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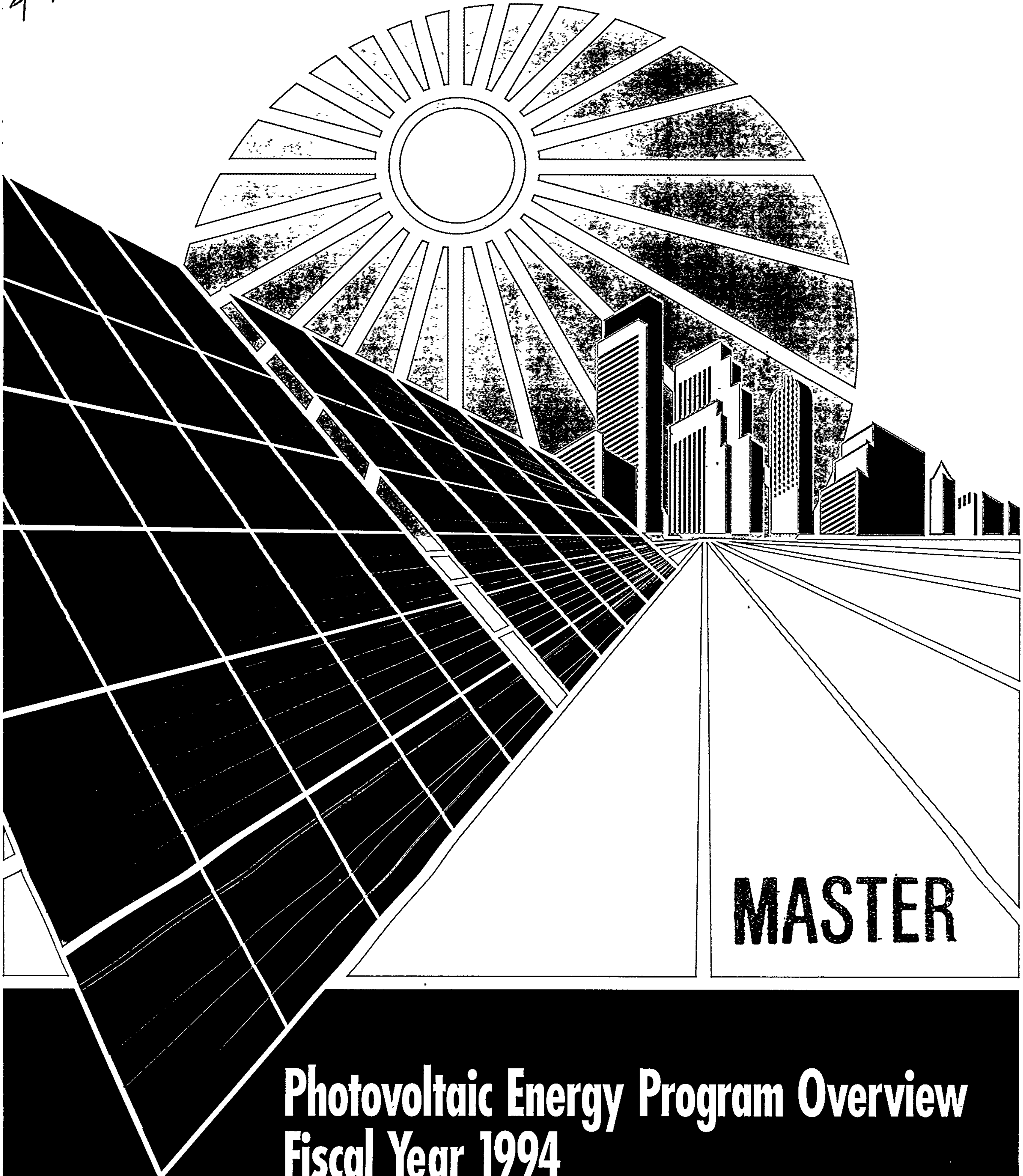


MASTER

# Photovoltaic Energy Program Overview Fiscal Year 1994

# 1994 PV Program Accomplishments

## Improving PV Systems

p. 2

The U.S. Department of Energy's (DOE) Photovoltaic (PV) Program helped participating manufacturers reduce their cost of producing PV modules by a per-company average of almost 50% through the PV Manufacturing Technology (PVMaT) project. The PV Program issued a new solicitation for research and development (R&D) projects emphasizing product-driven manufacturing.

Through PV:Building Opportunities for PV in the United States (PV:BONUS), teams of private firms developed prototypes of new products for incorporating PV into buildings.

The National Renewable Energy Laboratory (NREL), of Golden, Colorado, inaugurated the Solar Energy Research Facility (SERF), the nation's premier R&D facility for PV.

## Advancing PV Technology

p. 12

The PV Program shared a prestigious R&D 100 Award in fiscal year (FY) 1994, given by *R&D* magazine for the 100 most important scientific achievements of the year. The award was for a back-contact PV cell made from crystalline silicon (c-Si) material. SunPower Corporation, a small business of Sunnyvale, California, produced a prototype c-Si module using these cells, achieving a record efficiency of 21.6%.

NREL produced a small-area cell made from crystalline gallium indium phosphide/gallium arsenide with a record efficiency of 30.2% at 180 suns concentration.

Sandia National Laboratories, of Albuquerque, New Mexico, produced a large-area multicrystalline-silicon module with a record efficiency of 15%.

The PV Program established the Thin-Films PV Partnership Program in FY 1994 to coordinate U.S. research in thin-film PV, and to develop a stream of pre-commercial prototype products with U.S. companies (mostly small businesses), operating in this field.

NREL fabricated a small-area cell made from thin-film copper indium gallium diselenide (CIGS) material with a record efficiency of 16.8%, the highest efficiency recorded to date for this material.

Siemens Solar Industries, of Camarillo, California, produced a CIGS power module with a record efficiency of 10.3%.

United Solar Systems Corporation, of Troy, Michigan, produced a prototype module made from amorphous silicon (a-Si) with a record stabilized efficiency of 10.2%.

The Utility PhotoVoltaic Group (UPVG), representing 89 U.S. utilities, completed an authoritative study of near-term potential markets for PV by utilities.

The PV Program completed studies of the value of connecting PV power systems to utility transmission and distribution (T&D) grids: PV power plants connected to T&D grids at some locations are cost effective at today's prices.

NREL completed support of the first phase of a large-scale PV project demonstrating the feasibility of PV systems in remote villages in Brazil.

Sandia began procurement and technical evaluation of PV systems for the military.

## DISCLAIMER

# Introduction

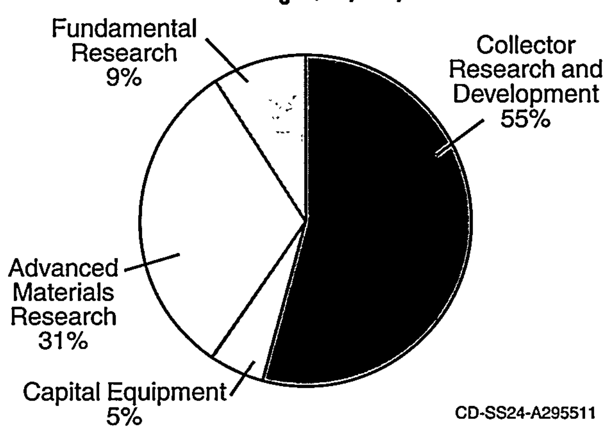
***The accomplishments of the PV Program in FY 1994 are part of a national plan, developed with U.S. industry, to maintain its preeminent position in PV technology, manufacturing, and worldwide market share.***

The PV Program's accomplishments for FY 1994 are based on a comprehensive R&D plan. The cornerstone of this R&D activity is to develop pre-commercial prototypes of new PV products based on advancing fundamental science. The underlying purpose of this R&D activity is to increase the productivity of U.S. industry.

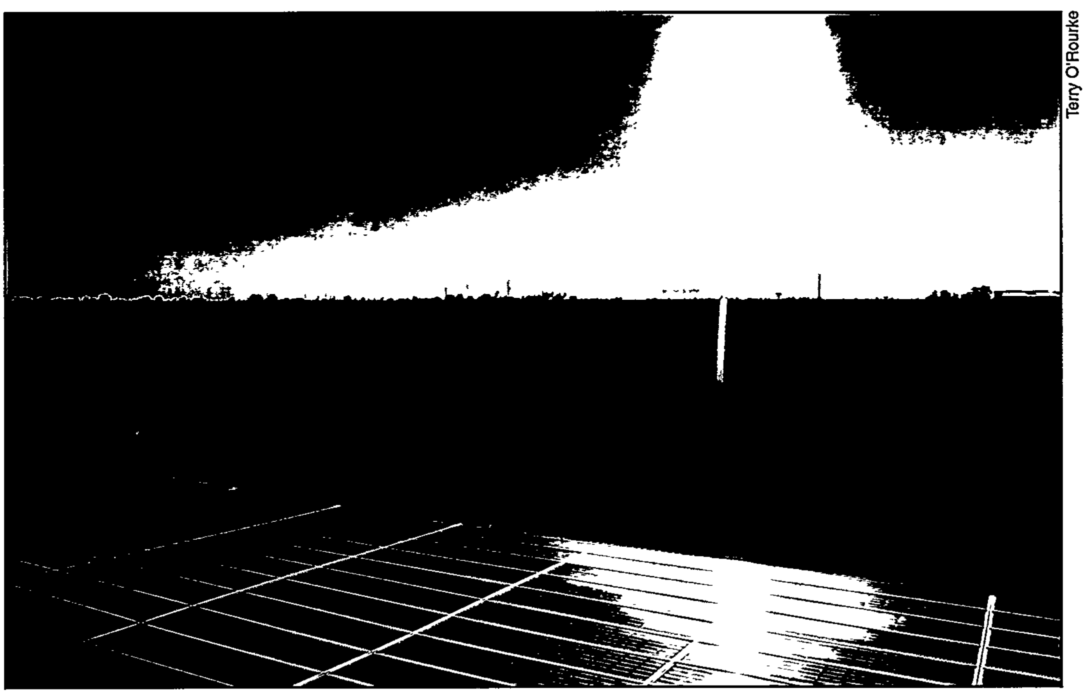
Current accomplishments are described in the *Photovoltaics Program Plan FY 1991 – FY 1995*, which underscores the steady advance of PV technology. In FY 1994, the PV Program began developing its next program plan based on guidance from industry. The PV Program's accomplishments during FY 1994 took place in three key areas: improving systems, advancing basic technology, and expanding markets. In each of these areas, the Program leverages its funding by sharing the costs of projects with its industrial and commercial partners.

**PV Program Funding in FY 1994**

**Total funding: $73,476,000**




The PV Program has a well-rounded plan for developing advanced PV technology and nourishing a competitive U.S. industry.




In FY 1994, the PV Program completed a study of the value of connecting PV generation to utility substations, such as this one near Fresno, California. This pilot PV project, sponsored in part by the Department of Energy, is the first such installation in the world.

# Improving Systems

*U.S. industry leads the world in driving down the cost of PV systems. The PV Program supports the leadership role of industry through cooperative research projects to improve PV systems and develop pre-commercial prototypes of new PV products.*

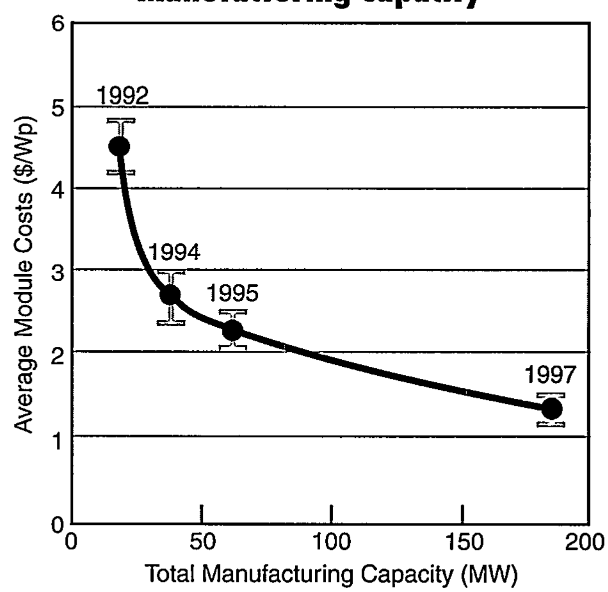
The PV industry made substantial progress in FY 1994 through participating in cooperative R&D projects with the PV Program. First, U.S. manufacturers substantially reduced the costs of producing modules under PVMaT, and began to apply the same cost-reduction techniques to complete PV systems. Second, the industry developed pre-commercial prototypes of new PV products for integration into buildings under PV:BONUS.

The PV Program also provides the services of DOE national laboratories to its commercial partners. A major highlight occurred at NREL in FY 1994, when the PV Program inaugurated the SERF.

## PVMaT

Working with DOE, the PV industry made a number of important advances through the PVMaT project in FY 1994. These advances included reducing manufacturing costs, increasing productivity, increasing the capacity of manufacturing lines, and improving the efficiency and overall quality of PV modules.

**Production Cost and Manufacturing Capacity**

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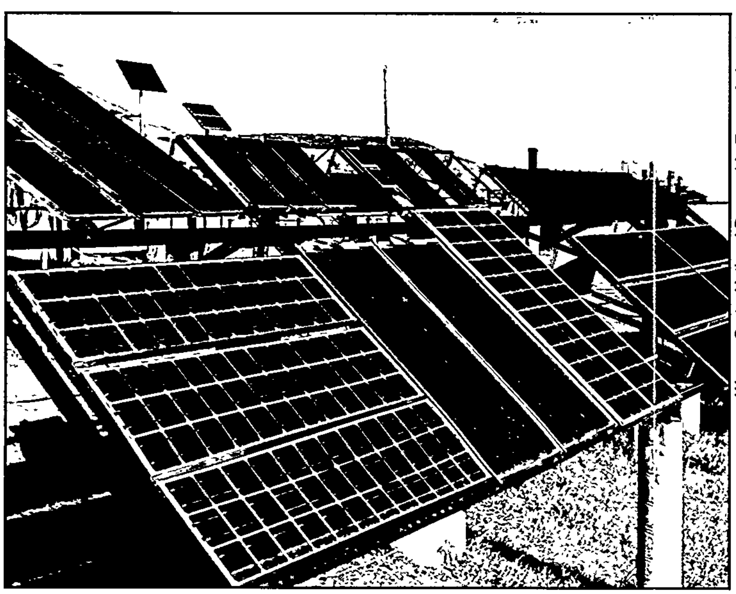
In a mere two years, the companies participating in the PV Manufacturing Technology project substantially reduced production costs and increased manufacturing capacity. The costs are projected to steadily decline during the next three years.



Warren Gretz, National Renewable Energy Laboratory

Engineers at the National Renewable Energy Laboratory of Golden, Colorado, test prototype PV modules produced by companies participating in the PV Manufacturing Technology project.

Seven companies completed their third year of Phase 2A PVMaT subcontracts with DOE. During this time, these companies cut their production costs by a per-company average of nearly 50%.

### Cooperative R&D with Industry

The PVMaT project, now in its fifth year, has four separate R&D phases. Funding for the project will total approximately $150 million, including $75 millon from DOE.

*Phase 1*: Twenty-two companies identified projects to improve PV module manufacturing. The subcontracts were completed in FY 1991.

*Phase 2A*: Seven companies are carrying out their recommendations from Phase 1 to make proprietary improvements and increase their manufacturing capabilities. The subcontracts are in their third and final year.

*Phase 2B*: Four companies continue with projects similar to those of Phase 2A. These 3-year subcontracts began in FY 1994.

*Phase 3A*: Two companies are addressing issues common to the PV industry as a whole, such as increasing automation of manufacturing lines and lengthening PV system lifetimes. These subcontracts began in FY 1993.

*Phase 4A*: Several companies will undertake R&D projects emphasizing product-driven manufacturing in FY 1995. Under these subcontracts, U.S. companies will improve the manufacture and reduce the cost of PV products and systems. The companies will seek to improve their processes for manufacturing modules and non-module components, packaging, manufacturing, assembling, and combining components into complete PV systems.

In FY 1994, the PV Program issued a request for proposals and received a response from more than 30 company teams. This response far exceeds that of previous phases, indicating keen interest by the PV industry in Phase 4 subcontracts.

## Industry Accomplishments Under PVMaT

Each of the companies participating in PVMaT is approaching the manufacture of cost-effective PV modules and systems in a different way. In FY 1994, the companies participating in PVMaT subcontracts made the following advances:

### Phase 2A

*AstroPower, Inc.*, a small business of Newark, Delaware, produces flat-plate PV modules made from its patented polycrystalline Silicon-Film™. Under PVMaT, AstroPower is developing both a machine to generate sheets of Silicon-Film™ and processes for fabricating its cells and modules on a large-area production line.

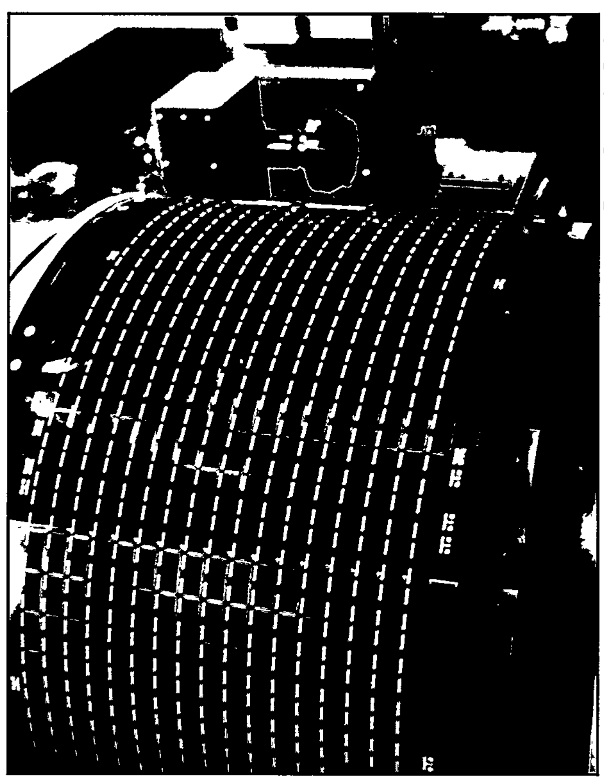
By FY 1994, AstroPower's accomplishments included fabricating a 15-cm x 45-cm, Silicon-Film™ cell, the largest silicon solar cell ever

AstroPower, Inc.

An AstroPower, Inc., employee showcases one of the company's new sheets of Silicon-Film™.

produced. AstroPower also increased its wafer production capacity to 4.4 megawatts (MW) per year and reduced the cost of producing the wafers by 53%. All together, it reduced module fabrication costs by 42%.

*Energy Conversion Devices (ECD), Inc.*, a small business of Troy, Michigan, manufactures modules made from thin-film a-Si. Under PVMaT, ECD is developing technology for continuously manufacturing rolls of films made from multijunction a-Si



Energy Conversion Devices

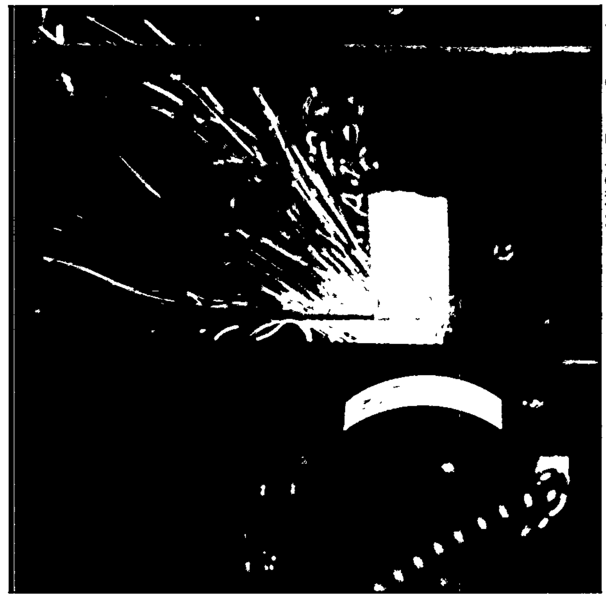
Energy Conversion Devices has been manufacturing rolls of films made from multijunction amorphous silicon alloys since 1993.

alloys. By FY 1994, ECD had demonstrated full-scale production runs of rolls of a-Si film with a total length of 762 m (2506 ft). The film had excellent uniformity and subcell yields that met ECD's quality standards of 99.7%. Uniformity is a critical property of thin films. The company also produced a triple-junction module, 0.37 $m^2$ (4 $ft^2$) in size, with a stabilized efficiency of 8.0%. Overall, ECD reduced material costs by 56%.

*ENTECH, Inc.*, a small business of Dallas-Fort Worth, Texas, produces concentrator PV modules that focus sunlight onto lines of solar cells made from single-crystal silicon. Under PVMaT, ENTECH is increasing the durability, quality, and performance of its concentrator modules; increasing capacity and automation of its manufacturing line; and reducing costs.

By FY 1994, ENTECH had developed several improved production processes to reduce material and labor costs. Working with 3M Company, of St. Paul, Minnesota, ENTECH developed an improved prismatic cell cover, reducing the material and labor costs of that processing step by 90%.

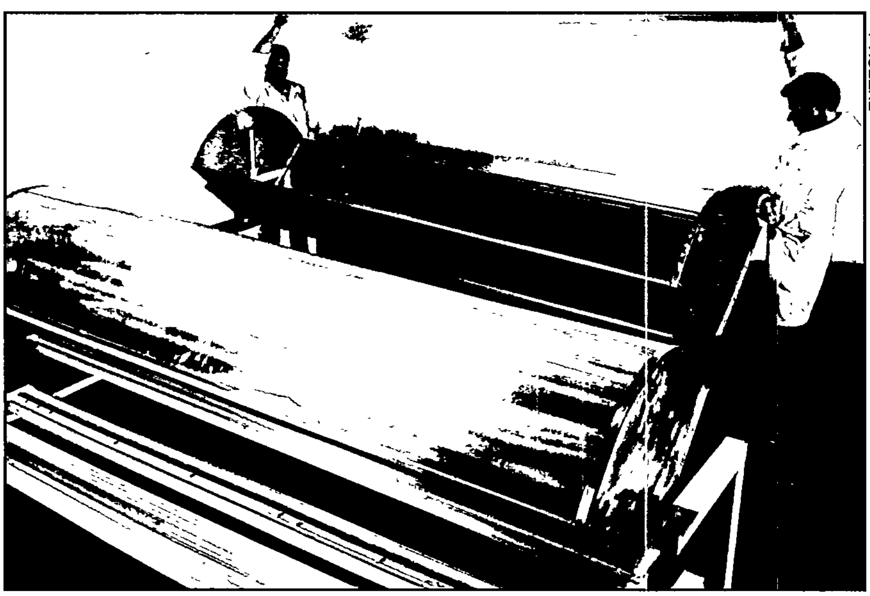
ENTECH also identified a team capable of producing all parts of its concentrator modules at a production capacity of more than 10 MW per year. As part of this team, three companies produce PV cells compatible with ENTECH's module, with efficiencies greater than 19%.


Mobil Solar Energy Corporation

This new workstation developed by Mobil Solar Energy Corporation (now ASE Americas, Inc.) cuts single-crystal silicon into wafers with a laser beam.

*Mobil Solar Energy Corporation*, of Billerica, Massachusetts, produces c-Si cells and modules. Mobil Solar was recently purchased by ASE Americas, Inc.

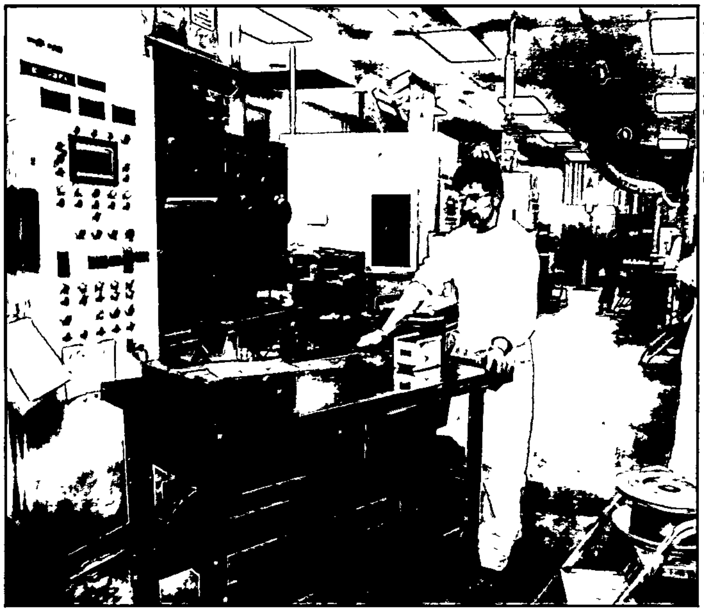
By FY 1994, Mobil Solar had produced thin (250-μm) silicon wafers from unique, octagon-shaped tubes, resulting in cells with an efficiency of 13.8%. In addition, the company developed a workstation on its production line for cutting wafers with a laser beam to increase throughput on the line by a factor of two. Overall, Mobil Solar reduced its module production costs by 15%.


ENTECH, Inc.

These concentrator PV modules produced by ENTECH, Inc., are rated at 430 W each.

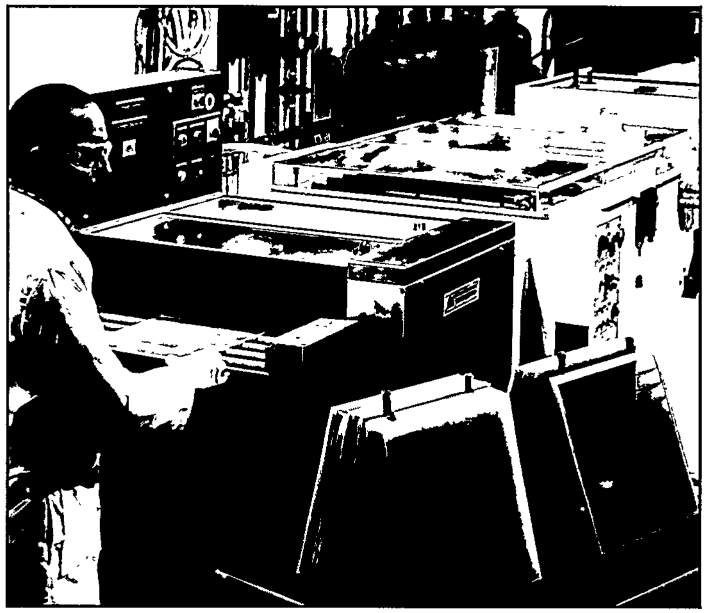
*Siemens Solar Industries*, of Camarillo, California, produces PV modules made from single-crystal silicon cells. Under PVMaT, the company is improving the quality of its crystalline ingots, increasing the efficiency of materials use through improved sawing of Si wafers, automating significant portions of its module manufacturing lines, and reducing the amount of hazardous waste generated during production.

By FY 1994, Siemens had improved the design of its crystal growers, resulting in a 30% reduction in the cost of producing crystalline ingots and a



Siemens Solar Industries

Siemens Solar Industries is increasing the efficiency of materials use and automating its production lines through participation in the Photovoltaic Manufacturing Technology project.



Utility Power Group

The Utility Power Group produces single-junction amorphous silicon modules.

savings of $300,000 per year. Furthermore, the company concentrated the waste streams, resulting in a 10% reduction in waste volume and a 20% reduction in waste-handling costs.

*Solarex Corporation,* of Rockville, Maryland, manufactures large-area, multijunction a-Si alloy modules. Multijunction modules are constructed in layers, each one tailored to absorb a different portion of the solar spectrum. Under PVMaT, Solarex is improving the quality of components and optimizing manufacture of its modules.

By FY 1994, Solarex had developed a monolithic (made in a single piece), multijunction, a-Si

Solarex Corporation

Solarex Corporation plans to increase its capacity to manufacture multijunction modules made from amorphous silicon to 10 MW per year.

module, 3700 $cm^2$ (4 $ft^2$) in size, with an initial efficiency of 8.9%. The company started commercial production of these modules and plans to increase production to 10 MW per year.

*Utility Power Group (UPG),* a small business of Chatsworth, California, and its subcontractor, Advanced Photovoltaic Systems, Inc. (APS), a small business of Lawrenceville, New Jersey, manufacture single-junction a-Si alloy modules. Under PVMaT, these companies are increasing module performance and reducing manufacturing costs. UPG is increasing production capacity, and APS is developing two new module prototypes.

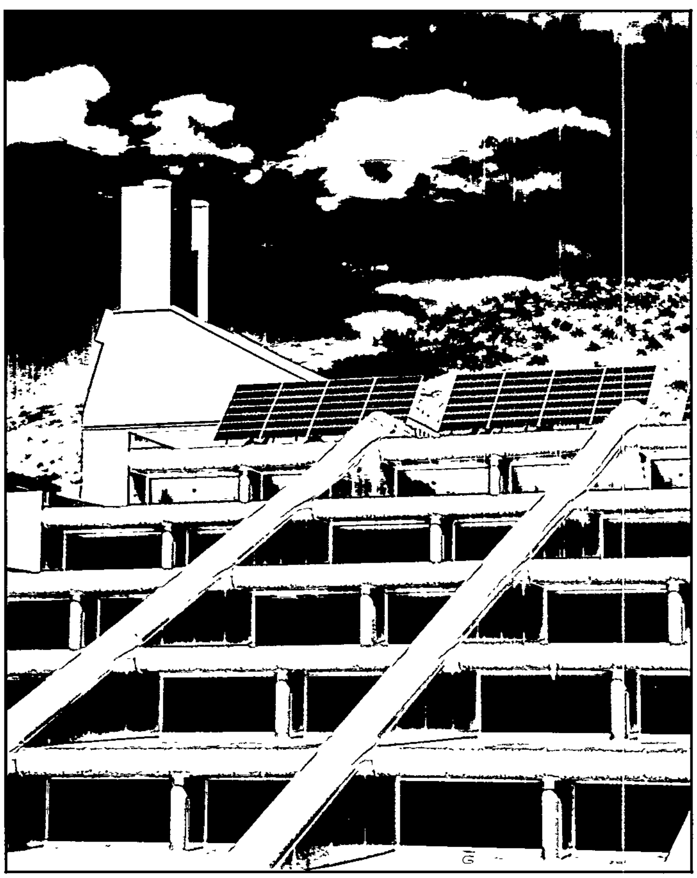
By FY 1994, UPG had substantially streamlined its module-production processes. For example, the company eliminated 30 steps from the process it uses for encapsulating and connecting the electrical leads of the module, reducing the cost of this production step by 81%. Overall, UPG reduced module production costs by 28% and increased its manufacturing capacity by a factor of five. APS developed prototypes of new modules and reduced processing time for producing modules, resulting in a significant reduction in cost.

### Phase 2B

*Golden Photon, Inc.,* of Golden, Colorado, is developing a new PV technology consisting of modules made from cadmium telluride (CdTe) material. This promising thin-film technology can substantially reduce the cost of PV modules. During FY 1994, the company completed design of its manufacturing line with a production capacity of 2 MW per year.

*Solar Cells, Inc. (SCI),* a small business of Toledo, Ohio, is developing a high-throughput manufacturing line of PV modules also made from CdTe. During FY 1994, SCI improved the mechanism for conveying raw materials and controlling pressure and temperature during processing. Overall, SCI increased production capacity by a factor of 100.

*Solarex Corporation's, Crystalline Silicon Division* is advancing its technology for manufacturing PV modules made from cast-ingot polycrystalline silicon. During FY 1994, Solarex engineers modified the design of one casting station, resulting in a 73% increase in capacity, and began using a new wire saw for cutting wafers from cast ingots.



Warren Gretz, National Renewable Energy Laboratory

These modules, produced by Siemens Solar Industries, are mounted on the roof of the Solar Energy Research Facility in Golden, Colorado.

*Texas Instruments, Inc., (TI),* of Dallas-Fort Worth, Texas, is developing its Spheral Solar™ PV technology. TI's innovative approach to module design uses small crystalline silicon spheres bonded to aluminum foil. During FY 1994, TI engineers developed equipment capable of producing several MW per year, demonstrated cell yields as high as 90% on a pilot production line, and produced a pilot PV module, 4000 $cm^2$ in size, with an efficiency of 8.3%. (TI closed its PV operations January 26, 1995.)

### Phase 3A

*Spire Corporation,* a small business of Bedford, Massachusetts, is developing automated equipment that assembles and solders silicon solar cells into cell strings. Forming the strings is an intermediate step in producing PV modules. The equipment can be programmed to handle cells of different sizes and thicknesses from various manufacturers. By using this equipment, module manufacturers will be able to reduce handling of cells, speed processing, and thus reduce overall costs.

In FY 1994, Spire developed and conducted demonstration tests of a prototype machine using silicon cells from several manufacturers. Spire will test the machine in a production setting in FY 1995.

*Springborn Materials Science Corporation,* of Enfield, Connecticut, is improving encapsulants for PV modules. In the past, some encapsulants made with ethylene vinyl acetate prematurely aged when exposed to ultraviolet (UV) insolation.

During FY 1994, Springborn scientists discovered some glass products used by PV module manufacturers transmit significantly less UV radiation than normal glass. Through accelerated UV testing, the scientists determined that the new glass significantly reduces premature aging of the encapsulants.

## PV Integrated Into Buildings

In addition to helping U.S. industry improve its manufacturing capabilities, the PV Program is helping position U.S. industry to profit from the huge potential market for PV-integrated buildings. For example, PV Program analysts predict a market on residential buildings of 20,000 MW by 2020.

PV can be integrated into buildings a number of ways. For example, modules can be mounted on the roof, or constructed as part of the roof or building facade.

PV can also be incorporated into new, innovative products. For example, semi-transparent thin-film a-Si can be coated onto glass using manufacturing processes similar to those used to coat glass for commercial buildings. PV-coated glass could be used for skylights or other locations where coated, semi-transparent glass would otherwise be used.

When PV is used in this way, it becomes part of the architectural structure of the building. Installing PV roofs and PV windows is more cost-effective for the builder, and can decrease the net cost of energy from PV.

### *PV:BONUS*

The PV Program is developing four prototype products for PV-integrated buildings under the PV:BONUS project, including: PV roofing, PV modular homes, alternating current (ac) modules for buildings, and utility-dispatchable PV systems. Each of these products is being developed by a team of firms with a range of buildings- and PV-related expertise. In addition, NREL distributed a newly developed curriculum to architectural schools dealing with PV-integrated buildings.

PV:BONUS is administered by DOE's Golden Field Office with technical support from NREL.

### *PV Roofing*

A team of eight firms, led by ECD, is developing PV systems based on ECD's a-Si technology that directly integrates into conventional roofing material. The team is developing PV roofing materials for two types of roofs—shingles and flat metal roofs. In FY 1994, the team completed construction of the prototype roofs and began outdoor performance testing at NREL.

In FY 1994, one member of the PV-roofing team, the National Association of Home Builders, began designing a prototype townhouse made with a PV-metal roof. The association plans to construct the prototype at its research center in Upper Marlboro, Maryland, beginning in FY 1995.

### *PV Modular Homes*

Another team, led by Fully Independent Residential Solar Technology, Inc. (FIRST), of Hopewell, New Jersey, is developing modular homes with PV modules incorporated into the roofs. Modular homes, mostly constructed in a factory and shipped to the site for final assembly, are becoming increasingly popular because they cost less than homes built entirely on-site by construction contractors.

In FY 1994, the FIRST team constructed and began testing two prototype homes in Ottsville, Pennsylvania. In FY 1995, the team anticipates constructing pre-production models of PV modular homes.

## The PV:BONUS Team Developing PV Roofing

Energy Conversion Devices, Inc., a PV cell manufacturer

United Solar Systems Corporation, a PV module manufacturer

National Association of Home Builders of Upper Marlboro, Maryland, a building trade association

Solar Design Associates of Harvard, Massachusetts, an architectural and systems engineering firm

Arizona Public Service Company, of Tempe, Arizona, an electric utility

Bechtel Corporation, of San Francisco, California, an engineering and construction firm

Detroit Edison Company, of Detroit, Michigan, an electric utility

Minoru Yamasaki Associates, of Rochester Hills, Michigan, an architectural firm

## Team Developing PV Modular Homes

Fully Independent Residential Solar Technology, Inc., of Hopewell, New Jersey, a nonprofit organization

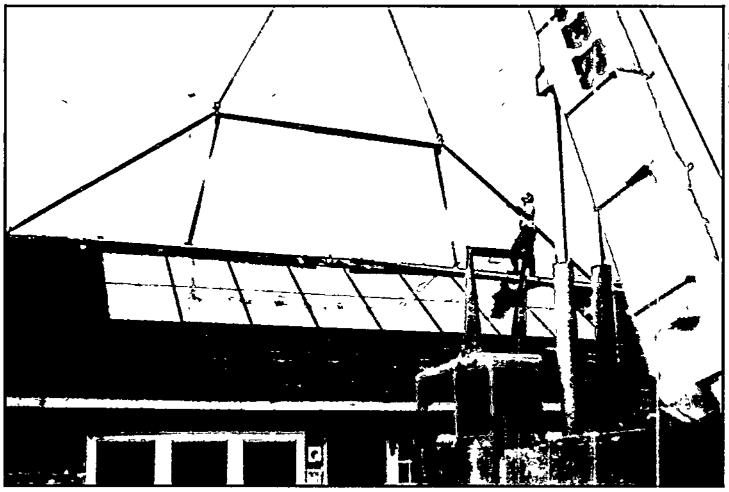
Bradley Builders of Tempe, Pennsylvania, a home builder

AvisAmerica of central Pennsylvania, a builder of modular, manufactured homes

### *AC Modules*

Almost all appliances use ac electricity exclusively; however, existing PV modules produce direct current (dc) electricity, requiring power-conditioning units to convert the dc to ac electricity.

Existing dc modules create several constraints in building design, including the requirement for dc wiring in parts of the building and ac wiring in other parts; the need to size inverters based on projected electrical loads and locate them somewhere in the building; and the limitation on the shape, orientation, and number of PV modules used in the building. An ac module would free



Lyle Rawlings

A prototype modular home, partially constructed in a factory and assembled on site at Ottsville, Pennsylvania, in FY 1994, has PV modules comprising part of the roof.

architects and building designers from such constraints.

In FY 1994, a PV:BONUS team led by Solar Design Associates, a small business of Harvard, Massachusetts, produced five pilot inverters for the ac module. The inverters, the key electrical component of the modules, are constructed into small junction boxes that fit inside the modules. The ac-module team began testing the pilot inverters for performance in laboratories at the Solarex manufacturing plant in Rockville, Maryland.

### Team Developing the ac Module

Solar Design Associates, an architectural and systems engineering firm

Solarex Corporation, a PV module manufacturer

ASE Americas, Inc. (formerly Mobil Solar Energy Company), a PV module manufacturer

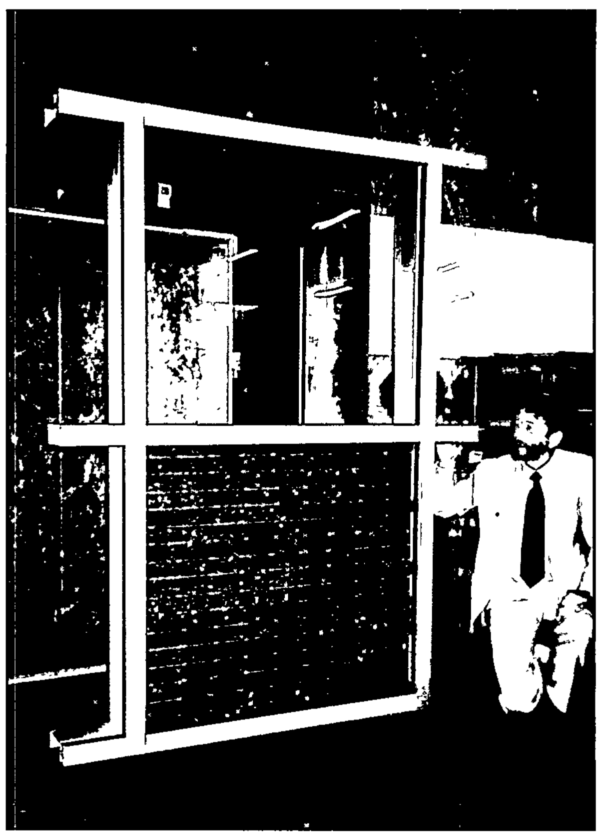
### *Dispatchable Peak-Shaving PV*

Also under PV:BONUS, Delmarva Power and Light Company, of Wilmington, Delaware, is developing PV systems with batteries that can be called upon to supply power dispatched by a utility. The utility would dispatch these systems during its peak periods—when it is experiencing the greatest demand for power from its customers.

The Delmarva Power team designed and installed a prototype dispatchable system on the roof of one of the utility's buildings in FY 1993. The team tested performance of the system during the utility's peak demand periods, which take place during the summer. Based on its performance, the team improved the design of the system in FY 1994, and performed a detailed market study for these systems inside Delmarva Power's service territory.

### *New Curriculum for Architecture Schools*

In FY 1993, NREL, the American Institute of Architects and Associated Collegiate Schools of Architecture Research Corporation of Washington, D.C., developed a course for architecture schools on how to incorporate PV into building designs. The corporation tested a pilot version at several architecture schools in FY 1994 and subsequently distributed them to 50 schools in North America. In FY 1995, it will modify the course into a form that will be useful to practicing architects.



Solar Design Associates

Steve Strong, president of Solar Design Associates, exhibits a prototype alternating-current module incorporated into a window-wall developed under the PV:Building Opportunities for PV in the United States project.

## New Laboratory Capabilities

In FY 1994, the PV Program inaugurated new laboratory capabilities at Sandia and NREL that increase the services provided to industry.

### Solar Energy Research Facility

First among the new facilities was the SERF, opened at NREL in FY 1994 to support PV R&D. Throughout the year, NREL moved 37 laboratories and 170 staff members into the facility with minimal impact on program projects. For example, researchers from the PV Device Performance Laboratory missed only 5 working days as a result of the move. The laboratory is a world-renowned facility for standard measurements of solar cell and module efficiencies.

In addition to housing state-of-the-art laboratories, the SERF is a model example of energy-efficient construction. Design features include daylighting, on-demand lighting, indirect evaporative cooling, variable-speed fan motors, passive solar design, and PV modules integrated into the roof of the building.

Warren Gretz, National Renewable Energy Laboratory

Vice President Al Gore visited the newly inaugurated Solar Energy Research Facility (SERF) at the National Renewable Energy Laboratory in FY 1994. The SERF houses the premier facilities in the nation for PV research and development.

### Power Processing Laboratory

In FY 1994, Sandia reactivated its power-processing test capability as part of the PV Systems Evaluation Laboratory. Projects under way at the laboratory involve improving the performance of such components as charge controllers for PV-battery systems, trackers that allow PV modules to follow the sun during the day, and inverters that convert dc to ac electricity. The projects are designed to improve the performance and reduce the cost of producing the balance-of-systems components connected to PV systems.

In FY 1994, Sandia engineers began a project at the laboratory to develop inverters in support of the U.S. Department of Defense procurement for mid-size PV systems. In order to run acceptance tests for these systems, the engineers designed a test bed for benchmark testing of the inverters. Benchmark testing involves evaluating hardware such as inverters from different manufacturers under a single set of performance parameters. The engineers can use this information to help procure the best inverter for a particular project,

#### Companies Evaluating Inverters at Sandia in FY 1994

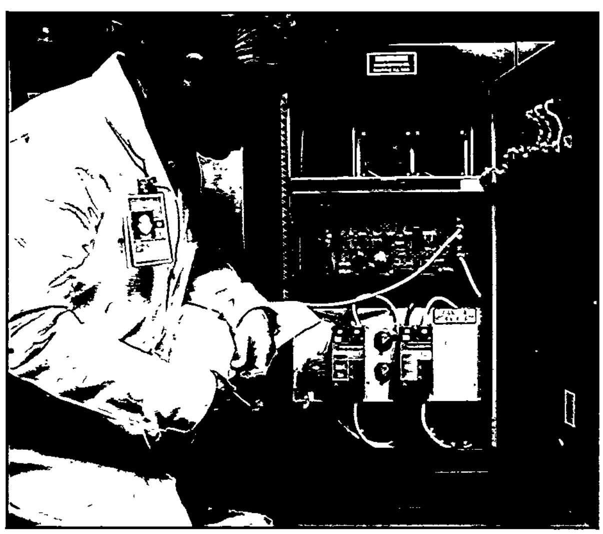
Abacus Controls, Inc., of Somerville, New Jersey

AES/Skyline Engineering, of Temple, New Hampshire

Omnion Power Engineering Company, of Mukwonago, Wisconsin

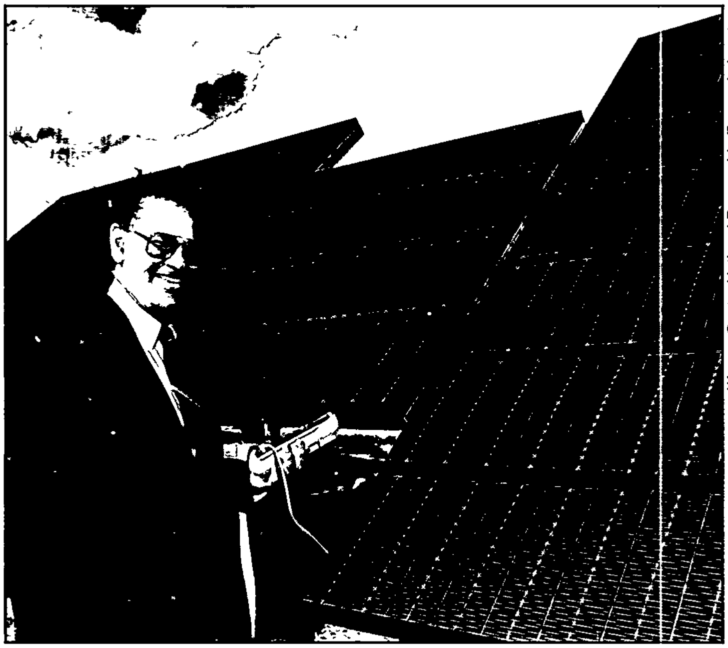
Pacific Inverters, of Spring Valley, California

Trace Inverters, of Gilington, Washington



Sandia National Laboratories

An engineer runs benchmark tests of an inverter at Sandia National Laboratories' new Power Processing Laboratory.




In FY 1994, the National Renewable Energy Laboratory connected these modules at its new Outdoor Test Facility to the local utility, Public Service Company of Colorado. The modules, made from amorphous silicon, were produced by United Solar Systems Corporation, of Troy, Michigan.

or to help direct research toward areas where all manufacturers need to improve.

As a result of the benchmark tests in FY 1994, Sandia engineers identified two areas for improvement in FY 1995: reducing radio frequency interference (RFI) and reducing noise.

Although RFI from most inverters was within Federal Communications Commission standards, some of them could interfere with nearby broadcast communications equipment such as televisions. In FY 1995, Sandia engineers will work with inverter manufacturers to design better RFI filters to reduce interference and noise during operation.

### Outdoor Test Facility

In FY 1994, NREL completed design and began construction of a new Outdoor Test Facility for performance and exploratory testing of PV modules. Testing modules and small PV systems outdoors at such a facility under field operating conditions is important for module manufacturers and potential users to verify performance.

One of the projects already under way at the Outdoor Test Facility is the establishment of a standardized performance energy rating testing (PERT) system. Such a system is useful for the PV industry because it allows module performance to be compared based on standardized tests. For example, the tests help users determine the amount of energy a module will actually deliver over time. In FY 1994, NREL engineers began establishing a PERT data base of existing modules and established an industry review committee to develop criteria and methods for rating energy delivery of modules.

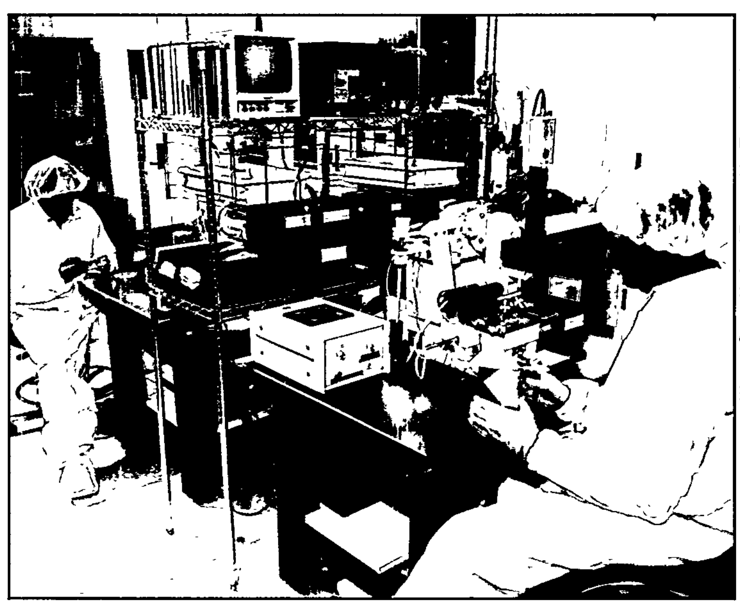
The project underscores the technical basis for the PV Program's support of industry because such methods form the basis for recommended practices and standards in the industry. Engineers then use these practices and standards to specify, procure, and install systems in the field.

## Program Services for Industry

Both NREL and Sandia have made additional facilities and services available to the private sector, including:

- *Measurement and Performance*

  Both NREL and Sandia have laboratories that perform thousands of state-of-the-art measurements for the PV industry. These include analyzing materials, characterizing devices, evaluating fabrication problems, and modeling performance with computers. In FY 1994, for example, program scientists performed more than 17,000 characterizations of cells and modules



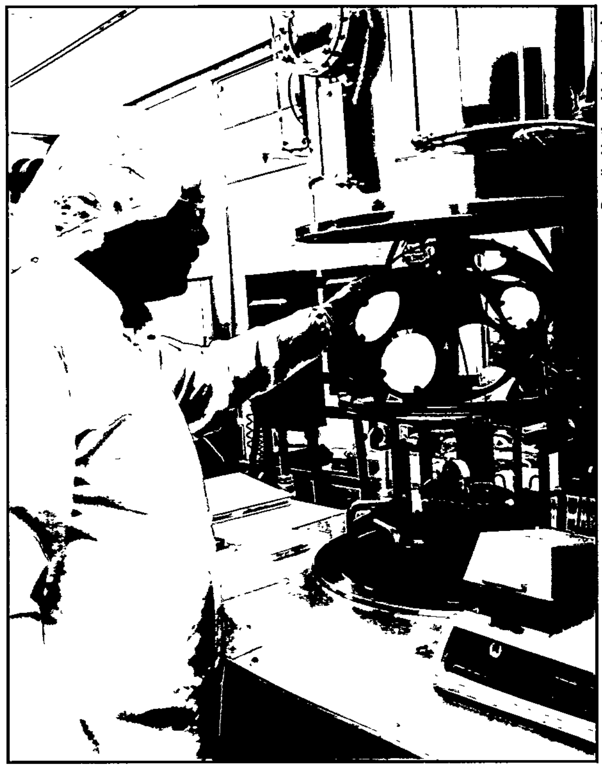

In FY 1994, the National Renewable Energy Laboratory opened the Clean Room at the Solar Energy Research Facility to incorporate advances in semiconductor science into PV technology.

for more than 100 research groups in industry, universities, and other research organizations.

- *Materials and Processing*

  NREL has facilities for crystal growth, thin-film deposition, and cell component and materials processing development. The material and device research capabilities extend from crystalline silicon to thin-film materials (for example, a-Si, copper indium diselenide [CIS], and CdTe) to gallium arsenide and other III-V materials.

  Sandia's Photovoltaic Device Fabrication Laboratory (PDFL) is available to integrate new c-Si solar cell designs and fabrication processes into manufacturing facilities.


Sandia National Laboratories

Program scientists produce advanced crystalline silicon cells using processing methods similar to those prevalent in today's PV industry at Sandia National Laboratories' Photovoltaic Device Fabrication Laboratory.

# Advancing PV Technology

***PV Program scientists and their research partners in industry and universities expanded the understanding of the fundamental mechanisms governing the formation and performance of PV materials.***

Advances in PV science continued in FY 1994 through research encompassing both crystalline and thin-film materials.

## Crystalline Silicon

About 95% of today's commercially available PV modules are made from c-Si cells—both single-crystal and multicrystalline silicon.

### Single-Crystal Silicon

In FY 1994, researchers at the University of New South Wales (of Australia) fabricated a new cell which broke the 4-year-old efficiency record for a one-sun single-crystal silicon cell. The cell, called the Passivated Emitter, Rear Locally Diffused cell, has an efficiency of 24.0%, the highest efficiency of any silicon cell yet recorded. It is fabricated on 10-cm-diameter wafers made from float-zone silicon, the highest quality and purest form of silicon. Sandia has supported development of the design of this cell for several years.

In another project using float-zone silicon, Honda R&D Company Ltd., of Siatama, Japan, incorporated c-Si cells produced by SunPower into a power module with an efficiency of 21.6%. This is the highest efficiency of any flat-plate module yet produced. SunPower provided the back-contact cells for the module, the cells for which it shared the prestigious R&D 100 Award in FY 1994 with Sandia. By producing a c-Si module with an efficiency greater than 20%, Sandia passed an important research milestone of the PV Program.

Sandia scientists are also working with solar-grade Czochralski (Cz) silicon, which is slightly less pure than the float-zone-type silicon. Cz silicon is, however, representative of that used by c-Si cell manufacturers. Improvements in production processes using Cz silicon can be quickly incorporated into these companies' production lines.

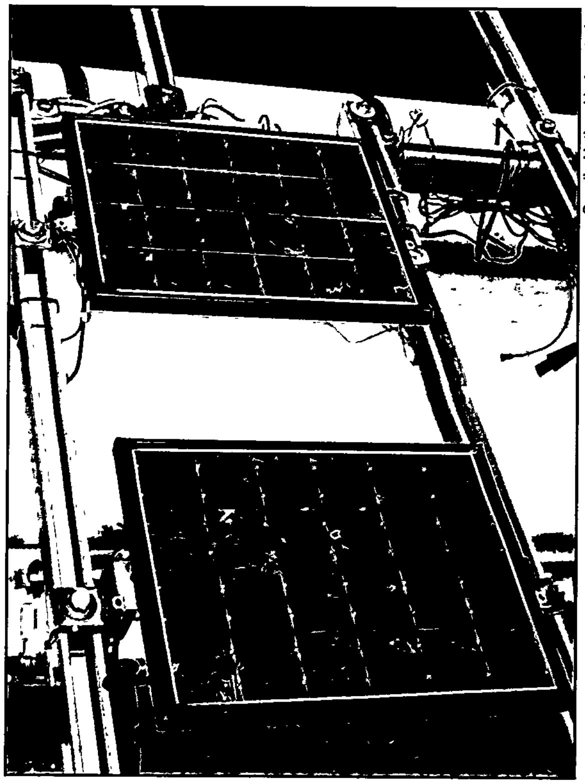
In FY 1994, engineers at Sandia's PDFL produced a cell, 4 $cm^2$ in size, using Cz silicon supplied by Siemens. At 18.3%, this cell efficiency is more than 1% higher than that of the best cell produced by Siemens, and provides directions for improving the company's processes.

Also in FY 1994, Siemens and Sandia began a collaborative project to fabricate thin, single-crystal cells (250 $\mu$m). Producing thinner cells would reduce manufacturing costs through more efficient use of single-crystal material and reduced handling.

Also in FY 1994, Georgia Tech scientists fabricated a cell produced from float-zone silicon with an efficiency of 16.9%, using "rapid thermal processing." Georgia Tech scientists produced these cells using two short processing steps, each less than 10 minutes, carried out at a temperature of 880°C. At this temperature, they can perform several processing steps at once, which can eventually lead to reducing the time and cost of producing the cells. Ultimately, these scientists hope to fabricate such cells in an hour or less. In FY 1995, the scientists will begin applying these techniques to producing multicrystalline silicon cells.

### Multicrystalline Silicon

Multicrystalline cells can be produced and processed at a lower cost than single-crystal cells because carefully producing a large, single crystal of silicon is not required. In FY 1994, PV Program researchers produced new cells and modules with record efficiencies and faster, lower cost production processes.



Sandia National Laboratories

In FY 1994, Sandia National Laboratories researchers built the first prototype multicrystalline silicon module with an efficiency greater than 15%.

In FY 1994, scientists at Sandia designed and built a prototype module made with multicrystalline silicon with an efficiency of 15.3%. This is the first time a module with 15% efficiency has ever been made with this material.

The Sandia engineers produced the module using cell-processing techniques similar to those developed at the Georgia Institute of Technology (Georgia Tech), of Atlanta, Georgia. DOE designated Georgia Tech as a University Center of Excellence for PV Research and Education. In FY 1994, Georgia Tech researchers produced a small-area multicrystalline silicon cell with an efficiency of 17.8%, the highest efficiency recorded to date for research cells made from this material.

The cell produced by Georgia Tech and the module produced by Sandia used high-quality multicrystalline silicon produced by Crystal Systems, Inc., a small business of Salem, Massachusetts. In FY 1994, engineers from Crystal Systems and scientists from NREL and Sandia improved the heat exchanger method used to fabricate the company's multicrystalline silicon. Using this method, heat flow is carefully controlled during processing so that the silicon solidifies along a nearly planar solid-liquid interface. The resulting material is made up of grains relatively large in size and with superior electrical properties.

## Basic Science

The PV Program also developed advanced scientific and measuring equipment to further advance PV technology. One example of high-technology equipment developed by PV Program scientists is the Scanning Defect Mapping System (SDMS), now being developed as a commercial product by U.S. industry.

The SDMS, designed and built originally at NREL, won the R&D 100 Award in FY 1993. The SDMS accurately and quickly—in less than 1 hour—measures the number and type of crystalline defects in a single-crystal or multicrystalline silicon wafer. Before the SDMS was built, scientists used laborious processes to characterize the crystalline properties of silicon, taking as much as 2 weeks for a sample.

NREL joined forces with Labsphere, a small business of North Sutton, New Hampshire, to license the SDMS. The company will market the SDMS to companies working with silicon in the PV and semiconductor industries to monitor and control quality in their production processes. Labsphere licensed the technology and produced a

Warren Gretz, National Renewable Energy Laboratory

In FY 1994, Labsphere began commercial production of this Scanning Defect Mapping System. The system, originally developed at the National Renewable Energy Laboratory, won the prestigious R&D 100 Award in FY 1993.

pre-commercial prototype in FY 1994; the company plans to begin commercial production and sales of the machine in FY 1995.

## Concentrator Cells and Modules

In FY 1994, the PV Program provided assistance to companies developing concentrator PV modules and produced new cells for concentrator modules. Concentrator modules use optical lenses to focus sunlight on smaller, highly efficient PV cells.

### New Modules

The Solar Energy Applications Corporation (SEA), of San Jose, California, installed concentrator modules into four arrays under a commercial contract with the Sacramento Municipal Utility District (SMUD), of Sacramento, California, in FY 1994. SEA uses low-cost acrylic concentrators with a low concentration ratio (approximately 10 suns)—the area of the concentrators divided by the area of the cells, measured in "suns."

In addition, ENTECH produced the largest PV module in the world in FY 1994 under the PVMaT project. The prototype module has a concentration ratio of approximately 20 suns and has a rated power output of 430 W.

The company installed four arrays in FY 1994 under a commercial contract with two utilities in Texas: one array in Fort Davis, Texas, with Central and South West Services, Inc., of Dallas, Texas, and three arrays with Texas Utilities of Dallas, Texas. Each has a rated capacity of 25 kW.

Both ENTECH and SEA developed several generations of prototypes under PVMaT and the Concentrator Initiative during FY 1992 – FY 1994. SEA's subcontract to Sandia under the Concentrator Initiative is scheduled to be completed in FY 1995.

### Record-Setting Cells

Cells used in concentrator modules are different than those used for flat-plate modules in several ways. Because there are fewer of them in a single module, higher quality, more efficient cells can be used more economically. They also provide a higher power output per cell.

In FY 1994, NREL scientists produced a small-area (0.1 cm$^2$) concentrator cell made from ($GaInP_2$/GaAs). The cell had an efficiency of 30.2% under a concentration ratio of 180 suns. By producing a cell with an efficiency greater than 30%, the scientists passed an important research milestone of the PV Program.

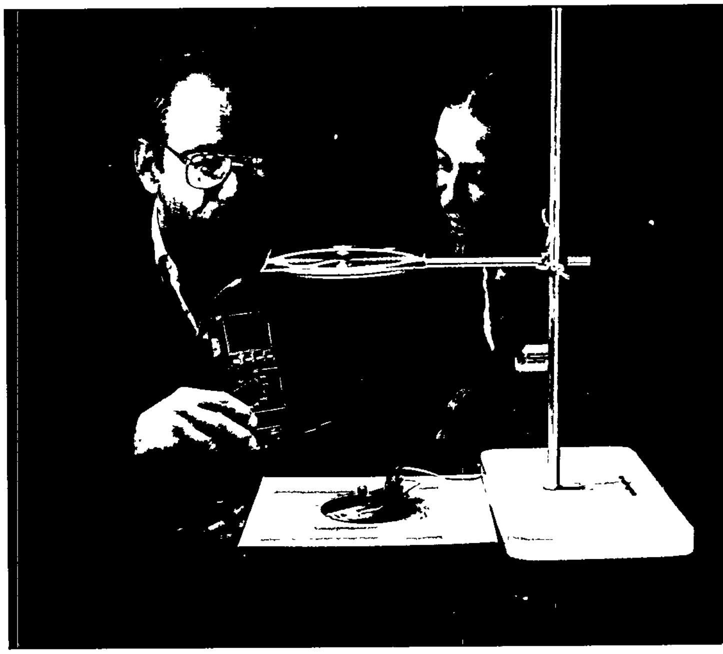
The monolithic, two-junction cell was produced by growing epitaxial layers of $GaInP_2$ immediately after the growth of a conventional crystalline GaAs cell. The scientists carefully chose the materials because their crystalline lattice structures are matched (to improve the monolithic crystal quality) and because they absorb a different portion of the solar spectrum.

Compared to a simple, single-junction GaAs cell, the efficiency of this cell is almost 20% higher. However, because of the monolithic design of this cell, processing takes only a few minutes longer.

In FY 1994, Applied Solar Energy Corporation and Spectrolab, both of Los Angeles, California, announced plans to make this cell for applications in space.

### Thin Films

Thin-film PV consists of modules made of very thin layers of PV materials. The layers are usually about 1μm–10 μm, or about 30 to 100 times thinner than cells and modules made from wafers. In addition to using small amounts of material, these



Warren Gretz, National Renewable Energy Laboratory

By producing a concentrator cell with an efficiency greater than 30%, National Renewable Energy Laboratory scientists passed an important milestone of the PV Program.

modules can be manufactured in a single series of steps (monolithically) with less processing and lower costs than conventional PV modules.

The PV industry and the PV Program both made significant strides in advancing thin-film technology in FY 1994. Two thin film companies passed the milestone of producing 10%-efficient prototype modules. By the end of FY 1994, at least five U.S. companies were either building manufacturing plants or planning to do so.

In FY 1994, PV Program scientists developed advanced methods of producing thin films and achieved record efficiencies in laboratory cells significantly higher than previous records. They also produced thin films that are stable in outdoor operating conditions, and furthered scientific understanding of the physics involved in the instability of samples produced with existing methods. The advances took place both in a-Si and polycrystalline thin films—CdTe and CIS.

### Amorphous Silicon

Two important advances took place in a-Si technology in FY 1994. First, an a-Si manufacturer, United Solar Systems Corporation, produced a prototype module with a stabilized efficiency of 10.2%. This is the first a-Si module yet recorded with a stabilized efficiency of more than 10%.

Second, NREL scientists used a novel method to produce a-Si material samples whose efficiency is stable when exposed to sunlight. The current method for producing a-Si materials is a relatively low-temperature (250°C) vacuum process called glow discharge. When a-Si modules produced with this method are exposed to sunlight, their performance degrades. For this reason, performance values for a-Si modules are usually quoted in terms of "stabilized efficiencies."

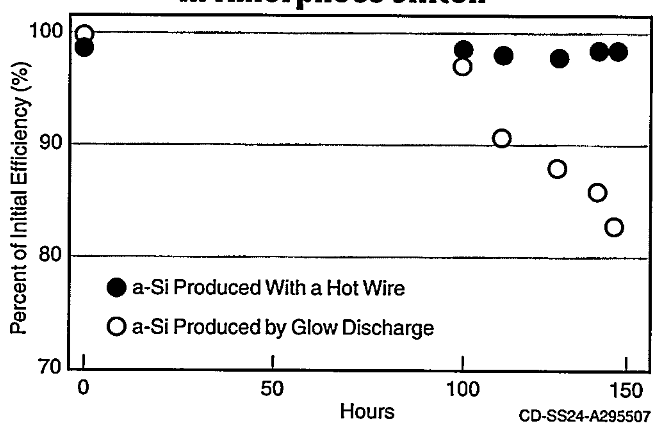
In FY 1994, NREL scientists produced samples of a-Si materials using a hot-wire technique. The hot wire, which is similar to that used in a tungsten filament lamp, produces temperatures of about 2000°C near the wire. Scientists then exposed the sample to lamps in a laboratory for 120 hours. Preliminary results of the test show no degradation of performance. For comparison, the performance of similar samples made with the glow-discharge method used in this test degraded 16%.

Scientists believe the higher temperatures produce a-Si with superior electrical characteristics (measured in terms of reduced defect densities).

Warren Gretz, National Renewable Energy Laboratory

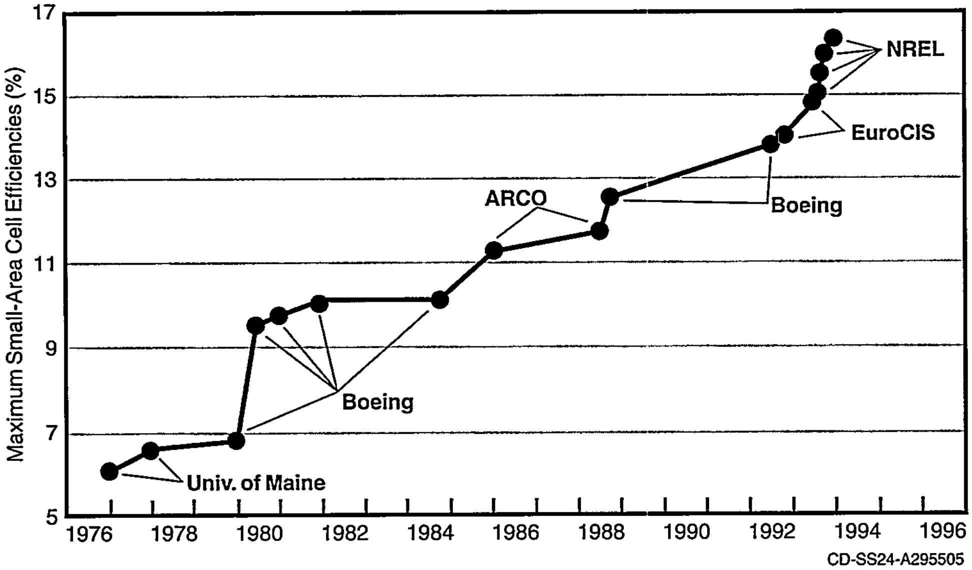
This research team from the National Renewable Energy Laboratory won the "Best of What's New" award given by *Popular Science* in FY 1994 for producing a thin-film copper indium diselenide cell with a record efficiency and a potential for very-low-cost production.

**Light Induced Degradation in Amorphous Silicon**



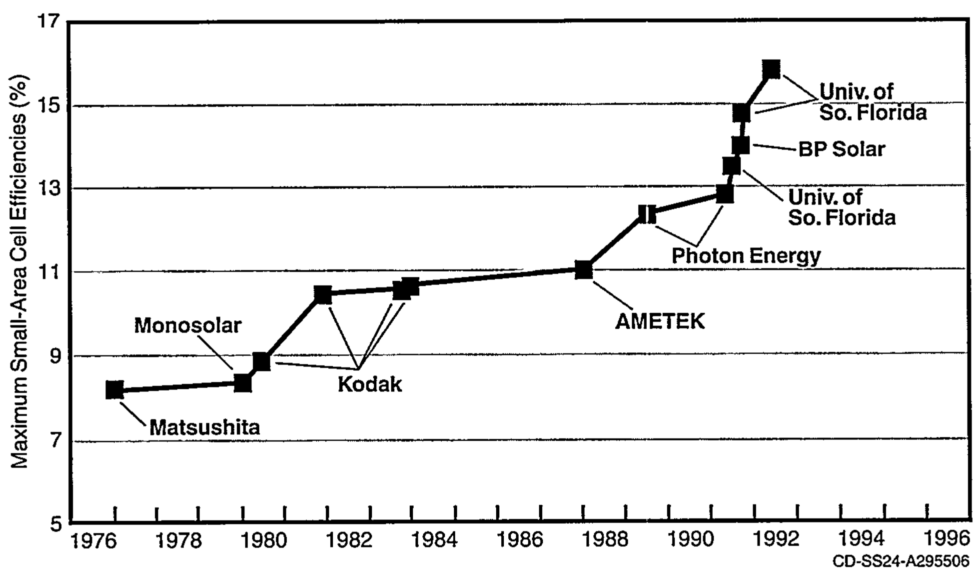

Scientists at the National Renewable Energy Laboratory used a hot-wire technique in FY 1994 to produce an amorphous silicon PV device that remained stable when exposed to simulated sunlight in a laboratory.

## Record CIS Cells




Scientists at the National Renewable Energy Laboratory developed small-area copper indium diselenide cells in FY 1994 with efficiencies of almost 17%, more than double those of a decade ago. These cells have the highest efficiencies of any thin-film cells in the world.

## Record CdTe Cells




In the last several years, there has been a remarkable increase in performance of small-area cadmium telluride cells in the laboratory measured at standard conditions.

In addition, the amount of hydrogen that remains in the a-Si material produced by a hot wire is low, about 2% of the total. By comparison, a-Si material produced by the glow-discharge method consists of about 10% hydrogen.

NREL scientists have hypothesized for several years that the presence of too much hydrogen causes instability. In FY 1994, scientists at the University of Oregon confirmed independently that a-Si material with a low percentage of hydrogen (produced by a different method) remains stable when exposed to sunlight.

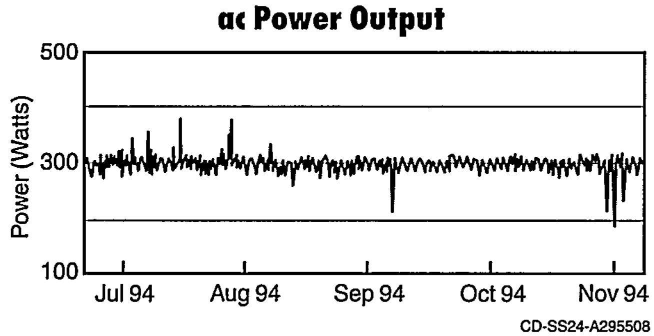
In FY 1995, NREL scientists will conduct more tests and produce a-Si samples with a hot-wire that have higher absolute efficiencies.

### *Polycrystalline Thin Films*

The PV Program is working to develop two polycrystalline thin films, CdTe and CIS, because performance of laboratory cells has been improving rapidly in recent years. Furthermore, NREL began performance testing in FY 1994 of the first arrays of CdTe and CIS modules.

This performance record continued in FY 1994, when NREL scientists produced a small-area cell in the laboratory made from copper indium gallium diselenide with an efficiency of 16.8%. This is the highest efficiency yet recorded for any thin-film cell.

Also in FY 1994, scientists at the University of Illinois at Champaign-Urbana produced a single-crystal sample of CIS in the laboratory. Having single-crystal CIS samples available for analysis will allow for the orderly, scientific characterization of the properties of CIS in the future.




The alternating current power output of a 0.4-kW array cadmium telluride module produced by Solar Cells, Inc., remained stable during performance testing at the National Renewable Energy Laboratory in FY 1994.

Industry progress in FY 1994 has been equally remarkable. Siemens Solar Industries produced the first CIS power module, 3892 $cm^2$ (4 $ft^2$) in size, with an efficiency of 10.3%. This is also the highest stable efficiency for a thin-film module to date.

Siemens shipped a 1-kW array of CIS modules to NREL to begin performance testing outdoors in FY 1994. Similarly, SCI shipped a 0.4 kW array made from CdTe modules. The details of the performance tests are provided to the individual companies; nevertheless, the output of the modules remains stable in outdoor environments.

NREL scientists verified in FY 1994 that modules produced by SCI had a power output of 55.4 W and an efficiency of 8.1%, a record for this material. Several other SCI prototype modules underwent performance testing outdoors at NREL throughout FY 1994. So far, output has remained stable.

## The Thin-Film PV Partnership Program

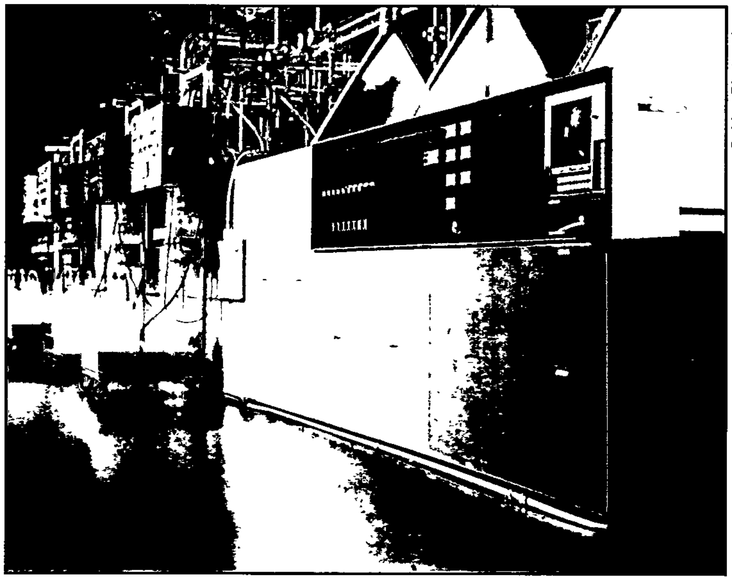
In FY 1994, DOE announced the formation of a partnership program to support development of thin-film PV. The 5-year program, called the Thin-Film PV Partnership Program, will be funded for about $180 million. DOE will provide about two-thirds and private industry will provide the rest.

The purpose of the thin-films partnership is to develop a continuous stream of pre-commercial prototype products. These prototypes start as ideas in research laboratories and end as fully tested technologies ready for private industry to license and deploy in the marketplace.

NREL began negotiating the first series of 11 contracts in FY 1994. The contracts, worth $29 million, are with six commercial partners in industry and five research partners in universities. Of the six commercial partners, four are small businesses. Each of the partners will supplement 10%–50% of the value of these contracts with its own funds.

The reason for combining all thin-film product R&D under one umbrella is because the thin-film PV industry is making particularly good progress in commercial development. By the end of FY 1994, at least five U.S. companies were either building new manufacturing plants or planning to do so.

Furthermore, many analysts believe thin films hold a leading edge for the future of very-low-cost PV. By combining the talents of scientists performing fundamental research with engineers developing prototype modules under one organization, the PV Program will help participating companies position themselves to be market leaders in the 21st century.



Golden Photon, Inc.

Golden Photon, Inc., is completing construction of a facility for manufacturing cadmium telluride modules in Golden, Colorado. The Thin-Film PV Partnership Program will supply a continuous stream of advanced thin-film technology to companies such as Golden Photon to incorporate into their manufacturing facilities.

## Sandia Shares R&D 100 Award

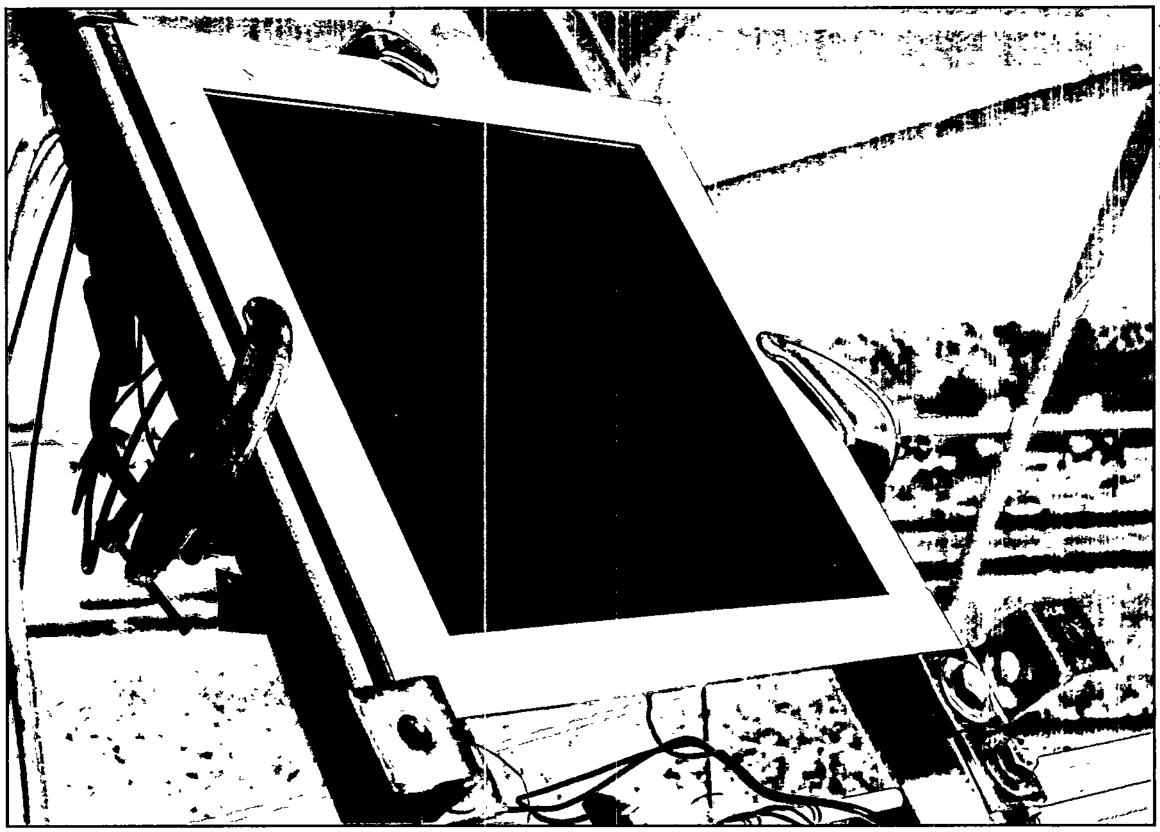
For the fourth year in a row, the PV Program received the R&D 100 Award in FY 1994. Every year, *R&D* magazine designates the awards for the 100 most important scientific advances of the year. This year's award was for supporting development of a high-efficiency c-Si cell called the back-contact cell.

The unique design of this c-Si cell leads to its high efficiency. Unlike conventional cells, which have metallic grids on the front and rear surfaces of the cell, all of the electrical contacts on this unique cell are at the back surface of the cell.

Another unique design feature is the construction of the electrical field inside the cell. Unlike conventional cells in which an electric field is formed by doping different layers of the c-Si with minute quantities of phosphorus and boron, large numbers of highly doped regions with much smaller junctions between them are on the back of this cell.

As a result, the back-contact cell has increased efficiency for at least two reasons. First, there is no top grid to prevent sunlight from entering the portion of the cell that is covered by the grid. Therefore, more charge carriers—oppositely charged electrons and holes—are generated in the cell. Second, the contacts are closer to where the charge carriers are generated. As a result, these charge carriers have less distance to travel and less opportunity to recombine. More charge carriers are collected in the electrical contacts, more electricity is generated, and the efficiency is higher.

DOE shares the award with SunPower, the Electric Power Research Institute (EPRI), of Palo Alto, California, Sandia, and Amonix, Inc., of Torrance, California.



Sandia National Labortories

SunPower Corporation has entered into a commercial agreement with Honda to incorporate its back-contact cell into a new commercial module. A prototype module, pictured here undergoing performance testing at Sandia National Laboratories, has a record efficiency of 21.6%.

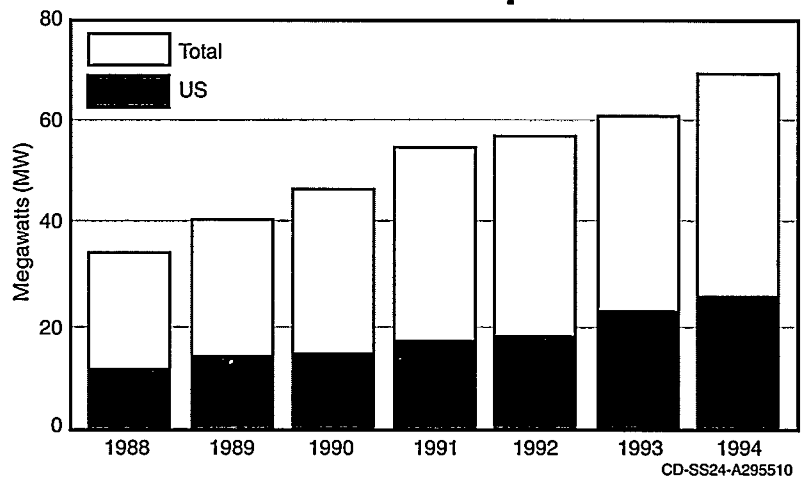
# Expanding PV Markets

***As PV technology continues to advance in worldwide markets, the PV Program helps U.S. industry enhance its leadership position.***

The PV Program inaugurated a number of projects in FY 1994 to demonstrate the value of PV systems for several important market segments by verifying their performance. The projects include domestic utilities, exports, and government applications for the U.S. Department of Defense and the National Park Service.

DOE sponsors only part of each of these development projects with other agencies and private companies, thus effectively leveraging program funds. DOE participates in these projects as part of a national plan put forward with U.S. industry to develop PV technology and expand worldwide markets.

**World PV Module Shipments**

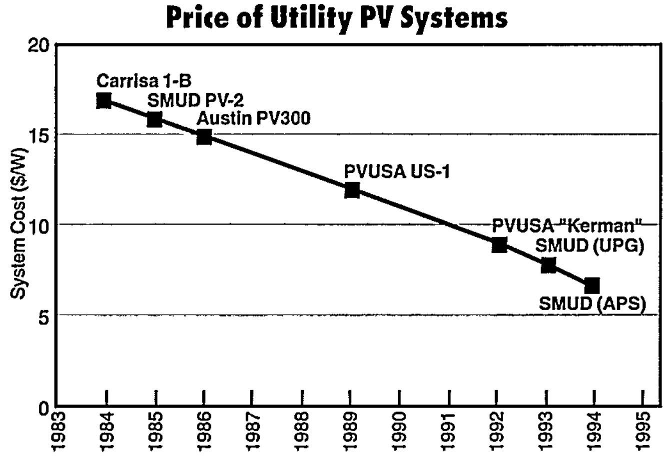



Annual worldwide sales of PV have increased at a rate of 17% per year for the last 10 years. In 1994, U.S. industry's share of this market increased to 36%, up from less than 30% in the late 1980s.

## Domestic Utilities

Utilities play a major role in all large-scale power generation, and, as a result, their activities take on strategic importance. In FY 1994, UPVG confirmed that utility involvement in large-scale PV markets is strong.

**Price of Utility PV Systems**




In FY 1994, the Utility PhotoVoltaic Group documented the steady reduction in price of utility PV systems during the last decade.

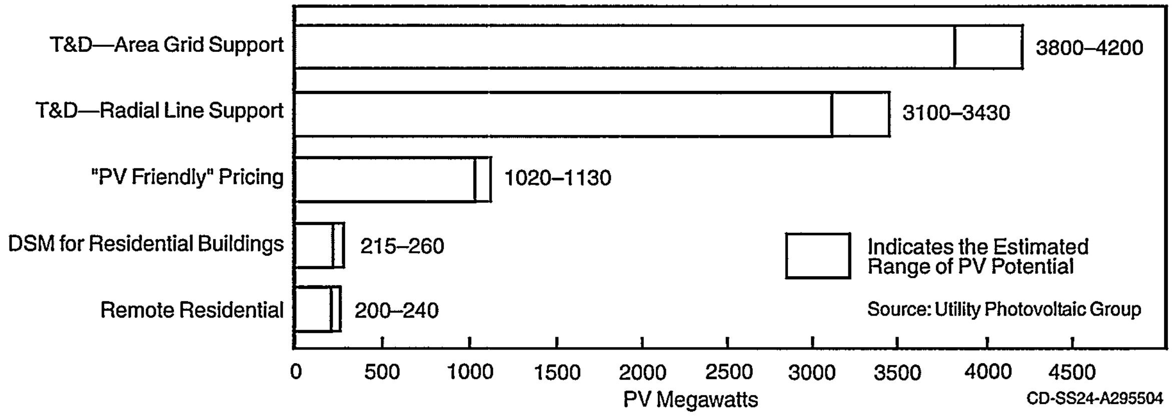
UPVG was formed in 1992 to accelerate cost-effective PV applications. It consists of members from 89 utilities, the American Public Power Association, of Washington, D.C., the Edison Electric Institute, of Washington, D.C., EPRI, and the National Rural Electric Cooperative Association, of Washington, D.C. Collectively, these 89 utilities produce almost one-half of the electricity consumed in the United States. The UPVG is supported by a grant from DOE's PV Program.

## PV Potential

In FY 1994, UPVG carried out a study of potential PV use by U.S. utilities. UPVG's members identified nearly 9000 MW of capacity that utilities would be willing to purchase at a price of $3,000 per kW as cost-effective systems.

The size of the potential market, 9000 MW, was much greater than expected. With a domestic utility market of this magnitude, UPVG outlined how the PV industry can begin a self-sustaining process whereby PV eventually becomes competitive with

## The Potential Utility Market for PV




In its groundbreaking study, UPVG identified a domestic utility market of 9000 MW when PV systems reach $3,000 per kW. The following are the five main components of that market.

*T&D area grid support* connects a PV system with a capacity of 200 kW–1000 kW to a T&D substation to supply added power to the area served by the substation. When the area experiences load growth, the PV system reduces excess loading on all the T&D lines and other equipment in the area.

*T&D radial line support* connects a PV system with a capacity of 50 kW–200 kW directly to a transmission line experiencing load growth, and therefore alleviates problems such as voltage drop and poor power quality. All together, there are more than 200,000 distribution lines in the United States; as many as 5% could be connected to a PV system.

*PV-friendly pricing* is a rate structure used by several utilities that allows grid-connected customers to choose PV as their main power supply. The utility installs and maintains the system on the customer's property, and charges a premium for the service. SMUD has the largest PV-friendly pricing program.

*DSM for residential buildings* is where PV systems located on a residence are controlled (electrically) by a utility for demand-side management (DSM). Thus, PV systems become part of the DSM industry, which currently has annual sales of more than $3 billion.

*Remote residential buildings* can use PV-generated electricity provided by a utility less expensively than connecting to a distribution line.

conventional power generation by consolidating existing markets and price reductions.

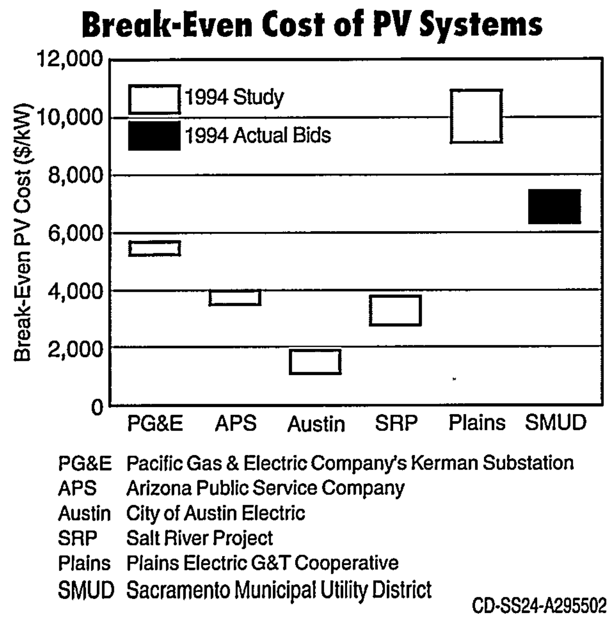
In FY 1994, 62 utilities expressed formal interest in participating in demonstration projects with UPVG. The initial proposals from these utilities had an aggregate capacity of more than 8 MW, with a combined utility investment of more than $38 million.

## The Value of Grid Support

The PV Program helped lay the groundwork for the UPVG study through its demonstration projects organized under the Photovoltaics for Utility Scale Applications (PVUSA) project. For example, the PV Program helped sponsor the world's first T&D grid support system through PVUSA. The system, rated at 500 kW, was installed near Fresno, California, in FY 1993. In FY 1994, the PV Program provided technical assistance to SMUD to install a second grid-support system, rated at 200 kW, in Sacramento, California. Also in FY 1994, PVUSA completed a study of the value of such PV systems for other utilities.

Sandia supplemented this work by sponsoring a study with four other utilities in FY 1994 to determine the value of PV for grid support. Each of the utilities participating in the study operates in a different economic environment and has a different solar resource than the others.

In related work, Sandia engineers helped develop a spreadsheet computer program in FY 1994 to help utility engineers quickly identify where they could locate cost-effective PV systems in their grids. Developed by the NEOS Corporation, a small business of Lakewood, Colorado, the spreadsheet allows utilities to perform quick cost-benefit studies that prove a PV system is worth more extensive analysis.




When used for grid support, the cost-effectiveness of a PV power plant depends strongly on its location and utility economics. Some utilities can obtain good value from PV installations for grid support at today's prices.

Each chose a substation that was experiencing load growth and evaluated the economics of installing a PV system at the substation. Each determined the "break-even" cost—the price at which PV systems would be economical at that substation.

The results showed that the cost-effectiveness of PV for grid support is strongly dependent on location and utility economics. But for some utilities, PV is already cost effective for grid support in certain locations. Based on the results of this study, these utilities now have tools to help evaluate when PV is cost effective for grid support.

## PV for Demand-Side Management

The PV Program is also verifying the value of using PV for DSM applications. Such a PV system can be valuable to utilities to supply capacity during peak periods to the extent that its output corresponds with the times the utility experiences its peak demand. The extent of this correspondence helps utilities determine the value of the PV for DSM.

NREL is developing a data base that utilities can use to evaluate the extent of the correspondence for their systems. NREL is collecting data from its own PV-DSM system on the SERF and from projects under way with the University of Delaware's Center for Energy and Environmental Policy. Furthermore, the State University of New York at Albany is looking at utility load profile and solar availability correlations.

The majority of the data base will be provided by projects sponsored by the U.S. Environmental Protection Agency (EPA). In FY 1994, EPA installed PV systems on the rooftops of buildings owned by 20 utilities throughout the country. The systems, which vary in capacity from 4 kW–12 kW, operate in different types of climates and in different types of utility load patterns. EPA is evaluating the extent to which PV can reduce emissions. NREL is collecting data from the installations for 3 years to analyze their usefulness for DSM.

NREL is also supporting development of analytical tools to analyze the economic viability of PV for DSM. Working under subcontract with NREL, analysts with the University of Delaware developed a spreadsheet in FY 1994 that both building owners and utilities can use to evaluate the economic performance of PV-DSM systems in buildings. In FY 1995, NREL will use the spreadsheet in case studies of PV-DSM systems in buildings with four participating utilities sponsored under the PV:BONUS project.

## PV For Export

Currently, 75% of this country's PV production is for export. In fact, the export market, mostly in developing countries, is the fastest-growing existing PV market. Furthermore, its potential size is huge. Greater than 40% of the world's population—approximately 2 billion people, mostly in the developing world—currently live without electricity.

Most of this potential market is for people who do not currently have a reliable source of electricity. Often, these people require small amounts of power for such applications as indoor lighting, television, pumping water, and refrigeration of vaccines for medical uses. PV is often the most cost-effective way to provide electric service.

In FY 1994, the PV Program identified the countries most active in installing PV systems worldwide: India, Brazil, China, Russia, Mexico, Indonesia, and South Africa. In FY 1994, the PV Program supported projects to stimulate markets for U.S.-made PV systems in each of these countries.

## Global Potential for Off-Grid PV

| Country | Population (millions) | Population Off-Grid (millions) | Potential PV Capacity (MW) |
|---|---|---|---|
| Africa (South of the Sahara) | 310 | 280 | 14,000 |
| Africa (North of the Sahara) | 135 | 56 | 3800 |
| Asia (Southeast) and Oceania | 520 | 375 | 26,600 |
| Brazil | 145 | 23 | 2300 |
| China | 1070 | 400 | 28,000 |
| India | 770 | 600 | 42,000 |
| Indonesia | 175 | 80 | 9800 |
| Mexico | 80 | 20 | 800 |
| Russia | 280 | 5 | 550 |
| South and Central America (Spanish) | 190 | 40 | 5250 |
| South and Central Europe | 195 | 15 | 1180 |

Source: Derek Lovejoy, "The Natural Resources Forum," May 1992, p. 102

## Delegation to India

DOE led a presidential mission to India in FY 1994 in order to secure commercial deals for industry and major governmental agreements. Secretary of Energy Hazel O'Leary headed the delegation, which included a number of representatives from the U.S. PV industry.

As a result of the presidential mission, Indian and, U.S. companies concluded commercial deals worth more than $1 billion. India and the United States signed formal documents for bilateral consultations on energy and, specifically, on renewable energy and PV. In FY 1995, the PV Program will continue to support the U.S. PV industry's increasing involvement in the rapidly growing Indian market.


U.S. Department of Energy

Department of Energy Secretary Hazel O'Leary led a presidential mission to India in FY 1994 to secure bilateral agreements on energy. Through this mission, the U.S. PV industry was able to conclude several important business agreements.

### Rural Electrification

On the other side of the world, the PV Program and NREL expanded demonstration programs of rural electrification in Brazil and Mexico in FY 1994. The purpose of the PV Program's involvement in rural electrification is to develop a model of how developing countries such as Brazil and Mexico can achieve their social and economic development goals while moderating the environmental impact that will inevitably accompany their economic expansion.

Roger Taylor, National Renewable Energy Laboratory

In FY 1994, 700 PV systems such as this one in Ceará, Brazil, were installed by the Brazilian energy ministry with support from the National Renewable Energy Laboratory.

### *Brazil*

The rural electrification program in Brazil, which began in FY 1993, is taking place in two phases. In Phase 1, Brazilian utilities in two states and the national ministry of energy (called Centro de Pesquisas de Energía Elétrica [CEPEL]) installed and will maintain PV lighting systems in 750 homes and 14 schools in the outback of northeast Brazil. Installations were completed in FY 1994; CEPEL will begin evaluation of the effectiveness of the systems in FY 1995.

In FY 1994, DOE and CEPEL committed to expand the project into six additional states in the northeast and Amazon regions of Brazil. The expansion was in response to requests by the utilities in those states to become involved. Phase 2 projects involve a greater variety of stand-alone, end-use applications, such as water pumping, telecommunications, and refrigeration. In addition, larger scale, hybrid village power systems will also be installed. Hybrid systems have at least two sources of power from, for example, PV, wind, diesel fuel, or some combination of the three, and a large enough capacity to supply the minimal electrical needs of a small village.

NREL began procurement of Phase 2 systems in FY 1994. NREL is supplying system integration and design assistance, and specifying supply of U.S.-manufactured components for use in the project. Phase 2 installations will be completed in FY 1995.

The project is a model for other village electrification projects because of the involvement of the local and state utilities and national energy institutions such as CEPEL. Such projects establish institutional and economic confidence in PV, and help solidify business relationships between U.S. and Brazilian firms.

In FY 1994, NREL received the Award of Merit for Technology Transfer from the Federal Laboratory Consortium for its work in the village electrification project in Brazil.

### *Mexico*

The rural electrification program in Mexico, which began in FY 1991, is expanding in scope in two states in northern Mexico. Each year, Mexico installs thousands of PV lighting systems for remote households throughout the country under a program to promote economic development in rural areas. In FY 1994, Sandia helped two states—Sonora and Chihuahua—install PV-powered water systems and train maintenance personnel.

Also in FY 1994, Sandia signed cooperative agreements to develop PV systems with the state University of Sonora, the National Institute of Electrical Research, and the Ministry of Energy and Mines.

## The States

The PV Program also awarded cost-shared contracts to state agencies and working groups in FY 1994 to address relevant policy and technical issues. Working through an initiative of 12 state working groups called Photovoltaics for Utilities (PV4U), PV Program analysts participate in a collaborative discussion among stakeholders in the PV and utility communities to eliminate policy and technical barriers to the adoption of PV.

In FY 1994, PV4U established a bibliography of important utility-related PV publications and launched a clearinghouse of PV documents. In addition, PV4U publishes a quarterly newsletter for states active in PV development.

## Federal Agencies

Federal agencies administer more than 30% of the total land area in the country. They have a large need for remote power that PV systems can fill economically and with minimal environmental impact.

Sandia continued progress on two projects in FY 1994 for increasing use of PV by federal agencies—PV for military bases and PV for the national parks.

### PV for the Military

The military has used PV for many years for tactical units in the field. PV generation provides a power supply for tactical and mobile combat units for situations when generator noise cannot be tolerated or when fuel supply lines cannot be secured.

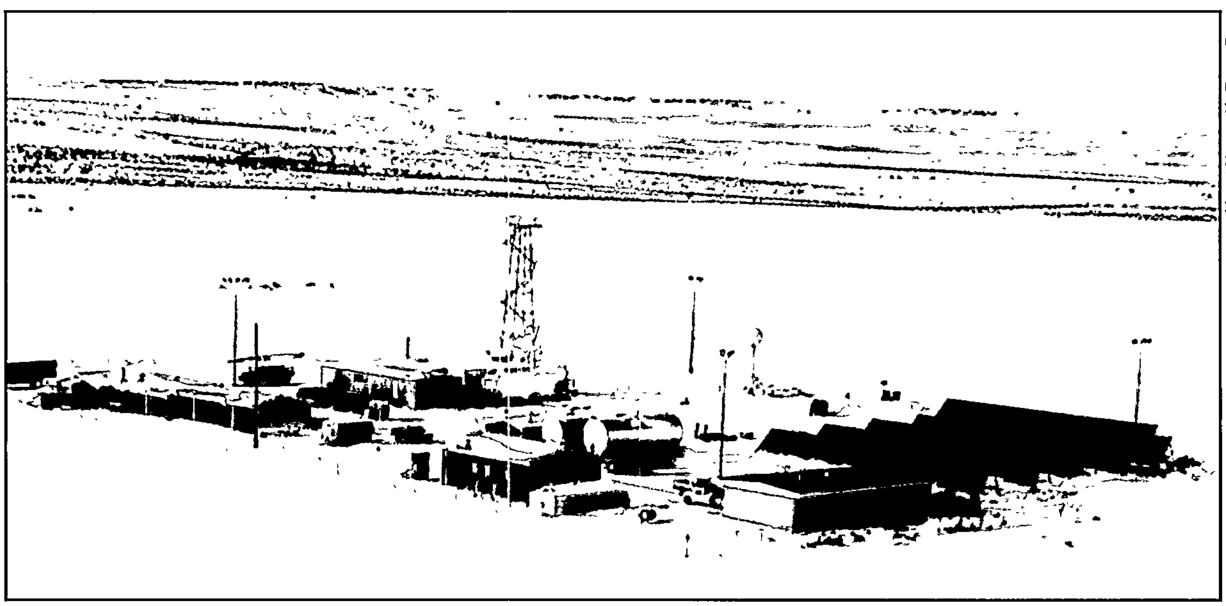
Sandia engineers are assisting the military in developing eight PV projects. The projects are funded cooperatively by EPA and the Defense Department under the Strategic Environmental Research and Development Program (SERDP). Through SERDP, Sandia is assisting the U.S. Marine Corps, the U.S. Navy, and the U.S. Air Force to install PV systems at military bases around the country. By providing assistance to other federal agencies in their PV projects, DOE effectively leverages its funding.

The eight SERDP projects involve technical advances for PV systems used by the military. The systems—rated 75 kW–300 kW—are larger than those used by tactical units and are connected to the utility grid. Seven are PV-diesel hybrid systems designed to replace mobile diesel-powered generators; the eighth is a grid-support system at the Air Force's Yuma Proving Grounds in Arizona.

The Yuma project involves the first grid-support system installed by the U.S. military. It is significant because military bases often produce their own electricity through a "mini-utility." The grid-support systems contain battery storage for added reliability and reduced overall demand. Sandia engineers will document the performance of this system for possible use on other U.S. military bases around the world. In FY 1994, they completed specification and began purchasing the hardware; installations are scheduled for FY 1995.

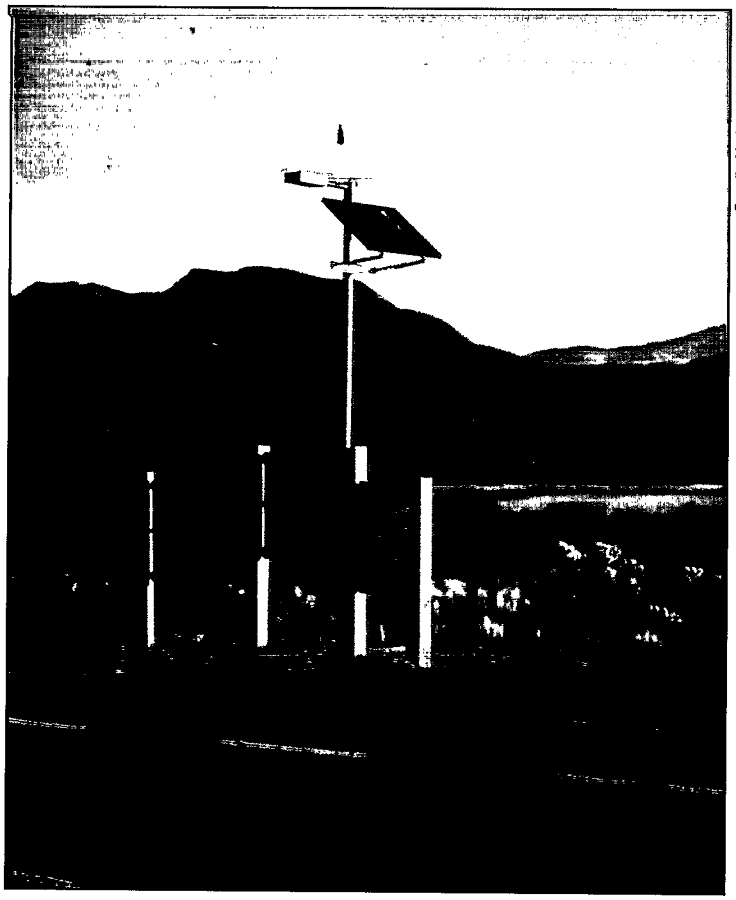
### PV for the Parks

The National Park Service is installing PV at national parks all over the country because PV systems have a negligible impact on these sensitive environmental areas and because the systems provide the most economic power supply. In FY 1994, Sandia and park service engineers conducted a study of the use of PV systems in the national



Mount Home Air Force Base

This 80-kW, PV-hybrid power system is located at Mount Home Air Force Base in Grasmere Point, Idaho. The system provides power for mobile radar equipment.




In conjunction with the Design Assistance Center at Sandia National Laboratories, the National Park Service is evaluating hundreds of sites in national parks for installing PV. At the Cholla Campground in the Tonto National Forest in Arizona, the Park Service saved $500,000 by installing PV.

parks. They identified 455 PV systems, 97% of which were operating without any problems. Furthermore, they found the users were satisfied with the systems.

With the help of the Design Assistance Center at Sandia, park service engineers completed evaluation of 367 potential sites for PV systems in national parks in FY 1994, and identified cost-effective opportunities for PV in 120 of them. The engineers also identified 659 separate projects where PV would be the best, most cost-effective source of power for the park service.

By FY 1994, Sandia and the National Park Service completed work at the Cholla Campground in the Tonto National Forest in Arizona. The campground is 9.6 km (6 mi) from the nearest electric utility grid, and estimates for extending a power line to the campground exceeded $750,000. On the other hand, PV systems cost $240,000 and now provide power for a number of applications, including area lighting, water pumping and disinfection, building ventilation, and hookups for recreational vehicles.

The park service will continue PV installations in national parks in FY 1995.

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