestion) conversion technologies will allow improved conversion of these feedstocks to liquid and gaseous fuels. This research is conducted in close cooperation with the emerging biofuels industry in order to exchange ideas and advances, extend scarce funds, and provide effective technology transfer.

Research Needs

Biofuels are the only renewable energy sources capable of directly producing high-value liquid and gaseous fuels. Consequently, research is focusing on these premium fuels by selecting a series of fuel cycles that match a biomass feedstock with a conversion technology to produce a specific fuel. The key is to link specific feedstocks with the most appropriate conversion technology to produce a specific high-value fuel at the lowest possible cost. For example, one fuel cycle links genetically improved wood energy crops with thermochemical pyrolysis conversion to produce gasoline.

The terrestrial feedstock element of the program emphasizes short-rotation woody crops grown specifically for energy. Researchers selected hardwoods for further research because they have the potential for higher productivity and lower costs, arising in part from their ability to coppice (regrow from a previously cut stump). In the last decade, more than 30 species have been examined and narrowed to 5 model species, which are adaptable to current forest land and unused or unproductive crop land. The average productivity



Mass clonal propagation permits the screening of trees by the thousands in a short time.

per acre has been increased 300%, from less than 2 dry tons per acre per year (dt/a./yr) to 6 dt/a./yr, while costs were reduced from $5.00 per million Btu (MBtu) to $3.00. Costs need to be further reduced to $2.00 per MBtu by 1996 through productivity improvements (to 10 to 12 dt/a./yr) and reduced fertilization and irrigation costs. In addition, multiacre, single-species growth tests are essential to understand management, disease control, and repetitive harvesting needs for large-scale plantings.

The terrestrial feedstock program also includes herbaceous energy crops such as grasses and oilseeds. Since its inception in 1984, this effort has concentrated on evaluating and selecting promising species for further development. Of 300 species screened, 25 are the most promising, with sweet sorghum identified as the best annual species and switch grass as the best perennial. For herbaceous energy crops, costs must be decreased to $2.00 per MBtu and productivity increased by the turn of the century.

For all terrestrial crops, the challenge is not simply to grow more feedstock, but rather to grow feedstock with specific characteristics that make the conversion process more efficient. The need is for terrestrial energy crops with chemical and physical characteristics suitable for either biochemical or thermochemical conversion. All plants are composed primarily of cellulose, hemicellulose, and lignin. Biochemical processes make more efficient use of cellulose and hemicellulose; thermochemical processes make better use of lignin. Researchers are adapting the emerging science of biotechnology and genetic engineering to alter feedstocks to fit better the conversion technology being used.

The aquatic energy crop program is focusing on microalgae for production of plant oils (lipids) for diesel fuel. A prerequisite for developing the technology for microalgal oil production is the identification of the strain or strains that can form the basis for outdoor, mass-culture systems. In 1982, extensive efforts began to collect and screen microalgae strains that are highly productive and can produce large amounts of lipids under fluctuating outdoor

A researcher "loads" a gel to separate DNA fragments of a tree using electrophoresis, one of the first steps in DNA cloning.

environmental conditions. Early strains exhibited productivity of 15 grams per square meter per day ($g/m^2/d$) and 20% lipids. By 1987, strains had been isolated that produced 25 $g/m^2/d$ or fixed 40% of their body weight as lipid.

Performance goals of 50 $g/m^2/d$ with 60% lipid content in a single organism grown in outdoor facilities are essential. Meeting such goals will reduce diesel fuel costs to $1.00 per gallon by the year 2010. The 3000 strains initially collected have been narrowed to the top 25 performers. These superior strains will provide the gene pool for the genetic improvements that are required to reach performance goals.

Biochemical conversion uses living organisms (bacteria and fungi) to convert biomass feedstocks to liquids (fermentation to alcohol) and gases (anaerobic digestion to methane). Today, ethanol is produced commercially from starch and sugar, both of which are expensive feedstocks with competing uses as food. The DOE program researches systems that convert cellulose and hemicellulose, the two principal components of wood and grass, to sugars that are then fermented to ethanol by current technology.

Research is focused on enzymatic hydrolysis: fungi have been identified that produce enzymes that selectively convert cellulose to sugar. The key research need is to use biotechnology and genetic engineering to develop improved organisms for better conversion of cellulose and hemicellulose, thus reducing costs.

Progress in this area is already promising. For example, only a few years ago, experimental enzymatic systems converted 60%-70% of cellulose to ethanol, with ethanol concentrations of 2%. Today, yields are approaching 90%, with ethanol concentrations of 4%. Only ten years ago, there were no organisms that could effectively convert hemicellulose to ethanol. Today, genetically altered organisms that convert hemicellulose offer the potential for reducing the cost of ethanol by 40%.

Additional improvements in the enzyme/yeast system for converting hemicellulose to ethanol are needed before the bench-scale system can be tested in a larger unit. Improvements are needed in enzyme productivity and reactor design before the cost of ethanol from cellulose, which has decreased from $4.00 per gallon in 1980 to $1.60 today, can reach its program goal of $0.80 per gallon by the turn of the century.

Before the energy crisis of the early 1970s, anaerobic digestion was used to stabilize sewage, with its energy uses largely unexplored. Today, it is a viable option for producing methane, the principal component of natural gas.

Anaerobic digestion technology consists of preparing the feedstock and its conversion to methane using a complex group of bacteria in a closed tank. Research needs include increasing the production of methane per unit of tank volume with improved stability and control. Perhaps more important is the requirement to understand the complex association of microorganisms involved in anaerobic digestion. Scientists are just beginning to identify bacteria and their life cycles so that biotechnology can be applied to improve them. The estimated cost of methane produced via anaerobic digestion has already decreased from $8.00 per MBtu in 1980 to $5.00 per MBtu today. Improvements in reactor efficiency and stability should further reduce costs to approximately $3.50 per MBtu by 1996.

Thermochemical conversion technologies use heat to break down the complex molecules of biomass feedstocks into more simple liquids and gases. Pyrolysis involves rapidly heating the feedstock in the absence of oxygen to obtain liquid fuel. As recently as the early 1970s, the technology for effectively producing liquid fuels from biomass did not exist. Today, scientists have experimentally produced a biocrude oil that can be upgraded to gasoline with an octane rating of 76. Research needs fall into two general areas: increasing the yields of biocrude oil, and improving the upgrading of the biocrude to gasoline. With present technology, conversion yields of biomass to gasoline hydrocarbons are 47 gallons per dry ton (gal/dt) of biomass. With continued research, yields of 98 gal/dt of biomass are possible. Research advances should decrease the cost of biocrude oil from an estimated $3.00 per gallon of aromatic gasoline with today's technology, to only $1.00 per gallon soon after the turn of the century.

In the 1970s, thermochemical gasification of biomass involved the production of low-Btu gas, which contained 10% of the energy content of natural gas. Today, we are concluding research on medium-Btu gas, which contains 50% of the energy content of natural gas. Continued research may one day result in a biomass-derived gas that has the energy equivalent of natural gas.

The DOE program is focusing on a cost-shared scale-up facility from which industry may provide medium-Btu gasifiers commercially. To support this effort, research is needed to remove from medium-Btu gas the impurities (tars and particulates) that can interfere with many of its uses. In addition, improved treatment of effluent streams from gasifiers is needed to minimize the environmental impacts of the technology. Finally, a determination needs to be made as to the feasibility of catalytically gasifying high-moisture feedstocks to produce high-Btu gas. With advances in research, costs for medium-Btu gas should be reduced from the current $8.00 per MBtu to $3.00 per MBtu within the next five years.

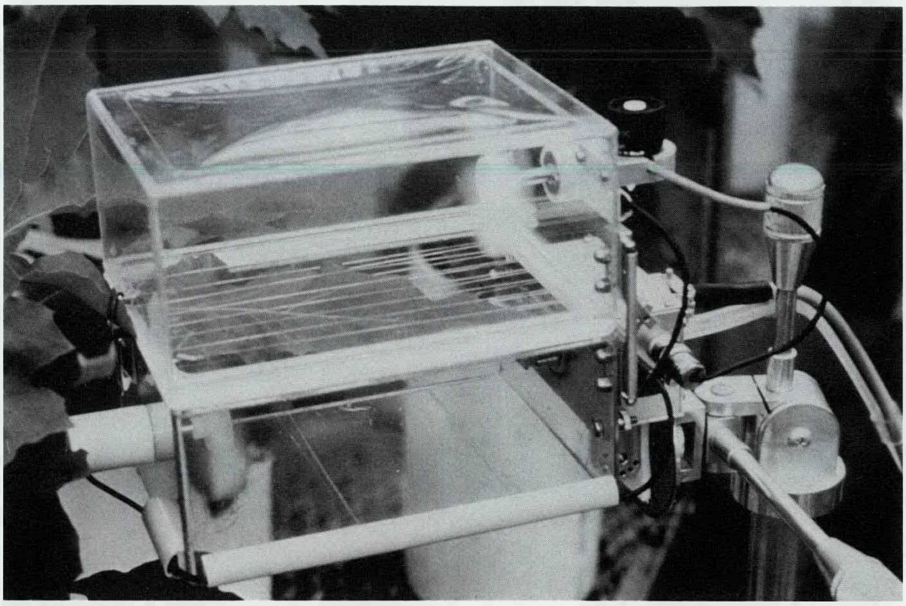
Hydrogen can be used as a renewable fuel as well as a medium for storage and transmission of energy. This concept was first seriously proposed as early as 1970, and interest intensified during the oil crisis of 1973. It is technically feasible to produce hydrogen from renewable resources, but the product is too expensive to compete in current fuel markets.

Hydrogen production processes being evaluated by DOE-sponsored research are steam gasification of biomass, carbon dioxide gasification of biomass, and photochemical water splitting. A critical technoeconomic assessment of hydrogen production technologies is being made to recommend research direction. For the near- to mid-term, high priority is given to methanol and hydrogen from biomass. Photoconversion processes that use photon energy to produce hydrogen, either by driving a chemical reaction or by splitting water, are a longer-term priority.

Research Activities

Terrestrial Energy Crops

Short Rotation Woody Crops. The focus of this research continues to be on the lead model species, *Populus*. In order to test the viability of large-scale plantings, *Populus* monoculture (single species cultivation) studies will continue on plots of 20-80 acres. Research is also aimed at using the emerging sciences of biotechnology and genetic engineering to improve the energy characteristics of short rotation species, as well as their tolerance of drought, disease, and pests. Lab and field tests on nitrogen-fixing species and in nutrient utilization will continue. By decreasing or eliminating the need for



Plant respiration studies at ORNL.

expensive fertilizer, this research offers the possibility of reducing overall production costs by approximately 3%.

Herbaceous Energy Crops. This element of the terrestrial crops program will focus on modifying selected herbaceous feedstocks by biotechnology techniques to increase productivity, stress and disease resistance, and energy traits for specific biofuels cycles. With the recent initiation of herbaceous screening trials in the Great Plains, more than 90% of U.S. cropland is now being screened for herbaceous energy crops. Research to define agronomic, energy, and nutrient requirements for the best of these crops will continue. Field research on winter rapeseed as a double crop in the Southeast will be concluded. Estimates are that winter rapeseed can provide as much as double the total on-farm diesel fuel required in the Southeast.

Aquatic Energy Crops

Research in this area will continue to focus on experiments to evaluate the performance of selected microalgae species in the outdoor test facility in New Mexico. This research will help to identify those microalgae strains with superior productivity rates and lipid content, as well as to address engineering issues associated with outdoor mass culture. In addition, physiological and lipid characterization studies will result in the selection of 6-10 strains for genetic improvement. Classical and advanced genetic techniques will be initiated on these selected strains to improve lipid production and fuel quality. Research will also continue on methods to improve processing and conversion of lipid oils to diesel fuel.

Biochemical Conversion

Ethanol. The focus of this research is on enzymatic hydrolysis, a process that uses enzymes to break down cellulose to sugars for fermentation to ethanol. Enzymatic hydrolysis will emphasize the simultaneous saccharification and fermentation (SSF) process. Research will also continue to improve pretreatment and develop longer lasting, stable enzymes, which has resulted in a cost reduction from $1.80 per gallon in 1986 to $1.60 per gallon today, an 11% improvement. The simultaneous isomerization and fermentation of xylose (SFIX) process will be investigated as a means of utilizing the xylose fraction of biomass. Xylose conversion rates should exceed 70% and fermentation time should be reduced to less than 48 hours. Lignin research will be limited to organosolv preparation and characterization for catalytic conversion to methyl aryl ethers, which can be used as octane boosters in gasoline.

Anaerobic Digestion. The program continues to focus on gaining a fundamental understanding of the basic biochemistry and physiology of anaerobic organisms. Researchers are developing monoclonal antibody probes to track specific organisms within an anaerobic digester. Once understood, these anaerobic organisms can be genetically improved to increase conversion efficiency. Research will also continue to improve reaction rates, increase yields, and establish anaerobic digestion reactor stability and control. With research advances, solids residence time may be decreased to under 20 days, and solids concentration may be increased from 10% to 20%.

Thermochemical Conversion

Pyrolysis. Experiments on zeolite catalysts, narrowed from 20 to the 3 most promising, will continue. These catalysts offer the potential for the simple, low-cost conversion of pyrolysis products to liquid transportation fuel. In the low-pressure pyrolysis process, the program seeks to improve overall efficiency and decrease the environmental impact of the technology by reducing coking from 8% to 4%. Research on the hydrotreating of heavy-end biocrude oils will continue. A key goal is to reduce the amount of expensive hydrogen needed to upgrade a barrel of biocrude oil from current requirements of 3200 cubic feet to 2200 cubic feet. In addition, efforts will continue to update and refine the model of chemical degradation of municipal solid waste under pyrolysis conditions.

Gasification/Methanol Synthesis. During FY 1989, plans are to award a contract for an industry cost-shared, experimental gasifier. Research will continue on steady-state experiments to produce a high-Btu gas from high-moisture feedstocks. Development of selected catalysts for gas cleanup will continue. Experiments indicate that catalytic processes can eliminate 99% of the tars produced in biomass gasification. Gas cleanup remains an important research issue for both syngas production and methanol synthesis. Methanol production has the added problem of requiring synthesis with an optimum hydrogen-to-carbon monoxide ratio of 2:1. Production of synthesis gas (which is predominately hydrogen) is a major element of the hydrogen research effort.

Municipal Solid Waste. Embrittling agents will be selected and tests initiated to produce powdered refuse-derived fuels (pRDF), which can directly replace as much as 10% of the petroleum used in existing boilers. In addition, analysis of densified refuse-derived fuels (dRDF) will be completed. To ensure that municipal waste technology is environmentally benign, experimental research on trace chlorinated emissions will continue.

Hydrogen

Research emphasis has been placed on developing high-efficiency, low-cost water-splitting processes via electrolysis at intermediate to high temperatures (200°-1000°C) and stable photochemical processes to produce hydrogen. Other research explores photobiological and photoelectrochemical techniques for the production of hydrogen and evaluates hydrogen power applications in integrated production, storage, and distribution systems.

Regional Biomass Energy Program

Congress has directed this program to "carry out activities related to technology transfer, industry support, resource assessment, and matching local resources to conversion technologies." Efforts will continue to advance the production of biomass energy feedstocks and their conversion to fuels and energy by the private sector, and the use of municipal waste for energy, by supporting regionally specific projects. Industry cost-sharing continues to grow, with one region leveraging $220,000 of federal funding with $740,000 of industry support. Such close government/industry cooperation is expected to continue during FY 1989.

Program Participants

Research Area	SERI	ORNL	BNL
Terrestrial Energy Crops		•	
Aquatic Energy Crops	•		
Biochemical Conversion	•		
Thermochemical Conversion	•		
Hydrogen	•		•

Geothermal Energy

Geothermal energy is the heat contained within the earth. Geothermal resources occur as four distinct types: hydrothermal (including steam and hot brine reservoirs), geopressured (brine under high pressure containing dissolved natural gas), hot dry rock, and magma (molten rock). Hydrothermal is the only resource currently in commercial production. Low- to moderate-temperature hydrothermal brines (50°-150°C) are used directly for space heating, greenhouses, and industrial processes. Hydrothermal steam is converted to about 1900 megawatts (MW) of electric power in California, and high-temperature (greater than 150°C) brines provide another 500 MW in western states. The other resources could be used in similar fashion, and geopressured brines could produce natural gas as well.

Geothermal energy is virtually inexhaustible, has few environmental effects, and at many sites is competitive in cost. However, the state of the technology precludes wider exploitation under current market conditions. The Geothermal Energy Research Program improves technologies for recovering more energy from hydrothermal resources in the near term, and it develops technologies to make geopressured, hot dry rock, and magma resources economic over the long term. The geothermal industry participates with DOE in establishing objectives and priorities and shares many R&D costs.

Research Needs

Hydrothermal

The principal technical barriers to the use of hydrothermal resources include the difficulty of locating reservoirs and confirming their potential; the high cost of drilling wells into hard, hot rocks; the inefficiency of systems that convert moderate-temperature heat to electric power; the chemical reactivity of brines; and the uncertainty of injecting spent fluids into the ground. The costs of surmounting these barriers discourage private investment in many hydrothermal sites that otherwise have a high potential for power generation.

Consequently, DOE's R&D strategy is to lower these barriers to a point where a much larger resource will be economically accessible. The overall objective of the program is to reduce the cost of electric power from liquid-dominated, moderate-temperature hydrothermal resources to 3¢-10¢ per kilowatt-hour (kWh) by 1992. This compares with a cost range of 4¢-18¢ per kWh for hydrothermal electric power as of 1986.

Geopressured-Geothermal

Geopressured brines can be produced by oil and gas technology adapted for that purpose. The dissolved methane is easily extracted from the brine, and the heat in the brine can be used directly or converted to electric power. But the production dynamics of geopressured reservoirs are quite different from those of hydrothermal reservoirs or oil and gas reservoirs. Major uncertainties about the resource include the sustainability of production, the methane content of the brine, and reservoir lifetime.

The strategy of geopressured-geothermal research is to determine the character of the reservoirs by long-term well-production tests, along with supporting geoscience research, and to assess the technology for converting thermal energy in the brine and gas to electric power at the wellhead. The objective is to improve the technology for producing energy from the geopressured-geothermal resource to a cost equivalent to 6¢-10¢ per kWh by 1995.

Hot Dry Rock

Experiments at Fenton Hill, N. Mex., have established the technical feasibility of extracting thermal energy from low-permeability rock formations with man-made reservoirs. But long-term flow testing of a large-scale reservoir is needed to confirm commercial feasibility. A larger reservoir has been created at Fenton Hill for the purpose of a long-term test. This test will prove the technology's ability to sustain large-volume flow, minimize fluid losses, and control thermal drawdown.

DOE's strategy is to conduct the test along with scientific research related to the test program. The objective of hot dry rock R&D is to provide the technology to enable industrial hot dry rock projects to generate power at the equivalent of 5¢-8¢ per kWh by 1997.

Magma

A shallow lava lake in Hawaii was the site of experiments that proved the concept of extracting thermal energy from molten rock, or magma. But the engineering feasibility of locating, accessing, and utilizing magma as a viable energy resource has yet to be shown. A technology for recovering energy from magma must include geoscience techniques to identify potential targets, better materials to operate under the high temperatures (up to 1200°C), and innovative methods for extracting the heat.

The strategy of the magma research category is to drill an exploratory well close to, but not intersecting, a prospective magma body and conduct corroboratory scientific investigations. The R&D objective is the creation of a technology by which energy could be produced experimentally from magma at an equivalent cost of 10¢-20¢ per kWh by the year 2000.

Research Activities

Hydrothermal — Reservoir Technology

Insufficient knowledge of the size, energy content, and productivity of hydrothermal reservoirs impedes their exploitation. Research in reservoir technology minimizes the risks associated with finding, developing, and producing hydrothermal resources.

Reservoir Analysis. R&D projects concentrate on areas that have a direct impact on the assessment of hydrothermal reservoirs and the measurement of their properties. Specific activities in FY 1989 include a reservoir modeling study using fracture flow to determine heat recovery and a critical analysis of well-testing methods.

Brine Injection. FY 1989 research will yield better tools for predicting the effects of injection on producing reservoirs and improved techniques for extracting heat. Research activities include field tests of chemical tracers, thermodynamic analyses of injected fluids, and studies of thermal breakthrough in fractured reservoirs.

Exploration Technology. Existing exploration techniques often fail in regions of recent volcanism, leaving potentially large resources undiscovered. FY 1989 R&D projects will improve analytical tools for finding hydrothermal reservoirs. Activities include the integration of surface and subsurface geophysical data to reveal hidden reservoirs.

Geothermal Technology Organization. To advance the technology in areas of common interest, several geothermal companies were assisted in forming a nonprofit association, the Geothermal Technology Organization (GTO). Members identify geothermal research needs in all areas except drilling — two or more members may cosponsor a research project based on these needs, with as much as 50% cofunding from DOE. A new, DOE cofunded GTO project at The Geysers geothermal field in California will examine microseismicity associated with fluid injection.

Hydrothermal — Hard Rock Penetration

Wells to produce and dispose of geothermal fluids account for some 30% to 50% of geothermal power plant costs. Hard rock penetration research seeks to reduce the costs of drilling holes in the hard, hot rocks and chemically reactive brines of hydrothermal reservoirs.

Lost Circulation Control. Circulating fluids are used to cool and lubricate the drill bit and to carry rock cuttings out of the hole. When a drill bit encounters voids or fractures in the rock, these expensive fluids are often lost into those spaces. In FY 1989, researchers will measure lost circulation zones in geothermal wells, test materials in the laboratory that can plug these zones, and develop systems for placing the materials.

Instrumentation under development for improved detection of deep-lying geothermal fluids.

Rock Penetration Mechanics. Oil and gas drilling technology often proves inadequate in high-temperature geothermal environments; new or improved technology must be developed. In FY 1989, researchers will field test a new, insulated drill pipe that resists heat flow through its walls. They will also bench test a new concept for transmitting data from bottom-hole instruments to the surface while drilling and evaluate advanced drilling concepts for hot, hard rock.

Instrumentation. Without reliable downhole data, geothermal wells may not be properly drilled or completed, and brine production may not be managed effectively. In FY 1989, engineers will develop modular, self-contained systems for collecting reservoir data in geothermal environments and upgrade tools for detecting fractures in the rock away from a borehole.

Geothermal Drilling Organization. Hydrothermal reservoirs confront drillers with a myriad of technical challenges. In response, geothermal companies and other industrial concerns were assisted in forming the Geothermal Drilling Organization. The members of this association identify their research priorities, and two or more may sponsor research projects funded jointly with DOE. In FY 1989, there are four such projects, largely involving heat-resistant hardware.

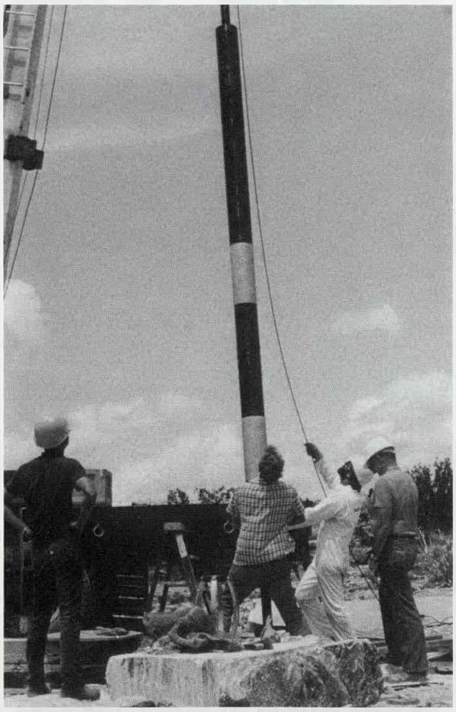
Hydrothermal — Energy Conversion Technology

The elevated temperatures and the scaling and corrosion potential of geothermal brines create problems for energy conversion and waste-disposal systems. The R&D effort in conversion technology attempts to overcome these problems with materials, equipment, and techniques leading to improved efficiencies in brine handling and utilization.

Materials Research. The chemical properties of brines take a toll on geothermal system performance. Corrosion can eat through or seriously weaken plant components, resulting in expensive repairs; the plugging of piping and tubing by scale can ruin equipment or cause a plant to be shut down. FY 1989 research includes field testing of polymer, concrete-lined, heat-exchanger tubing that resists fouling and corrosion; analysis of lightweight, heat-resistant cement samples that have been exposed to downhole conditions in industry wells; and development of high-temperature elastomeric components for downhole drilling motors.

Advanced Brine Chemistry. Understanding the complex chemistry of mineral-laden hydrothermal fluids is critical to achieving control over corrosion and scale. The FY 1989 research program contains an effort to improve a thermodynamic model of the brines that will serve to warn geothermal plant operators of the scaling potential. Other researchers are studying biochemical processes for detoxifying geothermal waste sludges to reduce disposal costs.

Heat Cycle Research. Although the moderate temperatures of many hydrothermal reservoirs severely limit the efficiency of energy conversion systems, most plants do not approach even these limits. Energy conversion research in FY 1989 includes field experiments to confirm heat-exchanger design criteria and to examine the feasibility of modifying operating practices at binary power plants to increase power output.



Prototype radar fracture mapping tool being lowered into hole at Belen, N. Mex., test site.

Geopressured-Geothermal Research

During FY 1989, flow testing of the Pleasant Bayou well in Texas will yield data on the response of a reservoir to production conditions. Construction and operation of a hybrid, 1.2-megawatt-electric (MW_e) power system, in cooperation with industry, will confirm the feasibility of generating electricity from heat and methane produced by the well. The Gladys McCall well in Louisiana will remain shut-in to monitor long-term pressure recovery of the reservoir. Work at the Hulin well site, also in Louisiana, will involve re-entry of this deep (more than 20,000 feet) well donated by industry. After assessing the well's condition, DOE will conduct short flow tests; if these indicate the presence of a large, geopressured reservoir, preparation will be made for a more extensive test to characterize the resource. Supporting research, primarily at universities, will include rock mechanics, reservoir analysis, geophysical data analysis, geochemical measurement and analysis, and environmental monitoring.

Hot Dry Rock Research

FY 1989 will be a year of preparation for the Long-Term Flow Test (LTFT) of the manmade reservoir at Fenton Hill, N. Mex. Engineers will complete the design of the surface facilities, order components and equipment, and begin installation work. Preliminary tests to establish the reservoir's operating characteristics, such as initial flow resistance, will be performed. The research program will include only activities that directly support the LTFT, such as absorption tests for chemically reactive tracers, laboratory studies of fracture healing, and re-analysis (with automation) of previously collected seismic data.

Magma Research

Researchers will drill the first phase of a deep exploratory well at Long Valley, Calif., to confirm geophysical data that indicate the presence of a magma chamber beneath the site. The drilling will begin a staged drilling/ scientific measurements plan that will span about four years. The first phase will take the well to a depth of 2500 feet. Supporting laboratory research on energy extraction from magma and on materials compatible with molten magma will continue in anticipation of an eventual energy-extraction experiment.

Program Participants

Research Area	BNL	INEL	LBL	LANL	SNL
Hydrothermal Research					
Reservoir Technology		•	•		
Hard Rock Penetration	•				•
Conversion Technology	•	•			•
Geopressured Research		•			
Hot Dry Rock Research				•	
Magma Research			•		•

Electric Energy Systems

The Electric Energy Systems (EES) Program supports research and development to improve the efficiency, reliability, and cost-effectiveness of the increasingly complex U.S. electric network. EES supports projects aimed at establishing the technical feasibility of new materials, processes, and concepts by which future electric networks can be more efficient, provide adequate energy supply during emergencies, integrate renewable and other dispersed generation technologies effectively, and resolve public concerns over the safety of electric transmission.

Projects sponsored by EES will help to ensure that a continuous and reliable electricity supply is available to consumers in the safest and most cost-effective manner possible while meeting national policy goals of energy efficiency, environmental quality, national security, and human health and safety. EES-supported projects will also help to reduce fossil-fuel use and its associated environmental emissions, which are thought to promote acid rain and the greenhouse effect.

Research Needs

The EES program currently includes research activities in electric field effects, reliability, systems, and materials.

The Electric Field Effects Program conducts unbiased research to determine if biological effects result from human or animal exposure to electromagnetic fields associated with high-voltage electric lines. Epidemiological studies performed outside the program have shown the possible relationship between electromagnetic fields and increased risks of human health hazard. Although biological health effects such as a slight heartbeat reduction in humans and circadian phase shifts in mice have been observed, no proven health hazards such as abnormal cell growth have been observed within the program. The aim of the program is to identify health effects on humans, explore physiological causes, and finally understand the mechanisms of interaction on the cellular level. Ultimately this will result in a clear determination of human health risks caused by exposure to electromagnetic fields.

The technical goal of the Reliability Research and Development Program is to develop technologies and concepts to enhance the reliability and efficiency of the electric network and to maintain essential service during emergencies. Two program areas have been implemented to achieve this goal.

First, the impact that an electromagnetic pulse (EMP) would have on a power system will be characterized and evaluated. Based on the results, mitigation strategies will be provided. Prior-year efforts resulted in the development of computer models to predict the behavior of an EMP transient on the civilian electric network.

A polished cross section of a yttrium barium copper oxide superconductor undergoing grain boundary analysis.

Second, the Power System Concepts (PSC) effort aims to develop system controls, computer models, communication protocols, and automation concepts to maintain the high level of system reliability. Maintaining the higher reliability of the electric network in light of increasing network complexity, increasing distributed generation sources, increasing load stability problems, and likely capacity constraints is vital to the U.S. economy.

The Athens Automation and Control Experiment, a major step toward advancing the use of distribution automation in electric networks, has recently been completed. This technology is now being transferred to industry. A research plan to pursue critical projects in the areas of on-line detection, harmonics, system integration, and adaptive protection is currently being developed.

Advanced concepts and systems to obtain significant improvements in the transmission of electricity will be pursued as part of the Systems Research Program. The current program emphasizes the development of technologies that allow higher power-transfer capacity over existing transmission corridors and provide more flexible bulk-power transmission to resolve capacity problems and improve system economics.

The Materials Research Program develops materials that can be used to successfully reduce the life-cycle costs of the nation's future utility equipment and to solve specific materials-related problems. The paths chosen to achieve this goal are to investigate fundamental properties and new materials necessary to improve electric equipment performance and reduce cost, and to develop practical conductors of high-temperature superconducting (HTS) materials to reduce losses and improve performance in power system devices.

Normal operating losses in the national transmission and distribution of electricity are substantial, accounting for some 8% of total output. The losses are about 200 billion kilowatt-hours (kWh), translating into an economic loss of $10 billion annually. This is equivalent to 40 gigawatts (GW) of generation capacity. Research into advanced technologies and materials can substantially reduce these losses. High-temperature superconducting cables alone can reduce the transmission losses to about 1%.

Specific research efforts are intended to move the program toward its long-range goals, which are to develop the technology that can ultimately reduce transmission and distribution losses by 10% (the equivalent of 70 million barrels of oil), improve energy efficiency by 10% (equivalent to 380 million barrels of oil), and affect load control to shift 10% of the peak load (equivalent to 42 GW of plant capacity) or a total of $84 billion.

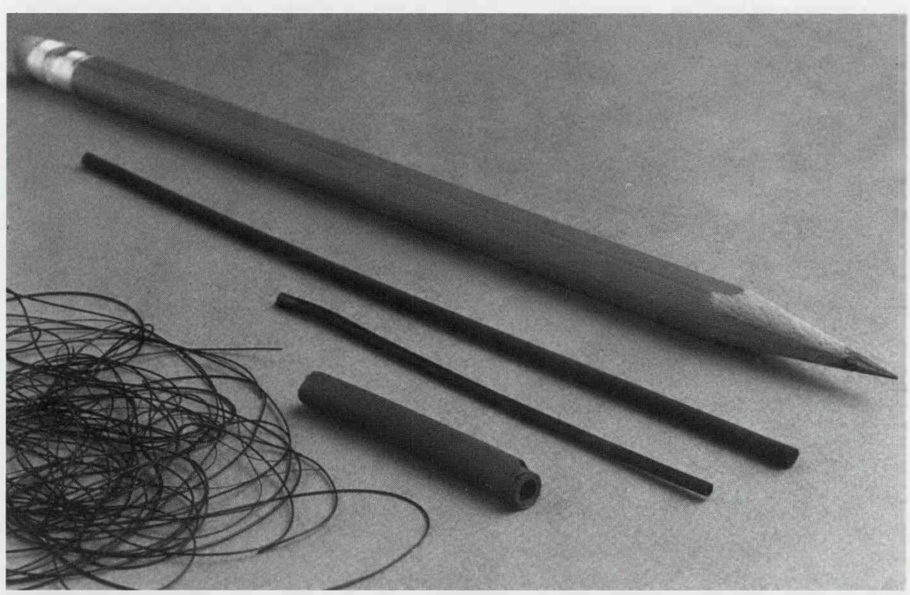
Research Activities

Electric Field Effects

Future work will focus on the effect of mixed electric and magnetic fields, long-term effects (particularly abnormal cell growth), and mechanisms of interaction on the cellular level. Specifically, in FY 1989 a four-year research effort on the promotion of cancer in small animals will be initiated under the auspices of the National Toxicology Program. The second phase of the study, funded by the Japanese Central Research Institute of Electric Power Industry (CRIEPI), will also be initiated and will focus on the effect of mixed electric and magnetic fields on the behavior and endocrinology of baboons. Researchers will continue experiments on the effects of electric and magnetic fields at the cell membrane level to search for mechanisms of cancer promotion. The analysis of data generated from human exposure to 6 kilovolts per meter (kV/m), 9 kV/m, and 12 kV/m electromagnetic fields will be completed.

Reliability

EMP Research. The current effort is primarily involved in the characterization of an EMP event. In FY 1989, the completion of tests and analyses of EMP effects on a power substation control unit is planned. The impact of



High-temperature superconductor formats.

high energy pulses on power and transmission systems will also continue to be assessed.

Power System Concepts. The objective of this effort is to research systems and devices to improve the control, detection, and restoration of both normal and disturbed power system states. The conceptual phase for on-line detection and recognition of instabilities will be completed in FY 1989, and a study on the techniques for coordinated system protection and control will be initiated. Other research activities planned this year are analytical and experimental studies on harmonics, concentrating on the nonlinear modeling of transformers.

Systems

Advanced Transmission Concepts. No new activities will be undertaken in this area. The ambient cable technology will be transferred to industry.

Hawaii Deep-Water Cable. The objective of this project is to determine the technical feasibility of designing, laying, and maintaining a deep-water power transmission cable. A cable 6000 feet in length has been fabricated for testing and in FY 1989, at-sea tests will be done along selected portions of the route that are expected to be treacherous. The development of an integrated system that includes controls, cable-handling equipment, and special navigation subsystems will also be completed this year.

Materials

Improved Efficiency. A study to investigate the most promising opportunities for conducting polymer components is being completed. Conducting polymers are a new class of compounds with the potential to significantly reduce the cost of many components in the electric delivery system. Some fundamental research has been initiated and will be continued on the power system applications of conducting polymers. This research includes aging and long-term degradation at interfaces by in situ characterization.

Superconducting Technology. This major new initiative, begun in FY 1988, is aimed at developing practical high-temperature superconductors for power system applications. Ten DOE laboratories have been funded to perform enabling research needed to develop practical HTS conductors and to begin the investigation of innovative HTS devices. University and corporate research partners are working with the DOE laboratories as a key part of the research strategy.

Additionally, a study that assesses the impact of HTS on power system and renewable energy applications was completed. Specific research goals (improving current densities of bulk HTS materials to the range of 100,000 amperes per square centimeter) have been identified to meet application requirements for a wide range of potential products including motors, generators, transmission lines, and magnets.

FY 1989 activities include the implementation of the HTS pilot centers at ORNL, SNL, and ANL. These new centers will facilitate interaction and assist industry in gaining access to laboratory processes needed for development of HTS products. The HTS research effort will continue to focus on the development of a practical superconductor that has improved mechanical and electrical properties. Bulk specimens in the form of pressed bars, wires, filaments, tapes, and coils will also be fabricated and tested.

Program Participants

Research Area	PNL	ORNL	BNL	ANL	JPL	NIST	LANL	SNL	LLNL	LBL	SERI
Electric Field Effects	•			•		•					
Reliability Research		•			•	•					
Systems Research		•									
Materials Research	•	•	•	•		•	•	•	•	•	•

Energy Storage

The Energy Storage (STOR) Program conducts research to provide the technology base for enhancing the use of energy storage systems in electric utility load leveling; in transportation; and in industrial, commercial, and residential applications. Energy storage systems enable greater efficiency and flexibility in the nation's energy system. Improved storage technologies offer the possibility of extended use of intermittent renewable energy sources and thus contribute to DOE's renewable energy objectives. Energy storage devices can improve efficiency by allowing for full-load operation during low-load conditions, improve the economics of intermittent renewable energy technologies, and provide peak power at competitive cost without the requirement of new generating capacity.

STOR's research strategy involves support for innovative research ideas, use of cost-sharing arrangements to involve private industry in research and development projects, and transfer of information and technology to industry as rapidly as possible.

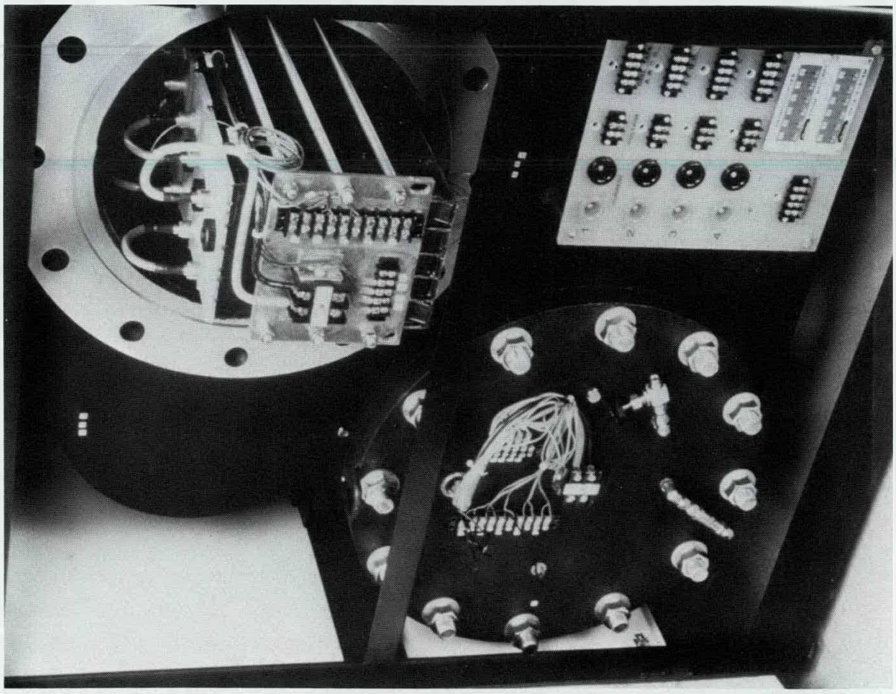
Research Needs

The STOR program currently includes activities in electrochemical research, battery development, thermal energy storage (TES), and superconducting magnetic energy storage (SMES).

The Electrochemical Research Program provides the fundamental research base that supports all end-use battery applications. General problem areas addressed by the project include identification of new electrochemical couples for advanced batteries, determination of technical feasibility of the new couples, improvements in battery components and materials, establishment of engineering principles applicable to electrochemical energy storage and conversion, and development of air-system (fuel cell, metal/air) technology for transportation applications. Major emphasis is given to applied research, which will lead to superior performance and lower life-cycle costs.

Electrochemical research has made progress this year toward attaining practical goals in the development of advanced batteries. An upper-plateau high-temperature lithium cell has cycled for more than 1000 cycles. The power performance of new sodium/organosulfur cells that operate at 100°-150°C is being characterized. Finally, a new flowing electrolyte, electrically rechargeable Zn/air cell has been successfully tested, and design calculations show 110 watthours per kilogram (Wh/kg), 140 watts per kilogram (W/kg), 60% energy efficiency, and $20 per kilowatt-hour (kWh) materials cost.

Conducting the initial engineering development of advanced battery systems judged suitable for electric vehicle, load leveling, and renewable energy applications is the goal of the Battery Development Program. The present



The largest experimental hydrogen-nickel oxide battery ever produced, undergoing testing at SNL.

program emphasizes the development of (1) an advanced battery that provides a load-leveling system that can deliver peak power at a competitive cost compared to combustion turbine peaking units, (2) advanced batteries that provide life-cycle advantages to intermittent renewable energy systems, and (3) an advanced electric vehicle battery that provides performance comparable to internal combustion engine (ICE) vehicles. Sodium-sulfur and zinc-bromine battery systems have shown performance potential at the cell and module levels for use in electric vehicles and load-leveling systems. These systems have performed near their desirable goals at the laboratory level, but testing of scaled-up systems must be performed to verify the viability of these technologies. Nickel-hydrogen offers performance improvements for remote stand-alone renewable energy applications, but is still too expensive to be economically viable.

The goal of the sodium-sulfur research effort is to design, fabricate, and evaluate a proof-of-concept load management module on the scale of 100 to 200 kWh. Significant progress has been made toward this goal. There was a 4-fold increase in zero defect electrolyte production in FY 1988, a 16-fold improvement in cell cycle life between 1984 and 1987, and significant developments in module testing. Performance of a 36-kWh load-leveling module deliverable will provide critical data to resolve the viability of zinc-bromine as a load management option. Demonstration of the durability of suitable materials for the deliverable has been completed, and a 1500-square-centimeter (cm^2) flow frame for use in the module has been designed, fabricated, and tested. Opportunities to develop a proof-of-concept nickel-hydrogen industrial partnership are being sought, but in the meantime significant progress has been made by reducing the cost of production another 12%.

Performance goals have been established for advanced batteries that, if attained, will allow batteries to be competitive with commercial products. Goals for advanced batteries for electric utility load leveling include a capacity of 20 to 100 kWh, 65% efficiency, and a system life of 30 years, all at a cost of $80 per kW and $80 per kWh. If these goals are achieved, battery storage could account for 10% (between 2.0 and 6.6 gigawatts [GW]) of total potential energy storage by the year 2000. Advanced battery goals for electric vehicles include energy efficiency of 70%, energy density of 70 Wh/kg, and peak power density of 130 W/kg. Attainment of these goals will permit vehicles to travel more than 100 miles on one charge. Significant market penetration is expected if costs of $70/kWh and lifetimes of six years (1500 charge/discharge cycles) can be achieved. Advanced batteries for longer ranges, approaching those of gasoline-fueled vehicles, are in the early stages of development. Goals for remote stand-alone advanced batteries include a 100-kWh capacity, 65% efficiency, and a 10-year life span.

The Thermal Energy Storage Program performs R&D on thermal storage systems to reduce the performance and cost barriers that hinder their implementation. Three areas are being investigated to increase the marketability of thermal storage systems. First, cost-effective techniques of storage suitable for building space conditioning are being examined. Second, techniques to incorporate waste heat into industrial processes to improve manufacturing efficiency are also being closely studied. Finally, the seasonal storage of large quantities of heat or chill is being investigated.

Current goals for advanced thermal storage technology include a capital cost of $26/kWh for high-temperature industrial applications with 85% efficiency. Long-term seasonal storage goals include 70% efficiency with capital costs of $60/kWh for installed capacity. Current diurnal thermal storage research is investigating innovative and cost-effective techniques such as clathrates (ice) storage, dual temperature storage concepts, and encapsulated phase change materials. Industrial storage is focused on implementing high-temperature (700°-1100°C) thermal storage for use in manufacturing processes. Seasonal storage is currently investigating the characterization and performance of aquifer systems for both heat and chill.

SMES is a utility storage technique that offers the potential for storing electricity at greater than 90% efficiency without conversion. A low-temperature 30-million-joule (MJ) SMES proof-of-concept unit was successfully developed and tested by the Bonneville Power Authority in the early 1980s. The advent of high-temperature superconductors has renewed interest in the SMES concept because of potential cost savings and performance improvement. This new initiative will evaluate alternative high-temperature compact SMES designs, emphasizing innovative concepts that reduce high magnetic fields and mechanical stresses.

Research Activities

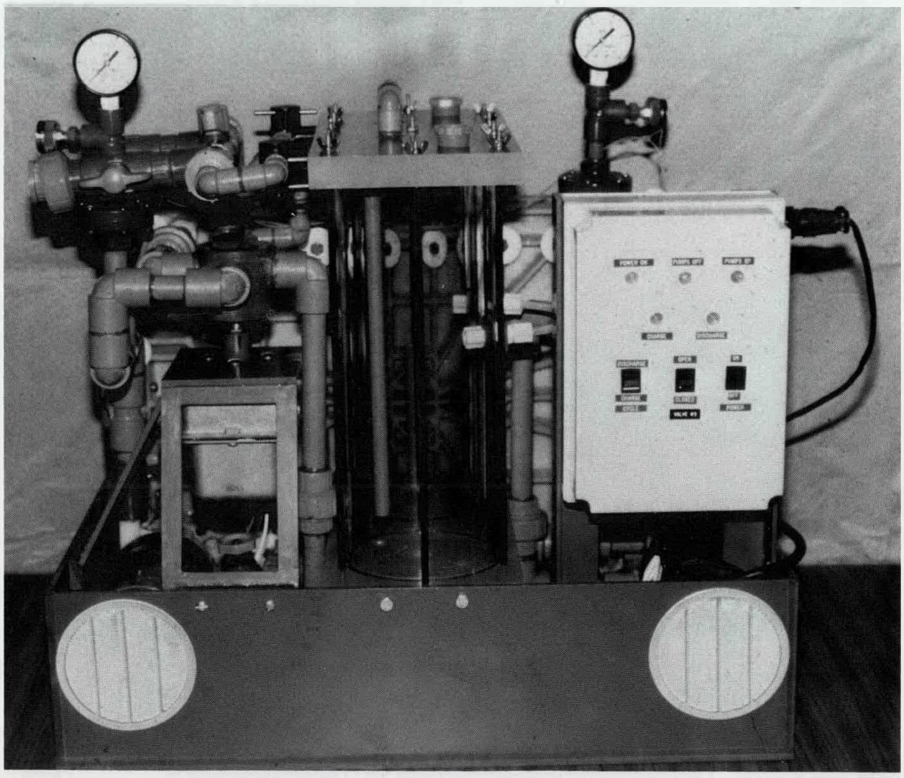
Electrochemical Research

Electrochemical Phenomena. The objective of this effort is to provide a thorough understanding of the scientific principles underlying the complex phenomena that govern the operation of rechargeable batteries and fuel cells. FY 1989 work will continue to support and do exploratory research of electrochemical phenomena, materials characterization, new cell components, and new electrochemical couples. Evaluation of intermediate-temperature sodium cells using ceramic electrolytes and metal chloride or organosulfur positive electrodes will be done in FY 1989, as well as characterization of novel molten-salt electrolytes.

Materials and Components. The aim of this project is to identify, characterize, and improve materials and components for use in high-performance rechargeable batteries and fuel cells. In FY 1989, development will continue on molten-salt electrodeposition and plasma-enhanced chemical vapor deposition (CVD) methods to produce corrosion-resistant coatings, and continuous, atmospheric-pressure CVD techniques to produce tailored electrode structures. Research on catalytic mechanisms at the electrode surface will be extended in FY 1989. Also, research will be continued on conductive ionic solids, dielectrics, polymer membranes, coatings, and composites.

Advanced Battery Systems. The goal of this project is to identify and initiate development of new electrochemical couples with the potential to meet or exceed advanced battery system performance goals. Room-temperature alternatives to high-temperature batteries will be explored in FY 1989. Specifically, a high power and high density lower temperature sodium metal chloride battery for load leveling will be identified, overcharge-tolerant lithium iron-disulfide cells will continue to be developed, and the zinc-air technology will be transferred to the private sector.

Electrochemical Conversion Systems. Major strides have been made in solving the key problems in applying advanced compact fuel cells for electric vehicle propulsion: power density, cost, and utilization of hydrocarbon fuel. Since 1984, the platinum (Pt) content has been reduced in advanced solid polymer electrolyte fuel cells using proton exchange membranes (PEMs) by more than a factor of ten. The goal is to reduce it by another factor of three. At the same time, the power density was increased from 0.24 W/cm^2 to 0.9 W/cm^2. This combination results in an improvement by a factor of 60 in the Pt utilization per watt. There has been a corresponding



An 8-cell, all-plastic zinc bromine battery being delivered to SNL for testing.

decrease in the intrinsic cost per kW without any detrimental effects on performance.

FY 1989 research will focus on determining the carbon monoxide levels that can be tolerated in PEM fuel cells with cathodes containing low Pt loadings and with various anode electrocatalysts. The use of metal bipolar plates in PEM fuel cells will also be decided.

Battery Development

Sodium-Sulfur Technology. Sodium-sulfur development efforts will focus on material and component improvements to address technical problems that currently prevent this high-temperature battery from achieving the projected goals of being a high energy and power density system. The cost-shared industrial contract with Chloride Silent Power, Ltd., will continue core technology development of advanced generation sodiumsulfur batteries and will concentrate on further improving corrosion, seal durability, and performance of beta-alumina. Three 4-cell strings of 10-amp-hour and 25-amp-hour cells will be evaluated for electrical performance, mechanical durability, freeze-thaw endurance, cycle life, and safety. Improvement of sodium-sulfur technology will concentrate on understanding beta-alumina fracture, developing improved chromium platings, and identifying contamination reactions. Late in 1989, the initial development of a proof-of-concept load-leveling or load-management module with a 100-kWh capacity will be initiated.

Zinc-Bromine Technology. This technology research will focus on key technical materials and configuration issues that are currently limiting performance and cost reductions. The major emphasis of the cost-shared industrial contract with Energy Research Corporation (ERC) in FY 1989 is the design, fabrication, and qualification of a 36-kWh load-leveling device deliverable by June. To meet this deadline, the 1500-cm^2 flow frame must qualify, auxiliary hardware must be designed, and a final design review must be held in January. Evaluating 5-cell and 30-cell stacks and doing life-cycle testing of two other ERC batteries will also be accomplished in FY 1989. Research will focus on improving materials' durability and the performance of the separators.

Other Battery Systems. Development of other candidate battery systems showing promise for either electric vehicles or load leveling applications will continue. The aluminum-air battery represents a mechanically rechargeable system with the potential for high energy and power density. This unique system offers a battery with the capability to power an electric vehicle with a range similar to that of ICE vehicles. A 10-cell aluminum-air module using advanced design and solids separation techniques will be constructed, evaluated, and optimized. A focused program will be initiated to develop suitable aluminum alloy anodes and improve the durability of the air cathode. The objective of the nickel-hydrogen battery development effort is to adapt this expensive shallow cycling space technology to deep discharge, terrestrial applications that are cost competitive with lead-acid batteries. Improvements in the nickel-hydrogen battery design that resulted in a 12% reduction in cost are expected to continue by researching thicker nickel plaques, hydrophobic backings, and catalysts. Stress cycle testing will also be done to evaluate cost-reduction effects. Field testing of the 7-kWh battery and photovoltaic array in a stand-alone system will continue, and scale-up of an 8-kWh battery for large stand-alone applications will be decided upon.

Thermal Storage

Thermal storage research will focus on seasonal energy storage, including applications to large-scale solar systems for building heating. Work on diurnal storage projects for near-term technology transfer will be completed. Required reconstitution and clean-up of aquifer test sites in Alabama, Minnesota, and Mississippi will be performed. The final test cycle at the St. Paul aquifer TES system is scheduled to be completed. The aquifer TES system computer code will be finished. International progress on developmental activities will be monitored.

Program Participants

Research Area	LBL	SNL	BNL	PNL	LANL	ORNL	ANL	SERI
Electrochemical Research	•	•	•	•	•		•	
Battery Development		•		•				
Thermal Storage				•		•		•
Superconducting Magnetic Energy Storage*								

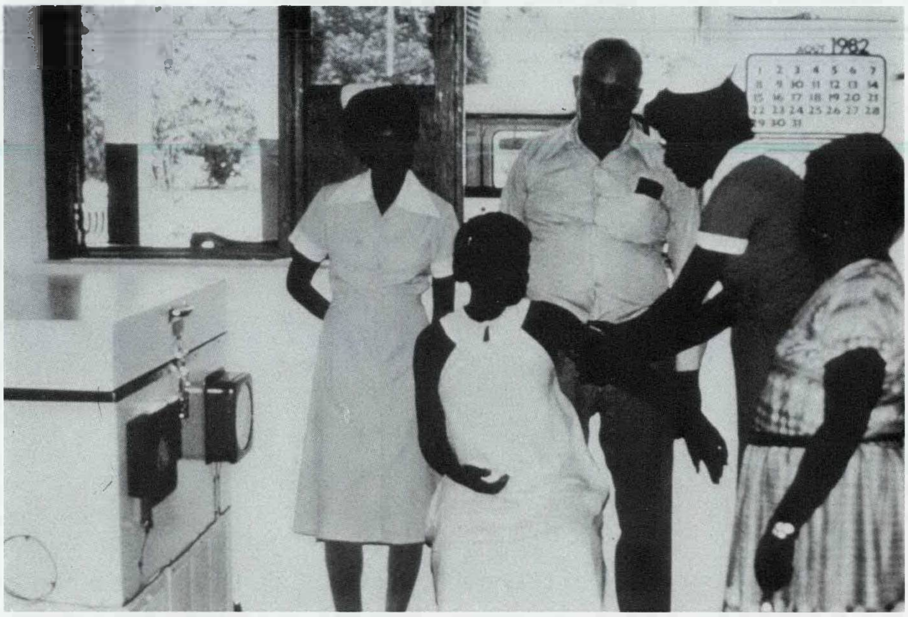
*To be determined

International Solar Energy Program

The primary activity of the International Solar Energy Program is to support the Committee on Renewable Energy Commerce and Trade (CORECT). CORECT is an interagency working group that facilitates the use of U.S. renewable energy products and resources around the world. Established by the Renewable Energy Industry Development Act of 1983, CORECT includes representatives from 12 member agencies. CORECT is chaired by the Secretary of Energy; day-to-day management is provided by the Director of the DOE Photovoltaic Energy Technology Division.

CORECT is divided into four subcommittees that conduct activities in their respective areas of specialty: education, technical competitiveness, market development assistance, and trade policy. There are also two special task forces. One task force examines available financing sources and recommends measures to improve access to financing by renewable energy firms, and the other identifies conferences, meetings, and trade shows for CORECT participation.

This solar rice dryer in Nepal can handle 75 tons of rice per day, and has been operating since 1984.



Largely through the educational efforts of CORECT, the World Health Organization and other agencies have recently endorsed photovoltaic-powered vaccine refrigerators.

Program Needs

Subcommittee activities are selected to respond to identified needs and issues facing the U.S. renewable energy industry. One such need is to provide decision-makers in the United States and overseas with technical and economic information on renewable energy. Another need is to improve the cost competitiveness of U.S. renewable energy products. U.S. industry also needs better coordination of federal export assistance programs and the identification and removal of trade barriers that inhibit U.S. renewable energy exports.

FY 1988 marked a year of progress for CORECT toward its goal of increased U.S. renewable energy exports. While the industry continued to mature and expand beyond the domestic marketplace, CORECT maintained its systematic efforts to incorporate U.S. renewable energy products and issues into the long-term plans of foreign markets that offer the most significant opportunities, including foreign utilities.

During FY 1988, CORECT completed a self-assessment of its activities in comparison to its objectives. The most significant accomplishment has been to demonstrate that renewables are a viable, competitive option for foreign utility planners and government decision-makers. In the conduct of its operations the committee noted four particularly successful strategies:

- CORECT was able to help federal assistance become more targeted and complementary to individual industry efforts by working closely with the renewable energy industry.
- The structure of CORECT (subcommittees and task forces, chaired by different member agencies) made it easier for CORECT to work on several different issues at the same time.
- CORECT took advantage of the existing international assistance framework of donor agencies and development institutions to inform potential users about the U.S. renewable energy industry. This accelerated education was particularly important for markets in developing countries.

- CORECT created the "reverse trade mirror" concept. This involves bringing foreign buyers to the United States, exposing them to U.S. operating experience, and reinforcing the technical leadership of U.S. companies.

Research Activities

CORECT's direction in FY 1989 and beyond will emphasize four areas:

Increased Financing Capabilities

Through a combination of efforts, CORECT hopes to improve the financial climate for U.S. suppliers. Specific activities will include educating bankers; establishing a private merchant bank to assist in the identification, development, and subsequent provision of banking services for renewable energy suppliers and project developers; and interacting more with assistance agencies.

Greater Use of Targeted Training

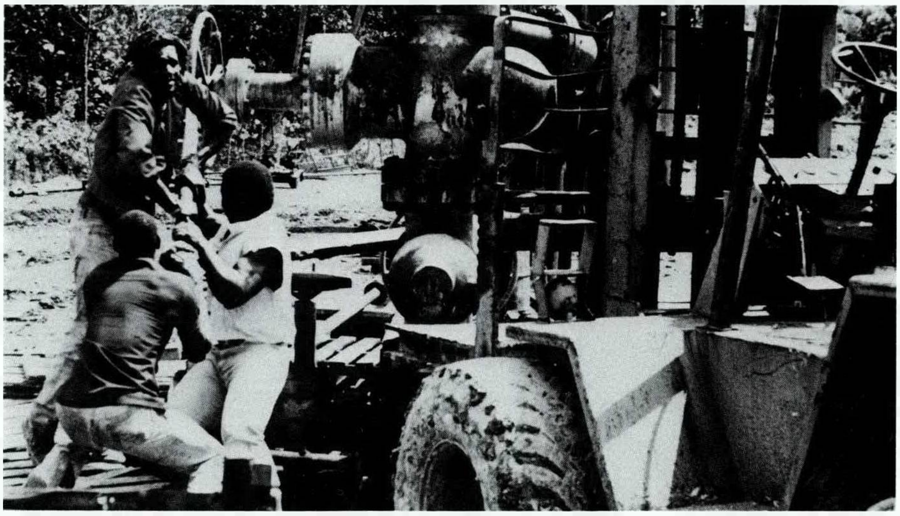
Training has been directed at educating decision-makers in foreign countries about the technical competitiveness of renewables compared with other forms of energy supply. In FY 1989, training will be expanded to address the more sophisticated issues related to marketing renewable energy products and services in developing countries. These issues include strategies for countering foreign competitors who tie foreign aid to the purchase of their products, and issues related to the sale of private power to utilities. Training will also cover operation and maintenance problems as well as institutional training designed to share U.S. experiences with small private power generation (PURPA, avoided cost, power sales contracts, etc.).

Increased Collaboration Between States and CORECT

Wherever state export programs fit into the CORECT agenda, the committee will seek greater cooperation in order to leverage resources. There is also a need for greater sharing of information on project opportunities both internationally and domestically.

Focused Market Development

CORECT will strive to link assistance programs in a more sequential and coordinated manner, as described in its report *CORECT Process and*



In St. Lucia, a Caribbean island nation, a 10-megawatt geothermal power plant is expected to save the government $135 million over the next 30 years.

Activities: 1988 and Beyond. A Caribbean Basin Trade Show and Conference, scheduled for mid-1989, is an example of this coordination. It will build on the project identification activities of prior years, and combine them with improved financing and education efforts stressing end-use applications in order to maximize business opportunities in this region.

Program Participants

Improving the export capability of U.S. renewable energy firms has required mobilizing more than 30 organizations to tackle several major issues. Different types of organizations are responsible for different aspects of each issue. The extent of this effort is apparent in one example — a matrix describing the responsibilities relating to one critical issue of financing export projects.

Financing for U.S. Renewable Energy Exports Organization Responsibilities

Program Area	Federal Agencies	Donor Agencies	Financial Institutions	Host Governments	Development Banks
Feasibility Studies	•	•		•	
Direct Loans	•	•	•	•	
Loan Guarantees	•			•	
Project Financing	•	•	•	•	
Equipment Procurement	•			•	•
Equity Partnerships		•	•	•	•

Resource Assessment

The Resource Assessment Program conducts research and development to provide solar radiation (insolation) data bases, analytical models, and resource assessments required by the solar energy community. Members of this community such as industry, research laboratories, and utilities use these data to design, develop, select, site, and project the annual energy delivery characteristics of a wide range of solar energy conversion devices and systems. Major activities include:

- Archival and improvement of the national insolation and spectral solar radiation data bases
- Quality control and evaluation of radiation data from the national solar radiation monitoring network and from a number of industrial, university, and other insolation measurement facilities
- Quantification of the natural variability of the solar radiation resource and the impact of atmospheric turbulence, clouds, and low-altitude air pollution on the available surface resource
- Development of computer modeling methods to predict specific radiation resource components (e.g., direct, diffuse, horizontal, or tilted surface) from measurements of global horizontal incident radiation and cloud cover
- Development of computer modeling methods to predict the resource at all potential system sites between the widely scattered measurement stations
- Archival, retrieval, and delivery of solar radiation resource data in appropriate formats for a wide range of user needs.

These research activities are closely coordinated with the user community and are a unique national function in assessing the huge U.S. solar energy resource. Data from the current 31-station national solar radiation monitoring network are obtained by cooperating with the National Oceanic and Atmospheric Administration (NOAA) through NOAA's National Weather Service (NWS), and National Climatic Data Center (NCDC).

Research Needs

The development of a new and improved data base that covers recent conditions and has an accuracy of 5% is one of the major objectives of the Resource Assessment Program. During the mid and late 1970s, the program developed a national insolation data base covering the 1952-1975 time period to support the development and application of solar energy conversion technologies. Studies since then have shown this data base to have inaccuracies of 30% to 50% because of data ambiguities, time gaps, and measurement inaccuracies arising from insufficient instrument maintenance and calibration, and failures of recording apparatuses. Research for estimating average annual radiation resources has reduced the inaccuracy to about 20%, which is still unacceptable for most solar energy system design needs.

In addition, the upper and lower atmospheric environment has changed substantially since the 1952-1975 time period because of increased air pollution (e.g., perturbations of the atmosphere by chemical aerosols, volcanic eruptions, and aircraft residues). For this reason, research activities are essential to improve the old data base as much as possible, and to obtain new accurate measurements of the current solar radiation resources in the United States. The goal is to establish an up-to-date 30-year (1961-1990) data base and analytic capabilities providing estimates of the annual solar resource at a given site to 5% accuracy, which is needed by the solar energy community.

Besides the need for improved data bases, solar experts have identified the following three broad categories of activities needed to support research and industrial developments.

Research data sets that characterize the complex spectral, spatial, and temporal nature of solar radiation are necessary. A research data set for describing spectral (e.g., wavelength or color distribution) radiation for various climates and elevations is specifically needed to guide the research and development of spectrally sensitive photovoltaic devices and several applications of solar heat technologies. Such devices and technologies need to be "matched" to the outdoor spectral radiation characteristics to obtain optimum design performance under field conditions.

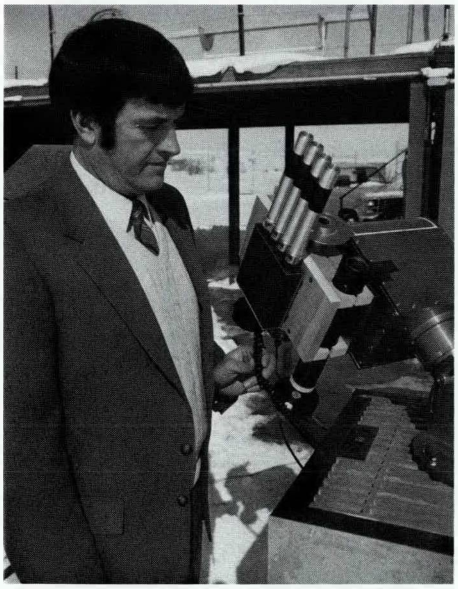
Models must be developed to extend measured resource data from a limited number of sites to reliable calculated estimates of the resource at many

The spectral solar radiation data base contains energy versus wavelength data for variable sky conditions such as those shown in this all-sky photo.

potential system sites, characterize the components and temporal variability of the resource, and assess the annual solar energy available to various solar energy systems.

Finally, a worldwide data base must be compiled to help U.S. industry in the design of commercial products that can compete successfully in international markets.

Research Activities



The Atmospheric Optical Calibration System.

During FY 1989, the key activities will include continued development and verification (by comparing calculated results with accurate current resource measurements) of improved analytical models for estimating solar radiation characteristics from available meteorological data. The improved models will be used to upgrade the historic insolation data (1952-1975), known as SOLMET/ERSATZ, from 10%-15% accuracy to better than 10% accuracy. Subsequently, insolation data will be improved in the following year to an accuracy approaching 5%.

Computerized quality control software will be operated in the NCDC data-handling system to monitor automatically the quality of the data received daily from the national solar radiation monitoring network. The Resource Assessment Program developed this software previously.

The Atmospheric Optical Calibration System (AOCS), which has been developed at SERI to provide low-cost radiation resource and spectral measurements, will be installed and operated at several sites during 1989. These AOCS measurements are used not only to measure the solar radiation resources as a function of time but also to provide immediate capabilities for calibrating solar cell performances at any site or time of day. SERI holds the patent for this unique instrumentation and is cooperating to make it available for development as a commercial product in 1989.

The program will continue archiving spectral solar radiation data and improving and verifying analytical models in cooperation with the Pacific Gas and Electric Company, the Florida Solar Energy Center, and EPRI.

Assistance to professors and students will be provided at five Historically Black Colleges and Universities (HBCUs) in the operation of local solar radiation measurement facilities.

The acquisition, quality control, evaluation, and archiving of resource data from about 75 measurement facilities including the NCDC, HBCUs, industry, national laboratories, state governments, and other organizations will continue in FY 1989. In addition, retrieval, packaging, and delivery of resource data will be accomplished to assist users in the design, siting, and projection of system performance and energy cost of solar power systems.

Technology Transfer

DOE views technology transfer as the transformation of R&D results into information, processes, products, and services that support the needs of the private sector and state and local governments. It emphasizes collaborative relationships between the technical staff of DOE laboratories and representatives of the private and public sectors. Ideally the transfer of new knowledge from the originating laboratory to the user does not occur abruptly but over a period of time, and involves a variety of communication channels.

Because all DOE renewable energy research activities are intended for application in the private sector, prompt, efficient transfer is a major objective. The technology transfer program promotes the exchange of knowledge before and throughout the research process. The involvement of experts and peers in the planning, review, and implementation of research projects is essential to the advancement of renewable energy sciences. Not only does it ensure that efforts are directed toward useful, achievable goals and research of potentially greatest usefulness, but it also provides one of the most efficient means of transferring DOE research results to the private sector.

Many of these techniques are employed as an integral part of each technology program and research area. Techniques are selected as a function of the nature of the particular research, the comparative novelty and risk of the technology under development, and the financial and technical capabilities of the research partners.

Research Activities

During FY 1989, laboratories and major contractors will continue to pursue cooperative funding for research. Final data are not fully available at this time, but historical data indicate a substantial research investment can be expected by private sector firms in FY 1989, in cooperation or cost-shared with DOE programs. Laboratories and contractors can be expected to continue pursuing policy initiatives that relate to intellectual properties (copyrights and patents) with increased emphasis in FY 1989, paving the way for faster exploitation of research advances within the commercial arena.

In addition to technology transfer activities specifically sponsored and funded within research programs, three general activities are funded through central accounts in order to accomplish economies of scale and productivity. First, a central public response service (the Conservation and Renewable Energy Information Referral Service) is operated to respond to more than 40,000 inquiries per year, which are directed to the White House and DOE from the general public and other audiences. Some 100,000 to 120,000 fact sheets, bibliographies, and other general publications are typically provided in

Communication Channels for Technology Transfer

- Development and licensing of intellectual properties
- Industry/university use of DOE laboratory facilities and equipment
- Industry/university participation in DOE research and information planning
- Collaborative and cost-shared research with states, universities, and industry
- Publication and distribution of special technical documentation
- Publication and distribution of technical and program progress reports
- Publication of research results in learned journals and the popular technical media
- Responses to specific inquiries from the scientific, industrial, and public sectors.

response to requests each year. Second, SERI operates a technical referral service, which responds to 2500 to 3000 inquiries each year, more than 85% of which come from the scientific, industrial, and business communities and are related to research conducted at SERI and other laboratories and universities. Third, crosscutting publications are produced to summarize significant research data and results across research areas and across organizations performing R&D. These publications use multiyear data in a manner not efficiently handled within individual contract reports. The final slate of products for FY 1989 has not yet been approved but will include some 20 major reports and 5 to 8 articles for scientific journals.

Solar Energy Research Institute Facilities

The Office of Renewable Energy Technologies dedicates a portion of the renewable energy research budget to maintain the scientific excellence of the facilities at the Solar Energy Research Institute.

Program Needs

The SERI research facility has been developed over the past 10 years, and now includes the Field Test Laboratory Building (a high-bay experiment building) and a number of small research buildings on a permanent site, and laboratory and office space in leased facilities. These structures house a variety of research tools, both state-of-the-art and older (although still serviceable) equipment. So that SERI can maintain a position as a world-class research institute and a functional organization, the facilities and equipment must be regularly improved or replaced. Improvements are also needed to assure safety of personnel and equipment as the experimental programs become more sophisticated and complex.

Research Activities

Improvements to the SERI facilities include both General Plant Projects (GPP) and General Purpose Equipment (GPE) items. GPP projects will include the completion of semiconductor/electrolyte interface research laboratory spaces by providing utilities and basic casework (furnishings), and various repair and maintenance activities on the site.

GPE activities will acquire replacements for aged automated office equipment including word processing hardware and printers, replacement and new microcomputer equipment and related communication hardware for institute local area networks, and the replacement of a 30-year-old precision lathe used for production of specialized research apparatuses in the SERI machine shop.

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