NREL PV

Working With Industry

Winter 1996/1997

A Focus on Firsts

There's nothing unusual about PV Program review meetings; the National Renewable Energy Laboratory has been holding them every 18 months for nearly 20 years.

But the 14th PV Program Review meeting, held in November 1996, had a few new twists. For the first time, NREL presenters combined forces with their colleagues at Sandia National Laboratories. And our guest speakers included Colorado Congressman Dan Schaefer and the head of DOE's Office of Renewable Energy and Energy Efficiency, Christine Ervin.

Schaefer, a founder of the House Renewable Energy Caucus, reminded the PV community of the need to educate legislators on the promise and benefits of renewables if we hope to secure a stronger commitment to this form of energy and more support for R&D. And Assistant Secretary Ervin, in introducing the newly formed National Center for Photovoltaics, noted that it's the cooperative work of NREL, Sandia, industry, and universities that continues to move PV from the laboratory to the marketplace.

In this issue of *PV Working With Industry*, we focus on these and other PV Program Review activities that showed how 1996 was another solid year of achievement—and firsts—in photovoltaics.

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First Rappaport Award Highlights 25-Year Solar Energy Odyssey

A Tribute from Ed Witt and PV Program Staff

Warren Gretz, NREL PIX01066

Lloyd Herwig shows off his personal collection of solar energy buttons after receiving the Paul Rappaport Award.

At the 14th PV Program Review meeting, we were fortunate to be able to honor some of the people whose pioneering work first prompted Congress to authorize our nation's renewable energy R&D programs.

Notable among those people were Dr. Lloyd O. Herwig, who retired from DOE last Fall, and the late Dr. Paul Rappaport, a PV pioneer and the first director of the Solar Energy Research Institute (now NREL). It is altogether fitting and proper that Lloyd Herwig's name was the one announced by NREL Director Dr. Charlie Gay, during a luncheon held at the Review meeting, as the recipient of the first Rappaport Award. This new award recognizes those who have made significant contributions to the field of photovoltaics.

Lloyd retired from DOE last Fall after more than 30 years of government service in a remarkable, 50-year professional career. Along with Paul, he was one of the first people to recognize the tremendous potential and promise of solar energy in our country. Twenty-five years ago, in 1971, these two solar pioneers and a few other members of a fledgling program at the National Science Foundation published a landmark report to Congress, *An Assessment of Solar Energy in the United States*. Many people believe that this report was the foundation for the nation's R&D programs in PV, wind, ocean, and solar thermal energy technologies.

As the new solar programs moved from NSF to the Energy Research and Development Administration in the early 1970s, and from there to the new Department of Energy, Lloyd moved with them in prominent program management positions. He was instrumental in establishing a world-class, thin-film PV R&D program at NREL (then SERI) in the 1980s. He also worked to establish the groundbreaking PV Manufacturing Technology project, hailed by several industry members as the most effective government R&D project they have ever participated in. In just 20 years, Lloyd took the results of one small research grant at NSF and helped to build it into a multi-million-dollar national R&D program with its own dedicated DOE national laboratory.

As we celebrate the new National Center for Photovoltaics, which was established to continue to move a promising renewable energy technology forward, it is especially gratifying to be able to look back in appreciation at the pioneers in this important effort. It is no exaggeration to say that the contributions to our program made by people such as Dr. Rappaport and Dr. Herwig have enabled the rest of us to keep moving the country ahead to a sustainable energy future. We would not be doing that without their vision, foresight, and perseverance.

For more information, contact Ed Witt, 14th PV Review Meeting Chair, at 303-384-6402.

PV Web Sites

NREL Photovoltaics . . . . . .http://www.nrel.gov/pv
What is PV? • Library • PV News • Partnerships • Research Projects • Facilities

DOE PV Program . . . . . .http://www.eren.doe.gov/pv
About Photovoltaics • News & Information • About Our Program

National Center for Photovoltaics . . . . . .http://www.nrel.gov/ncpv
DOE PV • NREL PV • Sandia PV

Center for Measurements and Characterization . . . . . .http://www.nrel.gov/measurements
Capabilities • Doing Business with the Center • Data Sharing

Basic Sciences and Materials . . . . . .http://www.nrel.gov/basicsciences
Materials Science • Biotechnology • Photoconversion

Renewable Resource Data Center . . . . . .http://rredc.nrel.gov
General Information • Information by Resource

Future Generation PV Technologies Conference . . . . . .http://www.nrel.gov/fgpv
Overview • Program Committee • Logistics and Registration • Program Agenda

Kicking Things Off

Warren Gretz, NREL PIX01065

The PV Review Meeting is well known for its highly informative technical sessions. But the kickoff speeches can also be instructive, and those given at the November '96 meeting were no exception.

For example, in his keynote address, Colorado Congressman Dan Schaefer told attendees that the U.S. House of Representatives' Renewable Energy Caucus could grow to as many as 120 members in 1997. The caucus ensured that $42 million was restored to the renewable energy legislative bill last year. Schaefer said that may have taught appropriators a lesson: "If you take it away, we [the caucus] will put it back."

Congressman Schaefer's efforts did not go unnoticed by Christine Ervin, DOE's Assistant Secretary for Energy Efficiency and Renewable Energy. "Congressman," she said in her speech, "you are making renewable energy a bipartisan issue, as it should be!" Emphasizing that PV is the premier renewable energy technology for the 21st century, Ervin announced that a new National Center for Photovoltaics had been established at NREL. The center will be a focal point for the nation's activities in PV R&D, deployment, and outreach. "Our goal," she said, "must be to transform the market."

Frank Stewart, who heads DOE's Golden Field Office in Colorado, focused on PV costs. Countering criticism that PV is too expensive, Stewart asked, "Compared to what? Compared to walking seven or eight miles a day carrying kerosene?" Stewart said that PV costs must be evaluated in the proper context, which includes the importance of bringing electricity to rural schools and clinics in the developing world.

NREL's and Sandia's work in PV is "for the long haul," noted NREL Director Charlie Gay, so we need a sustaining vision. The new paradigm in the national program is for R&D groups to work together closely. These collaborations will speed the flow of PV technologies to the marketplace, Gay said. The PV Review meeting itself was sponsored jointly by NREL and Sandia National Laboratories.

In her talk, Sandia's Margie Tatro articulated three key R&D questions that the PV Program should address: First, how do you make inexpensive cells without sacrificing performance? Second, how does power processing affect system performance? And third—a consumer concern—does the array perform as expected?

During his talk to the 14th PV Program Review Meeting, Congressman Dan Schaefer (R, Colorado) holds up a United Solar flexible solar shingle, emphasizing that this thin-film breakthrough will broaden the acceptance of building-integrated PV.

Joan Woodward, vice president of Sandia's Energy, Environment, and Information Technology Division, added that security and reliability are still key energy infrastructure issues. And retiring DOE official Lloyd Herwig agreed that the bottom-line marketing issues are still reliability, cost, and performance. Steve Hester of the Utility Photovoltaic Group pointed out the noticeable shift in the R&D community from centrally generated, utility PV power to more distributed, residential rooftop systems.

Tom Surek, NREL Technology Manager for Photovoltaics, focused on all the "firsts" in PV that occurred in the past year (see p.4). These included more record efficiencies as well as accomplishments in fundamental science, measurements, teamwork, manufacturing, products and standards, and international activities.

The consensus was that, though technical and market challenges remain, PV is a strong contender in the field of alternative energy.

For more information, contact Ed Witt at 303-384-6402.

First Glances

Jim Yost Photography/PIX02012

NREL researcher Sally Asher has used the time-of-flight SIMS unit to study problems as varied as impurities in CIGS to chemical residue on human hair.

It was definitely an Olympic year. Although no gold medals were handed out to National Photovoltaic Program members in 1996, they were honored for many "firsts" at November's PV Program Review Meeting. Tom Surek, Technology Manager for NREL's PV Program, highlighted several record achievements in his address at that meeting.

Those who hoped to hear about the latest record *conversion efficiencies* were not disappointed. For example, a copper indium gallium diselenide (CIGS) cell fabricated by NREL yielded an efficiency of 17.7%, topping last year's 17.1%. Solar Cell Inc.'s 8-ft^2 cadmium telluride (CdTe) module came in at 9.1% efficiency. And a world-record amorphous silicon (a-Si) cell with a stabilized efficiency of 12.1% was produced by United Solar Systems Corp. (see also p.6).

Firsts also occurred in *fundamental science.* Researchers produced a transparent TiO_2-based photochemical cell with a 7.8% efficiency. Other researchers deepened our understanding of hydrogen passivation by molecular hydrogen. Innovative nucleation and film growth concepts were also explored.

New and improved *deposition and analysis techniques* were developed in 1996. There were advances in the use of nanoparticle precursors for depositing CIGS and CdTe. CIGS cells produced by electrodeposition had measured efficiencies of 13.6%. Researchers created new transparent conducting oxides for CdTe and CIGS devices. Scientists were also able to boost the deposition rate of hot-wire-deposited a-Si. And a new "cluster system" is now operational for III-V film growth

News at Press Time

NREL PV Team Wins Technology Transfer Award

NREL will receive two awards for excellence in technology transfer from the Federal Laboratory Consortium, which represents more than 600 federally funded laboratories. One of these awards is for a photovoltaic technology—for the development and transfer of a tandem solar cell for powering satellites—and goes to Jerry Olson, Sarah Kurtz, Daniel Friedman, Alan Kibbler, and Charlene Kramer. The tandem cell, which uses two cells grown monolithically as one device, has a record-setting 29.5% conversion efficiency. The device's top cell is gallium indium phosphide; the bottom cell is gallium arsenide. The cell technology is being transferred to suppliers of solar cells for satellites, but could also provide the edge to make cost-effective concentrator systems for use on Earth. The space market for these devices is estimated to be a billion dollars per year in the near term, with the potential to increase in future years. The award will be presented to NREL in April 1997. *NREL Contact: Howard Brown, 303-275-3682*

Thin Film PV Partnership Recompetition Announced

A letter-of-interest (LOI) solicitation for the Thin-Film PV Partnership is planned for a May 15, 1997, mailing, with awards

and *in situ* analysis; the system includes molecular-beam epitaxy and metalorganic chemical vapor phase deposition units connected to an analytical chamber.

During 1996, NREL staff who *measure and characterize* materials, cells, and modules developed new capabilities for characterizing structural and chemical properties at the nanoscale. Working with companies such as AstroPower and Solar Cells Inc., NREL scientists created specialized techniques for determining diagnostics within the manufacturing line. They also used a large-area continuous simulator and a high-intensity pulsed simulator to measure the performance of prototype and commercial modules.

Progress in *codes and standards* hit on the key issue of module reliability. A flat-plate module qualification test standard was developed and approved. PowerMark was created to help with certification and accreditation of modules. Other projects focused on module energy rating and specifications of PV system-utility interconnection. NREL scientists produced a draft of a PV radiometric measurements guide. And researchers enhanced the calibration of primary reference cells and radiometers.

There were successes in *commercialization and manufacturing*, too. PVMaT, the PV Manufacturing Technology project, continued to help manufacturers lower costs, increase capacity, and improve efficiency. In 1996, program members expanded manufacturing based on current technologies such as ingot-based silicon. And non-ingot-based silicon, thin-film a-Si and CdTe, and concentrator technologies were manufactured for the first time.

Each year, more *PV products* are developed for new applications. Leading the list in 1996 were new modules for integrating PV into buildings. Companies prominent in this effort were Solar Design Associates, Ascension Technology, United Solar, Solarex, and FIRST (Fully Independent Residential Solar Technology, Inc.). In the area of new power systems and balance-of-system components, the leading companies were Utility Power Group, Solar Electric Specialties, Advanced Energy Systems, Trace Engineering, and Omnion Power Engineering Corp. And Midway Labs developed a low-wattage concentrator module.

Progress was made in *international PV projects*. We have gained extremely valuable experience by participating in the Brazilian rural electrification pilot project, and several other PV projects are under way in India, China, South Africa, and Mexico. Through the World Bank, Global Environmental Fund, and in-country sources, NREL has been involved in leveraging opportunities for PV growth.

In sum, 1996 was a banner year for Olympic-class athletes and for the world-class PV R&D community.

For more information, contact Tom Surek at 303-384-6471.

to begin January 1998. The *Commerce Business Daily* announced the LOI on January 16, 1997. The 30 existing contracts within the Partnership run out during January–June 1998, and the LOI is timed so that new awards can be made during this period, thus ensuring continuity among the winning participants. As in the previous 1994 LOI, most awards will be for work in the three leading direct-band-gap thin films (CIS, CdTe, a-Si), with limited awards in film-Si R&D. Awards will be made to industry and to universities as R&D and Technology Partners, and to support participation on our National Research Teams. The Partnership will award about 25–35 contracts, with an annual funding of about $11–$14 million. *NREL Contact: Ken Zweibel, 303-384-6441; Harin Ullal, 303-384-6486; Bolko von Roedern, 303-384-6480*

Abstract Deadline for Future Generation PV Technologies Conference

NREL is sponsoring the Conference on Future Generation Photovoltaic Technologies, March 24-26, 1997, in Denver, Colorado. This conference will emphasize in-depth technical discussions and assessment of recent achievements in “leapfrog” PV technologies with the potential to achieve very high efficiency and very low cost for the conversion of sunlight into electricity. Late News abstracts can still be submitted up to March 14 to Robert McConnell (NREL, 1617 Cole Blvd., Golden, CO 80401). Also check the Web site at *http://www.nrel.gov/fgpv* for conference logistics, speakers, and presentation titles.

While We've Got You All Together...

Warren Gretz, NREL/PIX01064

The PV Centers of Excellence have fostered the teaming of researchers at the national laboratories and universities, which has led to advances in understanding photovoltaics.

...smile for the camera!

There really was a lot to smile about at last November's National Photovoltaic Program Review Meeting. Program members were able to share a wealth of good news about recent developments in both crystalline silicon (c-Si) and thin-film PV technologies.

Because crystalline silicon is the most mature member of the PV technology family, national R&D in that area involves a lot of interaction with industry. A current PV Program objective is to work together to develop low-cost processing methods that will result in 18% efficient, large-area (more than 100 cm^2) commercial cells. An 18.6% efficient, small-area c-Si cell has already been developed at the Georgia Institute of Technology, one of the PV Program's Centers of Excellence in R&D.

The Centers of Excellence, like the R&D partnership programs, focus research conducted at universities, in the national laboratories, and in industry on the technical challenges that remain for various technologies.

Currently, impurity gettering and defect passivation are two important areas of investigation for c-Si. PV Program researchers also said they want to help reduce PV costs and boost efficiencies in the coming year by producing a c-Si device no more than 15 microns thick. And in optical modeling work, NREL's Bhushan Sopori announced a new computer model for solar cell designers that should be available soon. The model is sparking interest in industry as well as in the research community; it can be used in designing thin-film devices as well as c-Si cells.

A lot of good news also came out of the DOE/NREL Thin Film PV Partnership Program reviews, which focus on emerging technologies. One of these technologies, amorphous silicon (a-Si), took a big leap forward this past year when United Solar Systems Corp., a Thin Film PV Partnership Program industry member, achieved a stabilized, total-area efficiency of 12.1%. This boost in efficiency for a-Si is a world record.

Speaking of world records, NREL researchers announced that they have produced another impressive copper indium gallium diselenide (CIGS) device, measured at 17.7% efficiency. One of the Partnership Program's university members, the Institute of Energy Conversion (IEC) at the University of Delaware, has recently been able to improve CIGS devices made with very high concentrations of gallium. IEC is a Center of Excellence for thin-film R&D.

Meanwhile, an industry partner in the program, Golden Photon Inc., has turned out a new, large (about 3400 cm^2) cadmium telluride (CdTe) module that produces nearly 30 watts of power. Not content to stop there, Golden Photon has also produced a 14.7%-efficient CdTe cell on low-cost, soda lime glass.

In other work, Solar Cells Inc. turned out the most efficient (9.1%) large-area (6728 cm^2) CdTe module to date. At more than 60 watts, its output is the highest of any thin-film module. Good news, indeed, and there's more to come.

For more information, contact Ken Zweibel (303-384-6441), Harin Ullal (303-384-6486), and Bhushan Sopori (303-384-6683).

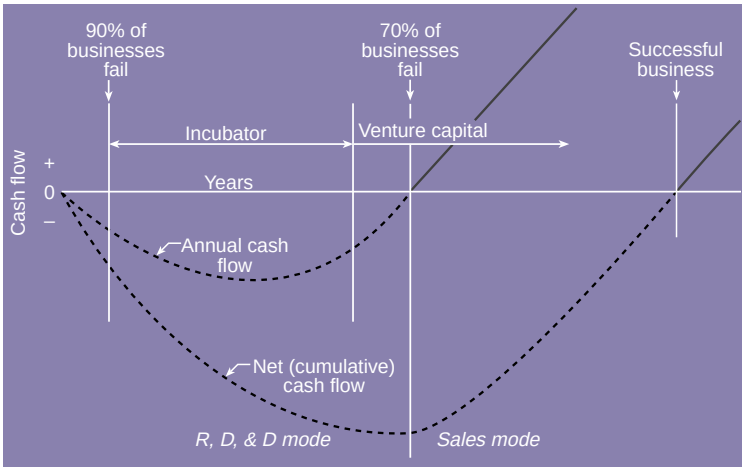
New "Buying Power" for PV

Now that most PV technologies are well along in technical development, attention is turning to financing issues. Sound financial strategies should ensure the success of both large-scale PV projects and the manufacturing companies that make them possible. Financing packages will also help make PV purchases easier for both commercial and individual consumers.

To update members of the PV R&D community on these issues, Christy Herig of NREL chaired a panel on financing PV deployment at the November 1996 Program Review meeting. Joining Herig in the panel discussion were Don Osborn of the Sacramento Municipal Utility District, Neil Holstad of the Tucson (Arizona) Solar Energy Corporation, Dr. George Cody of Exxon Research and Engineering Company, and Clay Aldrich of the Solar Energy Industries Association (SEIA).

Although Irvin Barash, a venture capital consultant, could not attend, he provided information on the typical growth cycle of a high-technology industry. Barash pointed out that, because initial investments are substantial, it usually takes quite a while for manufacturers of high-tech products to start realizing a net profit even after a period of healthy sales. The timing of venture capital investments at various stages in the manufacturing and marketing process is thus very important.

George Cody described a "learning-curve approach" to projecting the cost and performance of thin-film PV systems. This approach predicts reductions in manufacturing costs, to about 70% to 80% of previous levels, for every twofold increase in cumulative sales. The results of industry analyses support this approach, which should be good news for potential investors.



P219-B229405/Irvin Barash, Vencon Management, Inc.

This typical growth profile of a technological enterprise such as PV highlights two points: (1) Positive annual cashflow does not ensure business success; 70% of businesses still fail at this point. (2) Net cashflow is still negative when sales begin; sales does not mean that outside financing is no longer necessary.

Don Osborn, SMUD/PIX01096

A shift from utility central generation to residential and commercial rooftop PV applications is evident in a Sacramento Municipal Utility District project that resulted in PV panels on this California church.

Clay Aldrich added that most American consumers opt to finance their "big-ticket" consumer purchases rather than pay cash. In a recent survey, industry members told SEIA that new financing programs were needed. Residential PV systems now cost from about $5,000 to $35,000; larger commercial systems run higher. And it has usually been the purchaser's responsibility to locate and obtain financing.

After exploring existing or proposed government and utility financing programs and off-the-grid home mortgages, SEIA proposed two innovative financing packages: *SEIA Solar Finance* and *SEIA Solar Lease*. The new *SEIA Solar Finance* program already has about 40 applicants. In this nationwide program, the lender offers unsecured loans from $3,500 to $35,000 for 10 to 15 years at an established interest rate (for example, the Treasury rate plus 7%). *SEIA Solar Lease* is still being developed; it proposes a lease-package ceiling amount of $100,000.

Christy Herig pointed out that deregulation and competition are going to make it impossible for investor-owned utilities to remain a "zero-risk" industry. State by state, many different programs and strategies will emerge to deal with this situation. Though the times may seem chaotic, they also present opportunities that haven't existed in the energy industry before. It should be a good time for the renewable energy industry to make its mark, Herig said.

For more information, contact Christy Herig at 303-384-6546.

NREL PV researchers and managers interact with industry on several levels. Although we freely share our research results and the nonproprietary results of our subcontractors, many of our interactions involve the exchange of confidential information, including the results of certain measurements. The following are some notable recent interactions.

The **IEEE Standards Board** informed **NREL's Dick DeBlasio**, chairman of IEEE SCC21 for PV systems standards development, that the SCC21 PAR (Project Authorization Request) was approved by the Board. The approval letter designated the new project as P929, "Recommended Practice for Utility Interface of Photovoltaic (PV) Systems." Development of the recommended practice as a consensus standard will be coordinated and sponsored by SCC21 chairman DeBlasio, and development of the draft standard will be facilitated by the SCC21 PV System/Utility Working Group led by **John Stevens** of **Sandia**, with close coordination with **UPVG (Steve Hester)**. The approved PAR scope includes recommended practices describing the interface, functions, and requirements necessary in the interconnection of a PV power system with an electric utility. It also describes the acceptable and safe practices for accomplishing those functions and meeting the requirements. NREL Contact: **Dick DeBlasio, 303-384-6452**

Representatives from **Boeing** (Seattle, WA), **Optical Coating Laboratory, Inc.** (OCLI, Santa Rosa, CA), and **Teledesic** (Kirkland, WA) visited NREL to have technical discussion on PV technologies. Several **PV Program representatives** gave presentations on various organizational, technical, and market aspects of DOE's and NREL's PV Program. OCLI is interested in polycrystalline thin-film technologies for space applications, using expertise developed under the **DOE/PV Program** for terrestrial PV applications. Teledesic's requirements are for 840 satellites to be placed at low altitude for its "Information Skyway Project," which will be powered by PV. Total project cost for satellites and launching is estimated at $9 billion. Boeing will assist in array design. NREL Contact: **Harin Ullal, 303-384-6486**

The **Spire Corporation** of Bedford, MA, is developing quality assurance (QA) techniques and instrumentation for adjusting flash simulator testers to meet American Society of Testing and Materials specifications for Class A solar simulator performance. Spire asked **NREL** to assist in developing, testing, and validating QA instrumentation and techniques for proper spectral distribution of their simulator line. **Dr. Ted Cannon** and **Daryl Myers** assisted in this effort by measuring spectral distributions with the NREL-developed Pulse Analysis Spectroradiometer System as a benchmark against which to validate the proposed QA approach. Several issues were identified regarding the QA instrumentation calibration and technique, for which the NREL/Spire team developed solutions. The NREL expertise and equipment capability was recognized as providing valuable product quality data and an independent validation of their approach to a significant measurement problem. NREL Contacts: **Daryl Myers, 303-384-6768**; **Ted Cannon, 303-384-6763**

If one talks to personnel at **Jade Mountain** (a nationwide distributor of energy-efficiency products including PV modules), they will tell you that the lowest-cost and highest-efficiency new module that they sell is a concentrator module made by **Midway Labs**. In contrast to the approach of other concentrator companies, Midway has chosen to develop a small-wattage (230 watt) system that can compete in today's PV markets. Midway is interested in NREL's high-voltage, high-efficiency GaAs/GaInP cells because they would produce a higher voltage, allowing Midway to develop a 140-W product for water pumping. Many flat-plate, water-pumping systems use a tracker to provide the pump with adequate power in early morning and late afternoon. Thus, the concentrator module could compete with flat-plate systems in this market.

NREL is providing dual-junction (GaAs/GaInP) cells for Midway's evaluation and is planning a program to test the stability and performance of the cells under high concentration and in Midway's concentrator system. Assuming that the stability and performance testing goes well, introduction of the III-V cells into Midway's product should be relatively easy because the cells are already commercially available as a result of NREL's successful technology transfer to the space PV industry. The cell costs and efficiencies that are projected by the cell manufacturers are similar to the cost and efficiency of the Si cells Midway is currently using. A second company, **EDTEK**, has just completed a 1-kW concentrator system using GaAs cells. EDTEK is interested in the dual-junction GaAs/GaInP cells because their design operates at over 2000 suns, and NREL is undertaking a similar collaboration with EDTEK. NREL Contact: **Sarah Kurtz, 303-384-6475**

As part of the Thin Film PV Partnership Program, **Golden Photon, Inc.** (GPI), Golden, CO, has fabricated a thin-film CdTe solar cell with a total-area efficiency of 14.7%. The results were verified by NREL. The GPI cell was fabricated on a low-cost, sodalime glass on GPI's manufacturing line. The cell structure is glass/SnO_2/CdS/CdTe/graphite/Sn.

For a large-area module (about 4 ft^2), the power output measured at **NREL's Outdoor Test Facility** was 30.26 W at an insolation of 1033 W/m^2. This module was exposed to 2 months of natural sunlight at GPI's outdoor test facility in Golden. This also indicates improvements in GPI's stability performance of its modules. We had reported earlier that GPI has improved its module design by reducing the module weight from 23 lbs to 12 lbs. GPI has made substantial technical progress in addressing key efficiency, stability, and processing issues. NREL Contacts: **Harin Ullal, 303-384-6486**; **Ken Zweibel, 303-384-6441**

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Subcontracts

Subcontracted research with universities and industry, often cost-shared, constitutes an important and effective means of technology transfer in NREL's PV Program. From October 1996 through January 1997, we awarded 81 subcontracts (examples listed below) totaling more than $13 million. For further information, contact Tom Surek (303-384-6471).

ASE Americas
Market-Driven EFG Modules
$286,000 (12/14/95–2/28/99)

Community Power Corp.
Development of a New Commercial Enterprise for Renewable Energy-Based Electrification of Communities in Indonesia
$50,000 (10/1/96–4/1/97)

Interstate Renewable Energy Council (IREC)
State Solar Policy Forums
$65,000 (11/26/96–6/30/97)

Johns Hopkins University
Solar Energy Conversion at Dye-Sensitized Nanostructured Electrodes Fabricated by Sol-Gel Processing
$47,820 (7/15/93–9/14/97)

New Resources Group
Sunrayce 97 Management
$80,000 (10/21/96–8/31/97)

Pennsylvania State University
Wide-Bad-Gap Solar Cells with High Stabilized Performance
$123,791 (7/13/94–7/12/97)

Powermark Corp.
Photovoltaic Certification and Accreditation Management Support
$49,970 (11/18/96–11/18/97)

State of Hawaii
State of Hawaii—Solar Energy Policy Forum
$10,000 (11/21/96–2/28/97)

University of Massachusetts
Hybrid Power Project—Analytical Support
$50,000 (11/13/96–11/13/97)

University of Oregon
Indentifying Electronic Properties Relevant to Improving Stability in a-Si:H-Based Cell and Overall Performance in a:SiGe:H-Based Cells
$33,000 (4/18/94–4/17/97)

Publications

Dissemination of research results is an important aspect of technology transfer. NREL researchers and subcontractors publish some 300 papers annually in scientific journals and conference proceedings. PV program and subcontractor reports are available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161. For further information, contact Ann Hansen (303-384-6492).

Braunstein, R.; Dong, S. *Photocharge Transport and Recombination Measurements in Amorphous Silicon Films and Solar Cells by Photoconductive Frequency Mixing: Annual Subcontract Report, 15 May 1995—15 May 1996.* Oct 1996; 49 pp. NREL/TP-451-21704. NTIS No. DE96013112. Work by University of California, Los Angeles, CA.

Compaan, A.D. and others. *Optimization of Laser Scribing for Thin-Film PV Modules: Annual Technical Progress Report, 12 April 1995—11 April 1996.* Oct 1996; 21 pp. NREL/TP-451-21718. NTIS No. DE96013114. Work by University of Toledo, Toledo, OH.Dawn of a New Era: National Center for Photovoltaics. Oct 1996; 8 pp. DOE/GO-10096-324.

Guha, S. *Amorphous Silicon Research, Phase II: Annual Technical Progress Report, 1 August 1995—31 July 1996.* Oct 1996; 46 pp. NREL/SR-520-21964. NTIS No. DE96014327. Work by United Solar Systems Corporation, Troy, MI.

Han, D. *Experimental Study of the Factors Governing the Staebler-Wronski Photodegradation Effect in a-Si:H Solar Cells: Annual Subcontract Report, 1 April 1995—30 June 1996.* Oct 1996; 34 pp. NREL/SR-520-21928. NTIS No. DE96014326. Work by University of North Carolina, Chapel Hill, NC.

King, D.E.; Webb, J.D. Infrared Waveguide Sensor with Functionalized Monolayer for Detection of Airborne Pollutants. *Chemical, Biochemical, and Environmental Fiber Sensors VIII: Proceedings of the 1996 International Symposium on Optical Science, Engineering, and Instrumentation, 6-7 August 1996, Denver, CO.* SPIE Proceedings, Vol. 2836. Bellingham, WA: Society of Photo-Optical Instrumentation Engineers, 1996; pp.38-49.

Kroposki, B., Chairman. *Photovoltaic Performance Reliability Workshop, 4-6 September 1996, Lakewood, CO.* Oct 1996; 412 pp. NREL/TP-411-21760. NTIS No. DE96013115.

Venkatasubramanian, R. and others. Development of High- Performance GaAs Solar Cells on Large-Grain Polycrystalline Ge Substrates. Frost, H.J., et al., eds. *Polycrystalline Thin Films: Structure, Texture, Properties, and Applications II—Proceedings of the Materials Research Society Symposium, 27 November–1 December 1995, Boston, MA.* MRS Symp. Proc., Vol.403. Pittsburgh, PA: MRS, 1996; pp.483-488.

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***Industry Update,** from page 8*

United Solar (Troy, MI) has improved the efficiency of their best amorphous silicon triple-junction solar cell. Following a stabilization procedure (1000 hours of light exposure), the cell has been measured at **NREL** and is a new world record for amorphous silicon cells: 12.1% efficiency. The cell parameters are: area 0.27 cm^2; voltage 2.3 V; current density 7.6 mA/cm^2; and fill factor 69.7%. The previous best cell in a-Si was about 11.6% stabilized, also fabricated by United Solar. Improvement in efficiency is the goal of the **NREL Thin Film Partnership**, **Amorphous Silicon National Team**, within which this achievement was attained. NREL Contact: **Ken Zweibel, 303-384-6441; Subhendu Guha, 810-362-3120**

In the past several months, the production rate of silicon dendritic web solar cell blanks at **EBARA Solar, Inc.**, has more than doubled. Increased throughputs have resulted by overcoming production start-up problems and gaining greater insight into the web growth initiation process, partially with the help of **NREL's Crystal Growth and Devices Team**. The first silicon PV module products have been shipped to EBARA Solar, Inc., customers in Japan. Efforts are under way to increase module production through 1997. As a part of this effort, discussions are in progress to significantly increase activities under the funds-in CRADA between EBARA Solar, Inc. and NREL. These activities may include melt/crucible interactions, melt/growth modeling, melt replenishment, web growth improvements, defect characterization and passivation, and cell contacting studies. NREL Contact: **Ted Ciszek, 303-384-6569**

In separate activities during October, NREL staff continued to build linkages with international organizations. **Achilles Adamantiades**, principal power engineer with the **Industry and Energy Department at the World Bank**, visited staff at the **SERF** and the NWTC to obtain a better understanding of Laboratory activities related to international programs prior to attending the UPVG meeting. **Professor Ademola Salau**, **GEF coordinator for Climate Change in the Regional Bureau for Africa at the United Nations Development Programme**, along with **Sr. UNDP Consultant Dr. Jerome Weingart**, visited the SERF and the NWTC to work on planning the next steps in the recently approved (by GEF Council) "Renewable Energy Based Electricity for Rural Social and Economic Development in Ghana." Under the recently signed DOE/Ghana MOU, NREL will continue to provide technical assistance to UNDP and Ghana in project design and implementation. And **Dr. Stephan Lennon**, research manager for the South African electric utility **ESKOM**, discussed a wide range of renewable energy topics with staff from seven different NREL centers. Important links were also established between the ongoing South African and upcoming Ghanian projects. NREL Contact: **Roger Taylor, 303-384-6432**

Implementing part of an agreement between **DOE/NREL** and **China's State Science and Technology Commission (SSTC)**, **Halden Field** worked with scientists at **Beijing Solar Energy Research Institute (BSERI)** for 2-1/2 weeks. Measurement techniques for photovoltaic (PV) cells were conveyed to BSERI scientists by configuring equipment, performing measurements, and analyzing the error sources and results. Specific activities included reference-cell construction and calibration, simulator stability and spatial uniformity characterization, spectral mismatch computations, temperature coefficient measurements, and current-voltage curve measurements. In addition, Halden met with scientists from the **National Institute of Metrology** (spectral response measurements) and the **Chinese Academy for Space Technology** (primary reference-cell calibrations). BSERI wants to develop the capability for PV module performance measurements next and has expressed interest in further NREL assistance. NREL Contact: **Halden Field, 303-384-6685**

Tom Surek and others from **NREL** collaborated with **Masat Izu** and **Scott Jones of Energy Conversion Devices (ECD)** on a project funded by the **New Independent States-Industrial Partnering Program (NIS-IPP)**, conducted by **DOE** in consultation with the **Department of State (DOS)**, to support the startup of commercial production of the 2-MW triple-junction amorphous silicon Sovlux plant in Moscow, Russia. The work is now being extended to develop an innovative deposition process, gas-jet plasma deposition, which can substantially increase the deposition rate and lower the cost of the amorphous silicon modules. **Dr. Sharafutdinov** and his team at **Novosibirsk** invented the new process and will be developing it with Sovlux, as well as support from ECD and NREL (the latter under a CRADA between ECD and NREL). The NIS-IPP program is aimed at converting the extensive technical expertise at Russian laboratories from military to commercial uses which also benefit U.S. industry partners. **Tom Surek, 303-384-6471**

A team from the United States and Brazil worked on component checkout and startup procedures for the 50-kW PV-battery-diesel hybrid power system in the remote fishing village of Campinas, in the Brazilian state of Amazonas. The heart and brains of this system is an **Advanced Energy Systems** Static Power Pack. 50 kW of **Solarex** modules have been deployed at the site. A satellite-based communication system was installed by **Ascension Technology, Inc.** (ATI) for data collection. **NREL**, **ATI**, **Bergey**, and the Brazilian counterparts visited the second hybrid site at Joanes, on the island of Marajo near Belem, to inspect construction status and set up the satellite communication system. The civil works have been completed, and the wind turbine towers have been installed. The wind turbines, **Siemens**, PV modules, and batteries will be installed in January. Valuable experience is being gained on the difficulties of installing and operating hybrid power systems in remote regions. One clear message is the need for well-trained local technicians. A more intensive training program will be conducted prior to final commissioning. NREL Contact: **Roger Taylor, 303-384-6432**

University Corner

Professor Reuben Collins' team at the **Colorado School of Mines (CSM)** is developing a new technique to characterize polycrystalline materials using a near-field optical microscope. The team's work has the potential to provide a detailed picture of the electro-optical behavior of grain boundaries. **NREL's III-V Materials and Devices Team** will collaborate with CSM to supply them with polycrystalline GaAs (px-GaAs) samples. These samples will support the development of CSM's characterization technique, which will, in turn, strongly support NREL's development of improved px-GaAs solar-cell materials. NREL Contact: **Daniel Friedman, 303-384-6472**

Renewable Energy for African Development (REFAD) and the **Environmental Technology Consortium (ETC)** convened an **Historically Black Colleges and Universities (HBCU)** workshop, "Renewable Energy Technologies—Implications for HBCUs," at Texas Southern University in Houston, Texas, in October. REFAD is a development organization founded by renewable energy trade associations, and ETC consists of 17 HBCUs awarded the only funding under DOE's Environmental Technology Initiative. Four of NREL's seven PV HBCU subcontractors **(Texas Southern Univ.**, Houston, TX; C**lark Atlanta Univ.**, Atlanta, GA; **Southern Univ.**, Baton Rouge, LA; and **Hampton Univ.**, Hampton, VA) belong to the ETC. **NREL's Robert McConnell** described the work of the PV HBCU subcontractors (16 undergraduate research associates under 14 professors), as well as the summer internships and African projects in Ghana, South Africa, and Senegal undertaken by **Wilberforce Univ.** (Wilberforce, OH), **Texas Southern Univ.**, and **Central State Univ.** (Wilberforce, OH) with PV HBCU support. There was strong interest in the **DOE/NREL PV HBCU program**, especially for the summer intern program, which could leverage ETC funding for joint projects in Africa. NREL Contact: **Robert McConnell, 303-384-6419.**

The **NREL Crystal Growth and Devices Team** distributed multicrystalline and single-crystalline silicon sample wafers to NREL subcontract research teams at the **Massachusetts Institute of Technology (MIT)** and **University of California/Berkeley**. These wafers, made by the float-zone method at NREL during the past year, have various amounts of intentionally grown-in iron impurity, but are otherwise of high purity. Thirty-two wafers were supplied to MIT, and eleven wafers were sent to the University of California/Berkeley.

NREL researchers have quantified the effects of grain size and iron concentration on minority charge carrier lifetime in iron-doped samples. Additional studies of silicon PV device degradation effects due to iron will be conducted at the universities with this unique controlled sample set. Iron is a relatively prevalent impurity in low-cost silicon feedstock and has a detrimental effect on PV device performance. So, its understanding is crucial to developing cost-effective silicon photovoltaics. Many prior studies were clouded by the presence of other impurities in addition to iron.

The NREL Crystal Growth and Devices Team will begin to produce another sample set with varying amounts of iron coexisting with various p-type dopants. The new samples will contain controlled amounts of iron and boron in otherwise high-purity silicon. We will also examine the effects of other p-type dopants such as gallium when present with iron. NREL Contact: **Ted Ciszek, 303-384-6569.**

Publications, *from page 9*

Yang, C.M.; Atwater, H.A. Controlled Grain Size and Location in Ge Thin Films on Silicon Dioxide by Low Temperature Selective Solid Phase Crystallization. Frost, H.J., et al., eds. *Polycrystalline Thin Films: Structure, Texture, Properties, and Applications II.* MRS Symp. Proc., Vol. 403. Pittsburgh, PA: MRS, 1996; pp.113-118. Work by California Institute of Technology, Pasadena, CA.

PVMaT Fact Sheets. Dec 1996; 2 pp. each:

Advanced Photovoltaics Systems: Amorphous Silicon PV Manufacturing. NREL/SP-411-21587. DOE/GO-10096-298. NTIS No. DE96013080.

ASE Americas, Inc.: Process-Specific Issues for Thin Edge- Defined, Film-Fed-Growth Octagons. NREL/SP-411-21592. DOE/GO-10096-303. NTIS Order No. DE96013085.

AstroPower, Inc.: Silicon-FilmTM PV Manufacturing Technology. NREL/SP-411-21588. DOE/GO-10096-299. NTIS No. DE96013081.

Energy Conversion Devices, Inc.: Continuous Roll-to-Roll Amorphous Silicon Photovoltaic Manufacturing Technology. NREL/SP-411-21597. DOE/GO-10096-308. NTIS No. DE96013090.

ENTECH, Inc.: Improving ENTECH's Concentrator Module. NREL/SP-411-21599. DOE/GO-10096-310. NTIS No. DE96013092.

Siemens Solar Industries: Improving Czochralski Silicon PV Manufacturing Technology. NREL/SP-411-21590. DOE/GO-10096-301. NTIS No. DE96013083.

Solar Cells, Inc.: High-Throughput Manufacturing of Thin-Film CdTe Photovoltaic Modules. NREL/SP-411-21598. DOE/GO-10096-309. NTIS No. DE96013091.

Solarex: Cast Polycrystalline Silicon Manufacturing. NREL/SP-411-21593. DOE/GO-10096-304. NTIS No. DE96013086.

Spire Corporation: Automated Cell Assembly Research. NREL/SP-411-21589. DOE/GO-10096-300. NTIS No. DE96013082.

Springborn Laboratories: Encapsulant Materials Manufacturing Research. NREL/SP-411-21595. DOE/GO-10096-307. NTIS No. DE96013089.

Texas Instruments: Spheral SolarTM PV Manufacturing. NREL/SP-411-21596. DOE/GO-10096-306. NTIS No. DE96013088.

Utility Power Group: Amorphous Silicon PV Manufacturing Research. NREL/SP-411-21591. DOE/GO-10096-302. NTIS No. DE96013084.

25th IEEE: Conference Record of the Twenty Fifth IEEE Photovoltaic Specialists Conference, 13-17 May 1996, Washington, DC. New York: Institute of Electrical and Electronics Engineers, 1996.

PV Calendar

March 24–26, 1997
Conference on Future Generation Photovoltaic Technologies. Denver, Colorado. Contact: Joan Ross, NREL, 1617 Cole Blvd. Golden, CO. Phone: 303-275-4321. Fax: 303-275-4320.

April 25–30, 1997
Solar 97: Energy for a Sustainable Prosperity. *National Solar Energy Conference featuring 25th ASES Annual Conference, 22nd National Passive Solar Conference*, with *Soltech 97, ASME International Solar Energy Conference*, and *AIA Committee on the Environment Symposium*. Washington, D.C. Contact: American Solar Energy Society, Boulder, CO. Phone: 303-443-3130. Fax: 303-443-3212. E-mail: ases@ases.org

May 1–2, 1997
Solar Thin Film Photovoltaic Symposium. Newark, Delaware. Contact: Institute of Energy Conversion, University of Delaware, Newark, DE. Fax: 302-831-6226. E-mail: IEC25th@mvs.udel.edu

May 18–21, 1997
The Third Thermophotovoltaics Conference. Colorado Springs, Colorado. Contact: Tim Coutts, Phone 303-384-6561, E-mail tim_coutts@nrel.gov; or John Benner, Phone 303-384-6496, E-mail john_benner@nrel.gov

May 27–29, 1997
The World Sustainable Energy Trade Fair. Amsterdam, The Netherlands. Contact: European Media Marketing Ltd, 6th Floor, 22-26 Albert Embankment, London SE 1 7TJ. Phone: +44-171-582-7278. Fax: +44-171-793-8007. E-mail sustain@emml.demon.co.uk

June 23–25, 1997
PV Standards and Codes Forum. Golden, Colorado. Contact: Joan Ross, NREL. Phone: 303-275-4321. Fax: 303-275-4320.

June 30–July 4
1997: 14th European Photovoltaic Solar Energy Conference and Exhibition. Barcelona, Spain. Contact: Conference Organizer, WIP, Sylvensteinstr. 2, D-81369 Muenchen, Germany. Phone: +49-89-720 1232. Fax: +49-89-720 1291. E-mail: renewables@mail.tnet.de

July 22–24, 1997
International Symposium on Advances in Alternative/Renewable Energy, ISAAE '97. Johor Bahru, Malaysia. Contact: Secretariat, ISAAE, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Locked Bag 791, 80990 Johor Bahru, Malaysia, Attn: Mrs. Ani Idris/Mr. Othman Ayub. Phone: 60-7-5504758. Fax: 60-7-5566159. E-mail Othman@FKJ.UTM.MY

August 11–13, 1997
7th Workshop on the Role of Impurities and Defects in Silicon Device Processing. Vail, Colorado. Contact: Heather Bulmer, NREL. Phone: 303-275-4317. Fax: 303-275-4320.

September 29–October 3, 1997
26th IEEE PV Specialists Conference. Anaheim, California. Contact: Wendy Larsen, NREL, 1617 Cole Blvd., Golden, CO 80401. Phone: 303-384-6497. Fax: 303-384-6481.

October 14–16, 1997
The Asia-Pacific Initiative for Renewable Energy & Energy Efficiency. Jakarta, Indonesia. Contact: 5/F, 3 Wood Road, Wanchai, Hong Kong. Fax: +852-2574-1997. E-mail altdev@hk.super.net

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