NREL PV

Working With Industry

First Quarter, 1998

The Power of Choice

More than at any time in recent memory, the world's attention seems focused on energy issues and how they impact the planet's livability. Those of us in the PV community have much to contribute to the discussion.

Consider the spectrum of activities ranging from fundamental research to technology development, from systems engineering and applications to deployment. All are necessary and appropriate for the success of photovoltaics. All relate to a broader spectrum of issues facing society—climate change, job creation, domestic economic strength, and protecting the environment.

We all like to have choices—and this extends to the source of our energy. The U.S. Department of Energy's 5-year plan for the National Photovoltaics Program speaks to the power of choice and bringing the healthy status of international PV markets home to the United States. The National Center for Photovoltaics has a role in making PV the power of choice, with special emphasis on those applications and opportunities where it makes the most sense right now.

The research and development performed at the National Renewable Energy Laboratory and in collaboration with our industry partners is making PV an easier choice by reducing cost and increasing performance. We think NREL's enhanced ability to send up-to-the-minute measurements and characterization data over the Internet is helping to speed up the accomplishment.

The Million Solar Roofs Initiative adds another facet for the choice of PV. Many individuals may choose to purchase a PV system, not because it is the least-cost energy source, but because they feel it is the highest-value choice for them, their children, and their grandchildren. Clearly, people do not always buy for reasons of least cost, but for the perceived value of the choice. It's our job to enable U.S. individuals, communities, and states to exert their power of choice for PV because it benefits them and the world.

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A Million Reasons to Cheer for Solar

A Message from Peter Dreyfuss

Peter Dreyfuss is Coordinator of the President's Million Solar Roofs Initiative, a drive to place solar electric and solar thermal energy systems on the roofs of one million U.S. buildings by 2010. He joined the U.S. Department of Energy in August of 1997, following nearly 30 years of service in the community development arena, with a majority of that time devoted to energy efficiency, transportation, and environmental programs.

I am delighted to have this opportunity to introduce myself. As a long-time proponent of sustainable energy, I spent 20 years in the Kansas City area promoting renewables and energy efficiency at the local and regional level. Now to be coordinating a national program promoting solar energy—one with the strong support of the U.S. President and Vice President—well, this is as good as it gets.

As members of the PV industry and research community, I hope you are ready to explore what the Million Solar Roofs Initiative can mean for your endeavors. It was a pleasure to meet some of you at the recent dedication of BP Solar's PV manufacturing plant, and to stand together and cheer as Vice President Gore proposed a $2,000 solar tax credit for American homeowners and businesses.

My Million Solar Roofs assignment commenced last October, and it's been a busy several months since then. There have been scores of meetings with representatives from industry, utilities, and state and local governments to gather input and build consensus. Based on this, we are now finalizing plans to make the Initiative a reality. The process of actually counting toward a million installations will begin soon, when we launch the Million Solar Roofs Registry.

We've also been coordinating the federal agency effort—finding the money, following it, and making it available for use by agencies in purchasing solar energy systems. The plan to install solar systems on 20,000 government roofs is proceeding apace. The Federal Energy Management Program is already issuing multi-million-dollar Energy Savings Performance Contracts for new construction and building retrofits, and soon will be issuing one for $50 million for PV purchases.

Facilitating the first Million Solar Roofs partnerships has been another important focus. In Hawaii, local solar industry members are developing a partnership plan that involves solar industries, utilities, and the state legislature and governor's office. As a result, solar will be a vital component of both Hawaii's energy supply and its economic development plan. In California, the Los Angeles Department of Water and Power and the Sacramento Municipal Utility District are supporting Million Solar Roofs not only by installing rooftop solar energy systems, but by creating ways to bring new solar manufacturing businesses to the region. Maryland is also on board, with state leaders developing a comprehensive program to combine private and public resources to install solar systems on thousands of buildings, highlighting school rooftops, throughout the state. Partnerships such as these will form the backbone of the Initiative.

On a personal note, I hope to meet many more of you at SOLTECH '98 in Orlando, Florida, this April. My fellow panelists and I will present a Million Solar Roofs update—and we'd like to hear what you have to say.

To read more about the Initiative, visit the Million Solar Roofs Web site at: http://www.MillionSolarRoofs.org. Contact Peter Dreyfuss at 202-586-8779.

PV Web Sites

NREL Photovoltaics .....*http://www.nrel.gov/pv*
What's PV? • Info • PV News • Partnerships • Research Projects • Facilities

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

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

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

Measurements and Characterization..*http://www.nrel.gov/measurements*
Capabilities • Doing Business • Data Sharing • The Center

Renewable Resource Data Center .....*http://rredc.nrel.gov*
General Information • Information by Resource (Biomass/Solar/Wind)

Million Solar Roofs .....*http://www.MillionSolarRoofs.org*
Projected Accomplishments • The Program • Solar Energy Technologies

Panel to President: Spend More on Energy R&D

"Boost the funding for the U.S. Department of Energy's Photovoltaic Program from $60 million in Fiscal Year 1997 to $140 million in 2003." That's the recommendation of a recent White House-appointed panel on energy research and development (R&D).

The Energy R&D Panel of the President's Committee of Advisors on Science and Technology (PCAST) suggested that the additional funding could best benefit three areas. First, laboratory successes could be scaled up to first-time manufacturing. Second, further work in engineering science could lead to the development of large-volume, low-cost PV production. And finally, funding could also support R&D on system integration and on balance-of-systems components such as inverters.

The panel called for a substantially expanded program of PV R&D and commercialization for several reasons: PV technology offers multiple benefits to society, dramatic progress is being made, prospects are good for significant future gains, and government needs to play a strong role in launching a PV industry.

Another recommendation called for a major expansion of fundamental materials science research, to be cofunded by the DOE Office of Energy Efficiency and Renewable Energy and the Office of Energy Research. NREL's strong participation in both programs should facilitate this cooperation.

The Energy R&D Panel of PCAST was chaired by John Holdren of Harvard University and included 22 other members from various universities, energy organizations, industries, and utilities. Sam Baldwin—from NREL's Washington Office, but on loan to the National Science and Technology Council—served as the Executive Director of the study. The extensive final report was sent to President Clinton on November 4, 1997.

The panel used a "portfolio" approach to planning, with analysis focusing on a set of diverse criteria that cover environmental, economic, and energy issues. This approach moved beyond a conventional paradigm, which holds that long-term basic research is conducted without thought of practical ends. One panel finding, for example, is that many of DOE's energy-technology programs could be markedly improved if buttressed by research activities addressing fundamental questions raised by technology developments.

Funding increases were recommended for all energy technologies, including fission, fossil, fusion, efficiency, and renewables, although the panel recommended changing the emphasis in some programs—for example, promptly ending DOE's funding for direct coal liquefaction. The DOE PV Program was praised, citing strong progress on many fronts. Thin-film technologies, all of which offer the potential for very low module costs, were especially highlighted.

Chairman Holdren noted the importance of near-term federal action, "You can push the R&D pipeline so more stuff comes out, but if you really want some of these things to happen, you need sharp market signals."

For copies of the report "Federal Energy Research and Development for the Challenges of the Twenty-First Century," contact Sam Baldwin in NREL's Washington Office (202-651-7542) or check it out at: http://www.whitehouse.gov/WH/EOP/OSTP/html/OSTP_Home.html

Jim Yost Photography/PIX01504

PCAST panelists cite PV thin films as offering the potential for very low module costs. Here, NREL researcher XiaoNan Li uses a close-spaced sublimation system to make and study high-quality thin-film PV cells of cadmium telluride.

NREL Brings Materials Analysis

"We are always trying to keep our customers satisfied." That's how Larry Kazmerski, who heads NREL's Measurements and Characterization Division, summed up the raison d'être under which David Niles and a couple of other in-house "entrepreneurs" are working to build a virtual laboratory through real-time data sharing.

"For us," he continues, "this means rapidly relaying the results of our analyses to customers, while safeguarding proprietary information. And, increasingly, this means using our Web site to transfer data across the Internet."

No Time for Delays

Consider the example of Optical Coating Laboratories, Inc. (OCLI). This company is currently developing NREL's cutting-edge CIGS (copper indium gallium diselenide) technology to scale it up to make power modules. To meet its commitments, OCLI has to "come up to speed" quickly, to design, engineer, and manufacture high-quality cells.

Jim Yost Photography/PIX02018

Researcher Alice Mason uses NREL's electron probe microanalyzer (EPMA) to analyze the elemental composition of CIGS samples processed by OCLI. Once she obtains results, she posts the data directly to OCLI's high-security site on the Internet.

The company cannot afford delays. So it works very closely with NREL in two ways—with the scientists on the CIGS team of the Electronic Materials and Devices Division, who invented and patented the process OCLI is using, and with the Measurements and Characterization Division.

To get the quick turnaround it needs from Measurements and Characterization, OCLI sends cells to NREL via overnight mail. Researchers immediately make measurements on the cells and post the data on the Web, which the company accesses and downloads.

Not only does OCLI get measurement results within 24 hours of having made the cells—a heretofore unheard of response—but the data also remain proprietary because they are posted in a high-security area that is specified for the company and that is accessible only by authorized people. To gain access, customers must enter an ID number and access code. Further, the system has no features an outsider can break into and is self-disabling after a third failed attempt to log on.

Seamless Collaborative Research

Or consider an ongoing alliance between researchers at Sandia National Laboratories and those of Measurements and Characterization. They are working together on a project for the DOE Office of Basic Energy Sciences to design, fabricate, and characterize state-of-the-art semiconductor alloys. Sandia grows the devices using molecular beam epitaxy and sends them to NREL for characterization.

NREL researchers employ scanning electron microscopy (SEM), transmission electron microscopy, atomic force microscopy, and other systems to measure bright-field images, lattice images, diffraction patterns, and morphologies. Morphology measurements are often performed on the nanoscale. The high-resolution micrographs produced from these measurements contain an enormous amount of data and require a large amount of memory. The best way to transmit these kind of data quickly is electronically via the Internet.

All the Tools

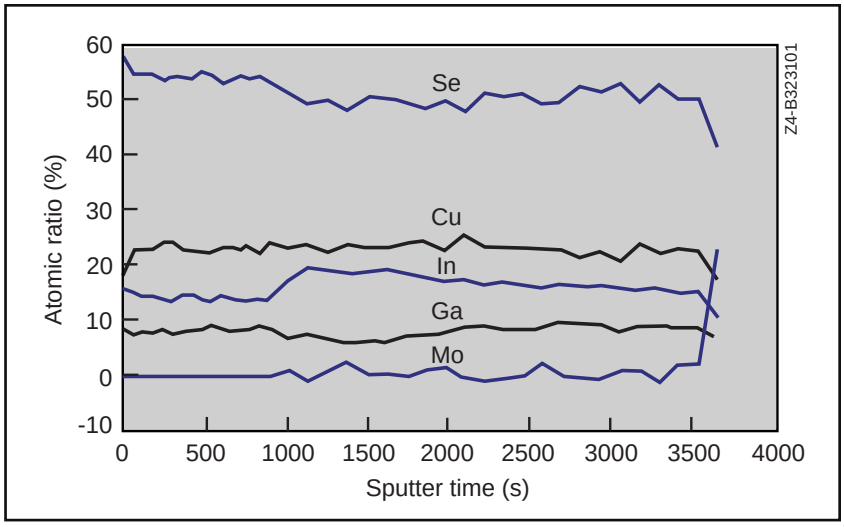
There are 54 other customers who regularly use the Internet to receive measurement results from Measurements and Characterization. They include private companies, subcontractors, CRADA partners, and other national laboratories. Seventeen of these customers are performing work that is not highly sensitive, and hence, they do not need a high-security site; instead, they opt for low-security sites that require only a generic ID and a generic password for access. Whether using high- or low-security sites, customers can receive Internet-posted data from measurements

to Your Fingertips

made with almost any of the Division's nearly 40 major systems. This represents enormous progress. In just over a year, the Division has gone from proving the viability of this approach for data transfer to laying almost the entire characterization capabilities of the Division at the customer's fingertips. With just a few strokes of the keyboard, one can access results from analytical systems whose capabilities range from detecting defects on the nanoscale to measuring the power output of modules—a range encompassing more than 12 orders of magnitude.

"This is just the beginning," David Niles assures us. "We are about to unveil the next phase toward the virtual laboratory and real-time measurement and collaboration" (see box below).

For more information, contact David Niles at 303-384-6624 or Larry Kazmerski at 303-384-6600. Also, check out the Web site at http://www.nrel.gov/measurements



EPMA data can be posted as a simple table showing elemental composition, or as a graph in which the atomic ratios of the elements (copper, indium, gallium, selenium, and molybdenum) are plotted against sputter time.

The Internet Lab

Consider this scenario. You are at your manufacturing plant, and wafers on the assembly line have begun to show an unexpected degradation. You send samples overnight to NREL to determine the cause. And time is of the essence.

After receiving an e-mail from NREL, you access the Measurements and Characterization Web site and find a menu indicating instruments you can select. Your samples are now ready to be measured. You select the SEM and are presented with a monitor and an electronic control panel. By clicking buttons on the control panel, you begin a compositional analysis of your sample.

Data are generated immediately. After watching the data and realizing what they mean, you click other buttons on the control panel and initiate an EBIC (electron beam induced current) analysis, in real time.

This is not a dream. It is pending reality that may be on your doorstep in a short time. It is the beginning of that virtual laboratory that Web technology has been promising the scientific and industrial communities—true, remote collaboration in real time.

Measurements and Characterization is heading in this direction in two phases. Phase one is a passive phase that will allow you to access our Web site to observe real-time measurements of your samples.

We are proving the prototypes for this capability. Currently, we can generate data that are nearly real time (with an approximately 20-second delay) and that may be observed from a remote site. The delay occurs because before the data are dumped on the Web screen, the program first takes a "snapshot" of the data and converts them to “jpeg” format for viewing on the Web.

The next step in the passive phase will be to enable the generated data to be dumped to the Web screen in real time. This phase should be ready for demonstration by April—you will be able to access the Web site and observe data being generated in real time from the X-ray photoelectron and Auger electron spectroscopy systems.

Once the prototypes are proven, we will extend this passive capability to all the major systems in Measurements and Characterization. Then you'll be able to observe results from a remote site, while an NREL researcher manipulates the experiment. You and the researcher can communicate over the phone and cooperate in performing the experiment, in real time.

Phase two is the interactive phase—the scenario painted in the opening paragraphs—in which you'll be able to control much of the experiment from your remote site and even dump the raw data being generated from the Web site to your own data system for reduction and enhancement. Although the realization of phase two is not on the immediate horizon, stay tuned—once phase one is up and running, we'll go to work on phase two.

Climate Change News: Our Man in Kyoto

With delegates from around the world having met last December in Kyoto, Japan, the words "global warming" and "climate change" seem to be on everyone's tongue. The recent news that the Earth's average surface temperature in 1997 was the highest ever recorded adds urgency to the discussion.

NREL's Patrick Keegan had a ringside seat at the United Nations Climate Change Summit. He went to Kyoto well-versed in the yin and yang of international climate politics, having joined NREL last November after spending 4 years with the International Institute for Energy Conservation. He left Kyoto more convinced than ever that climate change will be a driving force for U.S. and world energy policy.

The well-traveled Patrick Keegan joined NREL last November to bolster the Laboratory's international climate change activities. During his tenure at the International Institute for Energy Conservation, he served as director of the Institute's Climate Change Program and was a presenter at numerous international symposia. Prior to that, he was a utility consultant and spent 10 years in various management positions with the Washington State Energy Office.

"We've all heard the debates and controversies around climate change, but some statements are fundamentally accepted," says Keegan. "There is a greenhouse effect, there are greenhouse gases (carbon dioxide, methane, and oxides of nitrogen) and they are increasing, and this is bound to produce consequences."

The basic solution is to stabilize greenhouse-gas concentrations at levels where climate is changing at acceptable rates, which would require an estimated 60% reduction in fossil-fuel use. Possible approaches are to massively deploy renewable energy and energy efficiency or to construct hundreds (or thousands) of nuclear plants. Another alternative is to do nothing and learn to adapt. "Whatever we do, we know the approach must be global," says Keegan.

Keegan was familiar with the magnitude of U.S. influence at prior international conferences and gatherings, so it came as no surprise to see this trend continue in Kyoto. As the largest economy and the largest emitter of greenhouse gases, the United States also sent the largest delegation at 160. Other countries formed alliances to advance their positions, but the United States was most willing to act unilaterally. And in the end, it was the U.S. position that was basically accepted.

The sheer size and importance of the event created a carnival atmosphere in Kyoto. The more than 2,000 delegates, in a host of separate meetings and discussion groups, soon became groggy from all-night sessions. Of the thousands of lobbyists who paraded the halls, the biggest contingent consisted of those

News at Press Time

Dick Ahrenkiel Wins NREL's Highest Research Award

This year, **Dick Ahrenkiel** of the **Measurements and Characterization Division** received **NREL's** Hubbard Award. This award is presented annually to one researcher who has demonstrated a superior level of leadership and initiative in furthering the image of NREL as the nation's foremost solar and renewable energy laboratory. The Hubbard is the highest research honor within the Laboratory and is a focal point of the NREL Staff Awards Expo, which was held on March 4. Ahrenkiel, whose scientific achievements are world-renowned, was cited as a pioneer in several research areas. His own technical work continues to be a major factor leading to cooperative research and development agreements and Work-for-Others contracts in semiconductor characterization research, space PV, thermophotovoltaics, and electronic materials. In his current work with **AstroPower**, he developed a new technique to determine a fundamental property of silicon solar-cell material that immediately indicates semiconductor quality for producing high-efficiency cells. AstroPower quickly recognized the value of this technique and signed a Memorandum of Understanding with the U.S. Department of Energy to transfer the technique to its manufacturing line. Contact: **Larry Kazmerski, 303-384-6600**

Evaluation of PVMaT 5A Proposals Completed

The evaluation is now complete for proposals submitted in response to the **Photovoltaic Manufacturing Technology Project** (PVMaT) solicitation for Phase 5A, and offerors were notified as of January 20. Thirty-one proposals were submitted. The offerors proposed manufacturing R&D efforts totaling $97.3 million, with 48% cost-sharing. Seventeen of the proposals were submitted in the PV System and Component Manufacturing Technology area (5A1), and fourteen were in the PV Module Manufacturing Technology area (5A2). **NREL** expects to award 10 to 14 new PVMaT subcon-

opposed to an agreement, most of whom represented the U.S. business community. The pro-agreement U.S. business community—and yes, there is one—was well-represented by the Business Council for Sustainable Energy, whose members include such notable names as Enron and Honeywell. The environmentalists wore the serious faces, but even one of them came dressed in a suit of PV cells.

Various side events and displays added to the bustle, such as one that showcased NREL's and Keegan's participation in the Technology Cooperation Agreement Pilot Project. This project is an effort to collaborate with seven developing countries to remove barriers to private investment in technologies that will reduce greenhouse-gas emissions.

In the end, it was the strong hand of conference chairman Raul Estrada-Oyuela of Argentina that produced an agreement. He kept redefining what consensus meant. Eventually, there had to be consensus to remove something from the chairman's text!

The bottom line of the document that emerged, known as the Kyoto Protocol, is that the United States agreed to reduce greenhouse-gas emissions by 7% below 1990 levels, or 30% below what business as usual would have produced by 2010. Other industrialized countries such as Japan and countries of the European Union agreed to similar reductions ranging from 6% to 8%. Carbon trading, which had been a contentious issue, is part of the package for all participating countries.

"But of paramount importance is that the U.S. public and policy makers are engaged," says Keegan. "Even though ratification (by the U.S. Congress) will be an uphill battle, climate change is now front page news."

For more information, contact Patrick Keegan in NREL's Washington Office at 202-651-7544.

PV in the Spotlight at Disney World

What if you could gather 2 to 3 million people and tell them about PV technologies? And do it in a lighthearted way that engages the audience?

That scenario is unfolding right now at Disney World, where Roofus' Solar Neighborhood is on display. The exhibit, built by NREL and DOE, is part of EPCOT® Center's Science Jam, an annual outdoor exhibition that showcases the best of science and technology.

Roofus is a gregarious pooch who shows visitors his backyard, a paradise of PV-powered fountains, watering systems, and outdoor lighting. After that, he invites children to crawl in his PV-powered doghouse to play with his PV-powered toys! Disney expects 2.5–3 million people to visit the park during the March 13–May 31 run of the exhibition. NREL's goal is to expose as many of them as possible to photovoltaics and energy efficiency technologies.

The exhibit features PV modules from most of the major manufacturers mounted in cutaways of two houses representing the northern and southern portions of the United States. NREL's effort received substantial support from the PV and energy efficiency industries, including samples of emerging technology not readily available elsewhere.

"The emphasis is on telling people about DOE's Million Solar Roofs and Buildings for the 21st Century programs," said John Thornton, who heads up NREL's PV Market Development Team. "Those programs offer consumers products they can put to use in their own lives today. That's how we tell people about renewable technologies. Show them something they can touch and take home with them."

EPCOT communicators will give four daily performances and will also interact with visitors to answer questions and introduce a variety of energy-efficient and solar-energy hardware. When Science Jam ends in late March, Roofus' Solar Neighborhood becomes part of EPCOT's International Flower and Garden Show, which runs through the end of May. Then the exhibit could go on tour, ultimately ending up at NREL's Visitors Center.

For more information, contact John Thornton at 303-384-6469. Also, Roofus has his own interactive Web site at http://www.eren.doe.gov/roofus

tracts over the next 3 or 4 months. The actual number and timing will be a function of both individual negotiation results and funds available. The monitoring of resulting PVMaT 5A contracts will continue to be the responsibility of a combined **NREL/SNL Technical Monitoring Team**. This teamed monitoring has worked very well throughout the PVMaT project, and has provided a forum for both NREL and SNL to stay abreast of ongoing manufacturing R&D efforts and needs of the PV community. This teaming also provides a means for the subcontractors to identify unique areas where the laboratories can provide support. Contacts: **Ed Witt, NREL, 303-384-6402; Doug Ruby, SNL, 505-844-0317**

Coming Soon: RFP for University R&D for Future-Generation PV Technologies

In late March or early April, **NREL** will release solicitations for university research proposals for **future-generation PV technologies** and for **Historically Black Colleges and Universities**. The future-generation solicitation will consider proposals in all areas of PV-related research, including materials, devices, systems, measurement techniques, manufacturing processes, analysis, and theory. Responses must address the advancement of PV knowledge expected in the long term. Additional information on long-term PV technologies is available in the proceedings of NREL's 1997 Future Generation Photovoltaic Technologies Conference, available from the American Institute of Physics. Areas of particular interest to the program include thin-film crystalline silicon cells, innovative PV concentrators, dye-sensitized photoelectrochemical cells, organic solar cells, solar cells based on novel ternary semiconductors, hybrid device technologies such as PV-electrochromic panels, new measurement and characterization techniques, and other promising, innovative PV materials and technologies. Contact: **Robert McConnell, 303-384-6419**

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.

Under a funds-in project with **Siemens Solar Industries** (SSI), **NREL** has built and delivered a tester for silicon-ingot lifetime. SSI's **Greg Mihalik** and NREL's **Crystal Growth and Devices Team**, including **Tihu Wang, Marc Landry,** and **Ted Ciszek**, collaborated on the project, which was carried out at NREL. The new instrument is industrially rugged and uses a pneumatic system to move ingots up to 25 kg in weight into measurement position. The property of as-grown silicon crystals that correlates most closely with their future performance in solar cells is the charge-carrier lifetime, or τ. Measuring the τ values of the ingots before further processing is very desirable. Although procedures and instruments for measuring τ on wafers and small crystals have been developed, it is much more difficult to obtain a measurement on very large, heavily doped, solar-grade Si crystals of the type used in the PV industry. NREL researchers developed a novel probe that samples a small region of the crystal (making the local change in photoconductivity more evident and measurable) and that, when used with a powerful 940-nm diode laser and a low-noise electronics system, allows the reliable DC photoconductive-decay technique to be used on massive Si ingots. Contact: **Ted Ciszek, 303-384-6569**

After **Dick DeBlasio** received notification of approval from the IEEE Standards Board for the PAR to develop a "Recommended Practice for Qualification of Photovoltaic Concentrator Modules," the Concentrator Standards Working Group swung into action. **NREL** organized a conference call on December 15, 1997, to review the second draft of the proposed standard. Participants included **Mark Jackson (ENTECH), Bill Bottenberg (Photovoltaics International), Alex Maish (SNL), Bob Hammond (Arizona State University), Steve Hester (consultant), Craig Maytrott (Florida Solar Energy Center)**, and **Sarah Kurtz, Ben Kroposki, Tom Basso**, and **Bob McConnell** (all from NREL). **John Wohlgemuth (Solarex)** provided his comments by fax. The Concentrator Standards Working Group hopes to achieve the ambitious goal of completing its balloting on a proposed qualification standard in 1998. Contact: **Robert McConnell, 303-384-6419**

On January 15, **Tim Bruton**, Technology Manager for all crystalline silicon programs at **BP Solar**, visited **NREL** to discuss potential collaborations with NREL researchers. He gave a very informative presentation on the status and plans for BP Solar's worldwide PV activities, including the new CdTe manufacturing facility in Fairfield, California. BP Solar's approach to the PV market has changed from trying to choose "the winning" technology to developing a variety of technologies and targeting each for the appropriate market sector. The company prefers to sell entire systems, rather than be module or cell suppliers. BP Solar is the leading manufacturer in Europe and third largest worldwide, with the highest sales reported for any PV company. The CdTe facility in Fairfield is expected to produce 3 MW of modules by next year. Contact: **Tom Surek, 303-384-6471**

After 6 months of testing at **NREL's Outdoor Test Facility**, a 1-kW CIGSS array from **Siemens Solar Industries** (SSI) has shown excellent performance. Produced under the **Thin Film PV Partnership Program**, the array has shown two important characteristics: first, its calculated temperature coefficient for power is -0.44%/°C, which is equivalent to crystalline silicon modules, and second, the array has shown excellent stability over time and produces approximately 1 kW at Standard Test Conditions (1000 W/m^2 and 25°C). So far, the array performance characteristics are on par with crystalline silicon technology. SSI has also delivered its first commercial thin-film CIGSS products to NREL as part of the company's R&D efforts in the Thin Film Program. The two modules are rated at 5 W and 10 W. NREL's measurements show the 5-W modules are typically in the range of 5.5 to 5.6 W, and the 10-W modules range from 10.5 to 11.3 W. The CIGSS modules are currently being beta tested in the United States. Contacts: **Ben Kroposki, 303-384-6170; Harin Ullal, 303-384-6486**

AC modules and applications are making news at **NREL**. As part of the **PVMaT** 4A1 Program, **Solar Design Associates** delivered two AC module kits to NREL's **Outdoor Test Facility** (OTF). The kits each contain one large-area polycrystalline module from **Solarex** rated at 240 W, one micro-inverter from **Advanced Energy Systems (AES)** rated at 250 W, and mounting hardware for a ground-mounted system. NREL's **Ben Kroposki** said assembly, installation, and utililty grid-connection went smoothly for this first AC PV module kit at the OTF. Also, NREL's **Engineering and Technology Validation Team** provided facilities for humidity-freeze environmental testing of the AES's 250-W inverter intended for AC module applications. This 10-day test was monitored by **Underwriters Laboratories** (UL) for the purpose of listing AC modules that use the AES inverter. After completing ten 1-day cycles of 85% humidity at 85°C, followed by a -40°C freeze period, the inverter passed the hi-pot tests required by UL. Mounting brackets bonded to several different module rear-surface materials

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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 1997 through February 1998, we awarded 95 subcontracts (examples listed below) totaling more than $11 million. For further information, contact Ann Hansen (303-384-6492).

Chinese Ministry of Agriculture
Rural Electrification Using Photovoltaics in Northwest China
$100,000 (12/97–6/99)

Colorado State University
Device Physics of Thin-Film Polycrystalline Solar Cells
$421,995 (1/98–1/01)

Florida Solar Energy Center through the University of Central Florida
$CuIn_{1-x}Ga_xSe_2$ Thin-Film Solar Cells
$127,500 (1/98–1/01)

Georgia Institute of Technology
High-Efficiency Solar Cell Fabrication on Commercial Silicon Substrates
$443,000 (2/98–2/01)

ITN Energy Systems
Atmospheric Pressure Chemical Vapor Deposition of CdTe for High-Efficiency Thin-Film PV Devices
$796,375 (1/98–1/01)

Materials Research Group, Inc.
In Situ Sensors for Process Control of $CuInGaSe_2$ Module Deposition
$340,000 (2/98–2/01)

North Carolina State University
Characterization and Ti Gettering of PV Substrates
$330,000 (1/98–1/01)

University of California, Berkeley
Impurity Precipitation, Dissolution, and Gettering in PV Silicon
$445,000 (1/98–1/01)

University of North Carolina
Search for Factors Determining the Photodegradation in High-Efficiency a-Si:H-Based Solar Cells
$430,000 (1/98–1/01)

University of Oregon
Identifying Electronic Properties Relevant to Improving the Performance and Stability of Amorphous-Silicon-Based, Mid-Gap and Low-Gap Cells
$409,875 (1/98–1/01)

University of Utah
Characterization of Amorphous Silicon Thin Films and PV Devices
$283,992 (1/98–1/01)

Washington State University
Alternative Heterojunction Partners for CIS-Based Solar Cells
$350,523 (12/97–12/00)

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, as exemplified by the recent publications listed below. 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).

Bedair, S.M.; El-Masry, N.A. *New Approaches for High Efficiency Solar Cells: Final Report*. December 1997; 121 pp. NREL/SR-520-23266. Work by North Carolina State University, Raleigh, NC.

Birkmire, R.W.; Phillips, J.E. *Processing and Modeling Issues for Thin-Film Solar Cell Devices: Final Report*. November 1997; 167 pp. NREL/SR-520-23835. Work by Institute of Energy Conversion, University of Delaware, Newark, DE.

Brog, T.K. *Commercial Production of Thin Film CdTe Photovoltaic Modules: Final Report*. October 1997; 36 pp. NREL/ SR-520-23733. Work by Golden Photon, Inc., Golden, CO.

Guha, S. *Amorphous Silicon Research: Phase III Technical Progress Report, 1 August 1996–31 July 1997*. November 1997; 43 pp. NREL/SR-520-23543. Work by United Solar Systems Corp., Troy, MI.

Mitchell, R.L.; Witt, C.E.; Thomas, H.P.; Ruby, D.S.; King, R.; Aldrich, C.C. *Progress Update on the U.S. Photovoltaic Manufacturing Technology Project.* October 1997; 6 pp. NREL/CP- 520-22962. Prepared for the 26th IEEE Photovoltaic Specialists Conference, 29 September-3 October 1997, Anaheim, California.

Nelsen, E.; Hicks, A. *Million Solar Roofs* (flyer). October 1997; 2 pp. NREL/FS-520-23730. DOE/GO-10097-504.

Olsen, L.C. *Alternative Window Schemes for $CuInSe_2$-Based Solar Cells: Annual Report, 1 November 1995–31 October 1996*. October 1997; 29 pp. NREL/SR-520-23590. Work by Electronic Materials Laboratory, Richland, WA.

Perez, R.; Seals, R. *Photovoltaics Effective Capacity; Interim Final Report 2*. November 1997; 50 pp. NREL/SR-520-23097. Work by Atmospheric Sciences Research Center, The University at Albany, Albany, NY.

Photovoltaics in the Built Environment: A Design Guide for Architects and Engineers. September 1997; 264 pp. NREL/BK-550-23408. DOE/GO-10097-436.

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The five universities receiving awards under the new competitive procurement for the crystalline silicon program are the **University of California at Berkeley, Duke University, North Carolina State University, Georgia Institute of Technology,** and **Cornell University**. In addition, **Texas Tech University** has a subcontract to perform theoretical research on the impurity and defect passivation by hydrogen. The program's focus is to perform research that will lead to improvements and cost reductions in commercial silicon solar cell efficiencies by advancing cell fabrication technologies. The primary objectives include: improving the understanding of the mechanisms that limit large-area cell performance, developing processes to overcome these limitations to produce >18% efficiencies, performing research to identify low-cost substrate options for thin Si cells, disseminating research results, and assisting in the transition of these technologies into production. Contact: **Bhushan Sopori, 303-384-6683**

"Sunrayce 99" request for proposals were mailed to about **1,100 colleges and universities** across North America. Forty-four teams responded to the RFP and are entered in the race. The proposals will be reviewed by employees of DOE, General Motors, and Electronic Data Systems, and the top three will be awarded $9,000, $7,000, and $5,000, respectively. To be considered for an award, the proposals must have been submitted by February 18. However, new teams can still enter Sunrayce 99 until January 1999. On March 27–29, 1998, approximately 400 students and faculty advisors will attend a Sunrayce 99 Training Program in Atlanta, Georgia. Industry experts from across the country will give presentations on safety, photovoltaics, encapsulation, batteries, electric motors, aerodynamics, public relations, team management, and system engineering. Contact: **Byron Stafford, 303-384-6426**

About 35 researchers from the four Amorphous Silicon National Subteams attended the team meetings held at **NREL** in January. New team members include **P.C. Taylor** from the **University of Utah** and **X. Deng** from the **University of Toledo**. The teams will support the request from industry to research schemes to achieve modest increases in the deposition rate (e.g., from 0.3 to 0.5 nm/s) without loss of stabilized performance to allow higher output from the present manufacturing lines. Micro- and nanocrystalline silicon films will be investigated as an alternative to a-SiGe:H alloys for the narrow-bandgap component cell. **MVSystems**, **Penn State University**, and the in-house group at NREL will be preparing such films and devices. There is a strong fundamental scientific interest in the growth of microcrystalline layers, because it has now been well established that devices with the least amount of degradation and high stabilized performance are deposited near the amorphous/nanocrystalline transition, sometimes having small-volume fractions of nanocrystalline inclusions. The new "hydrogen collision" metastability model of **Howard Branz** (NREL) was presented, discussed, and found to be promising after many bewildering decades to describe Staebler-Wronski degradation. Contact: **Bolko von Roedern, 303-384-6480**

The 8th National Cadmium Telluride R&D Team meetings were held at the **Florida Solar Energy Center (University of Central Florida)** in January. On January 15, the **Stability Working Group** held its third CdTe Module Accelerated Life Test meeting. The key U.S. CdTe company (**Solar Cells, Inc.**, Toledo, OH) participated fully in the meeting. Issues of global diffusion of impurities versus local defect conversion are being proposed to explain the degradation of the cell I-V characteristic. A "rollover" occurs in the I-V characteristics at voltages larger than V_{oc}, indicating back-junction diode formation. On January 16, the **High-Efficiency Devices Working Group** met. Devices made on **Golden Photon's** high-resistivity, tin-oxide (HRT)-coated, low-cost glass substrates indicated positive results in device performance. Experiments are being planned to further understand the role of HRT and to improve device performance. Other discussion topics were the modeling of the CdTe solar cells and the study of the CdS/CdTe alloy formation observed by the various research groups. Contacts: **Tom McMahon, 303-384-6762; Harin Ullal, 303-384-6486**

Publications, Continued from p. 9

Sites, J. R. *Device Physics of Thin-Film Polycrystalline Cells and Modules: Annual Subcontract Report, 6 December 1995–5 December 1996*. October 1997; 36 pp. NREL/SR-520-23589. Worked by Colorado State University, Fort Collins, CO.

Swanson, R.; Tan, T.; Sopori, B. *Seventh Workshop on the Role of Impurities and Defects in Silicon Device Processing: Summary of the Panel Discussions, 11–13 August 1997, Vail, Colorado*. October 1997; 15 pp. NREL/CP-520-23549.

Wohlgemuth, J. *Cast Polycrystalline Silicon Photovoltaic Module Manufacturing Technology Improvements: Annual Subcontract Report, 1 January 1996–31 December 1996*. October 1997; 37 pp. NREL/SR-520-23623. Work by Solarex, Frederick, MD.

Industry Updates, Continued from p. 8

were also subjected to the humidity-freeze cycling. Following the test, these brackets remained attached while supporting a 35-lb weight. Contacts: **Ben Kroposki (OTF), 303-384-6170; Holly Thomas (PVMaT), 303-384-6400; Carl Osterwald (Standards), 303-384-6764**

Recent research activities within the **National CIS R&D Team** have helped **International Solar Electric Technology** (ISET) make marked improvements in its nonvacuum deposition of thin-film CIS absorbers. Recently, about 100 samples of 2"x2" substrates were processed into solar cells at ISET's facilities. There is no Ga or S in these films. **NREL** verified efficiencies in the range of 11.5% to 11.6%. When substrate size is increased to 4"x6", adhesion problems can result from even small blemishes (1–2 mm^2). However, understanding gained from the national teaming activity has helped ISET overcome these adhesion issues, resulting in improved submodule performance. This should help ISET scale up its thin-film CIS pilot-line activities in the near future. Contact: **Harin Ullal, 303-384-6486**

On January 15 in New Orleans, implementation of the **PV Global Approval Program** (PVGAP) for PV component and system certification and test-facility recognition on a global scale was initiated for the United States. **SEIA** was designated master licensee in the United States, and delegated the U.S. administration of PVGAP to **PowerMark Corporation**, which will be the technical and audit entity for inspections under the UL NSI (National Supervisory Inspectorate). **NREL** was represented by **Dick DeBlasio**, who is the IEC TC82 Chairman and a PVGAP board member. PVGAP requires that IEC TC82 standards be adopted and used by the PVGAP program. A similar implementation meeting was held in Brussels, Belgium, on February 11 to initiate the European PVGAP activity. The U.S. model was adopted, whereby the **European PV Industries Association** was designated the PVGAP master licensee. Contact: **Dick DeBlasio, 303-384-6452**

On February 20, James Wilkie, Technology Manager for Photovoltaics for **Shell International Renewables** (Shell Centre London) and Roy Levitch of **Shell Oil** (U.S.) visited **NREL** on a fact-finding mission. They spent the day meeting with management and staff of the **National Center for Photovoltaics** and discussing the **DOE/NREL PV Program**, PV technologies, U.S. and international markets, and in-house research in CdTe, CIGS, dye-sensitized cells, amorphous silicon, crystalline silicon, and III-Vs and concentrators. Shell leadership is interested in business opportunities in renewables, and is evaluating both CIGS and CdTe as leading contenders for a serious commitment to thin films. Contact: **Ken Zweibel, 303-384-6441**

NREL's John Benner, Kannan Ramanathan, and **Harin Ullal** visited **ITN Energy Systems**, Wheat Ridge, CO, on February 19 to present the latest results on CIGS junction studies of interest to the thin-film PV industry. Representatives from **Global Solar Energy** of Tucson, AZ, and **Materials Research Group**, also of Wheat Ridge, were also in attendance. Kannan Ramanathan presented a talk entitled, "Understanding Junctions in $CuInGaSe_2$." In the discussion that followed, industry representatives indicated their strong desire to collaborate with NREL researchers. Contact: **Harin Ullal, 303-384-6486**

John Pern and **Steve Glick** of **NREL** have conducted accelerated exposure tests (AETs) over 750–850 hours for solar cell samples from **Spire Corporation** and a new encapsulant from **Evergreen Solar, Inc.**, and over 1200 hours for a-Si minimodules from **Iowa Thin Film Technologies**. The AET employs three DSET Suntest CPS tabletop exposure systems, two Oriel solar simulators, and an oven at elevated temperatures. Encapsulated Si solar cells that are fabricated at NREL were also tested in parallel. The exposed samples are periodically characterized with spectrophotometric analyses (transmittance, color indices, fluorescence) and/or I-V measurements. The test results to date have been summarized, delivered, and/or presented to participants from Spire, Iowa Thin Film, and Evergreen Solar. NREL also performed a test run of Tefzel/EVA encapsulation for the CIS thin-film laminated on flexible supporting material for **ITN Energy Systems** with encouraging results. Although more work will be performed with thinner EVA films, a better approach that will use a hot-roll-press lamination process was recommended to the ITN participant. Contact: **John Pern, 303-384-6615**

PV Calendar

April 25–30, 1998, *SOLTECH '98*. Sponsor: SEIA/UPVG. Location: Orlando, Florida. Contact: UPVG. Phone: 202-857-0898 Fax: 202-223-5537.

June 13–18, 1998, *Solar '98: Renewable Energy for the Americas*. Sponsor: ASES. Location: Albuquerque, NM. Contact: ASES. Phone: 303-443-3130 Fax: 303-443-3212.

July 6–10, 1998, *2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion*. Sponsor: WIP. Location: Vienna, Austria. Contact: WIP. Phone: +49-89-7201235 Fax: +49-89-7201291.

July 20–23, 1998, *Federal Emergency Management Agency Workshop: Technology Solutions for Emergency Management Challenges*. Sponsors: FEMA, NREL, others. Location: Argonne National Laboratory, Chicago, IL. Contact: John Thornton. Phone: 303-384-6469 Fax 303-384-6490.

July 20–23, 1998, *PV Standards and Codes Forum*. Sponsor: NREL. Location: Winter Park, CO. Contact: Dick DeBlasio. Phone: 303-384-6452.

August 16, 1998, *Center of Excellence Silicon Team Meeting*, and **August 17–19**, *8th Workshop on Crystalline Silicon Solar Cell Materials and Processes*. Sponsor: NREL. Location: Copper Mountain, CO. Contact: Bhushan Sopori. Phone: 303-384-6683 Fax: 303-384-6531.

September 8–11, 1998, *15th NREL/SNL PV Program Review Meeting*. Sponsors: NREL, SNL. Location: Denver, CO. Contact: Mowafak Al-Jassim. Phone: 303-384-6602.

September 20–25, 1998, *1998 World Renewable Energy Congress V*. Sponsor: UNESCO and others. Location: Florence, Italy. Contact: A.A.M. Sayigh. Phone: +44-0118-961-1364 Fax: 44-0118-961-1365.

October 6–8, 1998, *Village Power '98*. Sponsor: NREL. Location: The World Bank, Washington, D.C. Contact: Roger Taylor. Phone: 303-384-6432.

October 12–15, 1998, *4th Conference on Thermophotovoltaic Generation of Electricity*. Sponsor: NREL. Location: Denver, CO. Contact: Tim Coutts. Phone: 303-384-6561.

November 3–4, 1998, *PV Performance and Reliability Workshop*. Sponsor: FSEC. Location: Cocoa, FL. Contact: Dick DeBlasio. Phone: 303-384-6452.

November 19–21, 1998, *ENERGEX '98—The 7th International Energy Conference and Exhibition*. Sponsor: University of Bahrain. Location: Manama, Bahrain. Contact: Dr. W.E. Alnaser. Phone: +973-688381 Fax: +973-688396.

This quarterly report encourages cooperative R&D by providing the U.S. PV industry with information on activities and capabilities of the laboratories and researchers at NREL.

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