Happy Anniversary

The big Two Zero! This July, the National Renewable Energy Laboratory celebrated its 20-year anniversary of working in renewable energy and energy efficiency. Back in 1977, a small group of scientists and engineers opened the doors of the Solar Energy Research Institute, NREL's predecessor. Today, some 700 people do research and help to support activities in areas that include photovoltaics, solar thermal, biomass, alternative fuels, wind, and buildings technologies.

Throughout these two decades, photovoltaics has been a primary focus at the Lab. And as this issue of *PV Working With Industry* will highlight, the PV world of NREL and its partners is busier than ever.

Activities range from the new to the familiar. One new initiative is the Million Solar Roofs—recently announced by President Clinton and Energy Secretary Federico Peña—the first major solar initiative in over a decade. Another new activity is a workshop sponsored by the National Center for Photovoltaics to help DOE, NREL, and Sandia staff understand the needs and concerns of the PV industry as the latest annual operating plan is being formulated for the National PV Program.

NREL's R&D groups in PV also continue to expand their capabilities; for example, the Measurements and Characterization Center has developed a rapid and secure means to transfer data electronically to research and industry customers. Other work, as in the area of standards and codes, is bringing benefits to consumers, utilities, and manufacturers. This issue gives you a glimpse of some of these activities and more, and how NREL is involved to better serve the PV community.

NREL PV

Working With Industry

Features

Departments

Spring/Summer 1997

A Splendid Sight: Solar Rooftops Across the Country

An Editorial by James E. Rannels

Warren Gretz, NREL/PIX03665

Jim Rannels, DOE's Acting Director of the Office of Photovoltaic and Wind Technologies, gives his wholehearted endorsement to the Million Solar Roofs Initiative.

These days, when I look at a solar panel, one thought comes to mind—how sweet it will be to see 999,999 more of them.

We in the PV community know that one million solar rooftops will be a splendid sight. And President Clinton is on our side. "Now we will work with businesses and communities to use the sun's energy to reduce our reliance on fossil fuels by installing solar panels on one million more roofs around our nation by 2010," he said.

The Energy Secretary agrees. Federico Peña says: "These solar energy systems will generate electricity and provide hot water. Accomplishing this goal takes two steps: energizing our federal facilities and resources, and second, collaborating with the people and companies who build and use these solar systems."

Thinking about the Million Solar Roofs Initiative—and the promise it holds—sort of takes your breath away. Of those million rooftop systems, more than one-half are slated to be PV and the rest solar hot water. Any way you look at it, that's a lot of solar systems.

This massive deployment of solar technologies will reach schools, libraries, private homes, and large and small businesses. By relying on market forces and consumer choice, Million Solar Roofs will build on state and local actions to remove market barriers and generate grassroots demand for solar technologies. Eighteen states have passed laws (e.g., net metering) to promote the on-site use of solar technologies, and other states are providing solar incentives as they deregulate electric markets.

Million Solar Roofs will support companies and consumers who have already made the decision to invest in solar energy. For example, 68 utilities, serving 40% of U.S. electricity consumers, have formed a consortium to buy $500 million worth of PV panels by 2003. On the federal front, Executive Order 12902, signed by President Clinton in 1994, calls for the accelerated purchase of solar energy systems for federal buildings. This alone could be a big boost, because the U.S. government is the largest owner of buildings in the world, spending $3 billion annually on electricity.

So let's take this opportunity to show the American public that our industry has come of age. And while we're at it, let's show world markets that our PV technologies are still cutting edge—and getting sharper all the time.

It's time for everyone to learn what we in the PV community have known for a long time: Solar energy will ultimately be a major part of our energy future, and that future is closer than many people think.

To learn more about the initiative, visit the Million Roofs Website at http://www.eren.doe.gov/millionroofs, *or contact Jim Rannels at 202-586-1720.*

PV Websites

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 & Information • About Our Program

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

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

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

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

Million Solar Roofs .....http://www.eren.doe.gov/millionroofs
Projected Accomplishments • The Program • Solar Energy Technologies

Photovoltaics & Electronic Materials .....http://www.nrel.gov/pvem
(Available this fall, see article on page 3)

Coming This Fall . . . to a Website Near You!

We are bringing you some things that are old . . . and much that is new—from NREL's Center for Photovoltaic and Electronic Materials (PV&EM).

Among the old things are those we have always strived for: good service . . . knowledge and expertise . . . solid consultation . . . fine partnering for R&D . . . noteworthy technical and scientific information.

The new runs from the "neat" to the "gee whiz," all of which, along with the old, are packaged in the upcoming PV&EM Website.

First you'll notice the dynamic site entry—definitely "neat." You can get a sneak preview by glancing to the lower right of this page, though in print we can only show the design in its two-color version.

We hope the "gee whiz" runs through much of the rest of the site, from how easy it is to navigate the site, to the types of information you can glean, to how fast and easily you will be able to get that information.

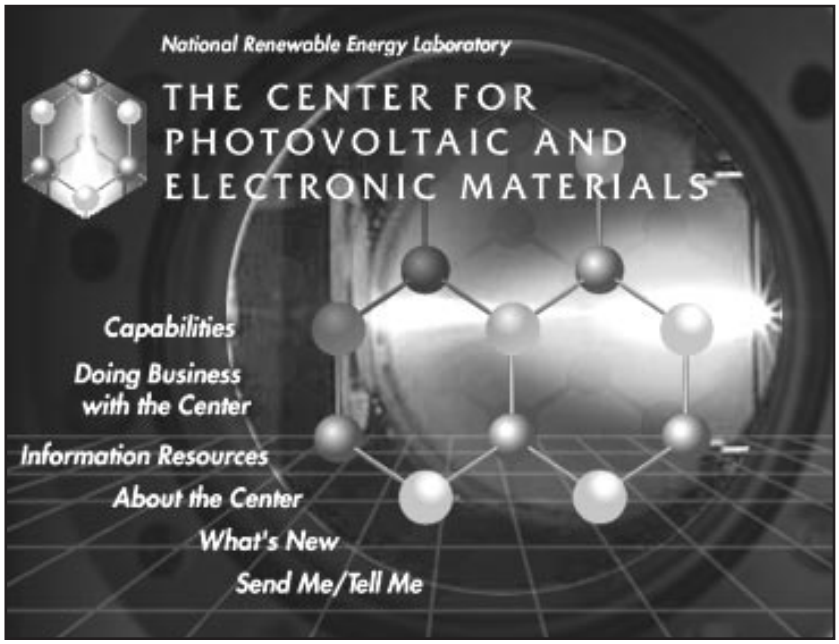
One of the most important aspects of the site, for example, is the Capabilities section. We list, discuss, explain—in both cursory and detailed fashions, and graphically and schematically—our capabilities, which span the entire process from the conception of a photovoltaic or electronic device, to making that device, to integrating that device into a larger system, to using it in an application. Here, you can find out about the materials we grow or the device structures we design; explore the properties of those materials and the advantages of those structures; and learn about the techniques and systems we use, their theories of operation, and their applications. You can learn about the teams that grow the materials, that design and make the devices, and that work with manufacturing processes. And you can easily locate contacts, within teams or within the Center in general, with whom to discuss your problem or concept, desired services, or aspects of R&D.

The new Website will also enable you to more easily do business with NREL and the Center. You'll be able to find out what kinds of business you can do with us, what relationships we can form, what technologies are hot and what are not, and what technologies are available for licensing or further development. And you can contact members of our business development team, who will walk you through the process of setting up a service or relationship.

Want to find out about the latest advances in R&D? Then click on Information Resources, where we present the latest journal articles, conference papers, books, and patents published by members of the Center. You can call up abstracts for more information, or order copies of the latest articles and papers. Or, you can link to other sites—ones that are relevant to your fields of interest in PV and electronic materials.

All of this and more will be available sometime this midfall. But for the future, we have much more planned for this site. We will, for example, set up the ability to exchange data electronically (password protected, of course) with our partners, initiating a true virtual lab—something that we have already pioneered on the Website for our sister center, the Center for Measurements and Characterization (see article on p.6). We will put up articles on important new innovations and applications. And, down the road, we will build an infrastructure to allow automatic html encoding of all of our articles, papers, and documents, so that you may download from your computer those research results that are important to you. Such an ability to so easily communicate scientific information is, after all, one of the great promises of the Internet.

For more information, contact Dave Ginley at 303-384-6573 or at david_ginley@nrel.gov.



Deb Braun, Gary Cook, NREL

Soon you'll be able to visit our new Website at http://www.nrel.gov/pvem. We plan to go "live" sometime this fall.

When PV Industry Members Speak, the Gov

"DOE. NREL. SNL. It doesn't matter. They rarely listen to industry's needs. Or if they do, they don't often follow through with a relevant program of action." How many times have you or another member of the solar industry heard or said something like that about the nation's government-funded research and development programs?

Over the years, industry members of the photovoltaic R&D community have expressed concerns like these to PV program participants at the U.S. Department of Energy (DOE) and its national laboratories, which include the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL). Too often, these complaints have been justified or at least understandable. That's one big reason why the National Center for Photovoltaics (NCPV) was formed by government R&D groups: to help make such comments a thing of the past.

Start with a Workshop

To begin establishing program operating plans that are relevant and responsive to the nation's needs, NCPV members from DOE, NREL, and SNL sponsored a two-day workshop on July 14 and 15 of this year. They invited a number of leaders in the U.S. PV community to the workshop to discuss topics of current importance. Those invited included representatives of the PV industry, university research groups, module and balance-of-systems (BOS) manufacturers and integrators, and the marketing sector.

Cécile Warner, NREL/PIX05249

At the July workshop, panelists who discussed key issues, roles, and responsibilities relating to PV systems integration and applications development included (left to right) Steven Strong, Steve Chalmers, Chuck Backus, and Ed Kern.

They allocated each of six topics to a discussion panel; each panel consisted of three to six experts in photovoltaics. Workshop facilitators asked each panel to discuss the critical issues that should be addressed in their particular topic area; the roles that the government, private industry, and universities should play in PV-related activities; and the priorities that should be assigned to these activities. The critical difference between these discussions and many held in the past was that the government participants took on the role of listeners. Their message to attendees was, "We're here to listen to what you have to say."

This listening audience included Jim Rannels and Richard King, DOE PV program management; Stan Bull, NREL's Associate Director of Research Operations; and members of the NCPV Operations Office, which includes representatives from both SNL and NREL.

Reverse the Process

The topics of the six panels mirrored the major elements of the flow of PV-related technologies from the research laboratory to the marketplace. In reverse order, these topics were PV Market Development and Conditioning, PV Systems Integration and Applications Development, Balance-of-Systems Component Engineering and Development, PV Module Manufacturing and Process Development, Applied Research and Exploratory Development, and Fundamental Research and Innovation. The topics were discussed in reverse order, from market issues to research issues, so that needs could be discussed in the panel discussions before solutions were offered (see box at right for panel members).

The workshop's sponsors wanted it to be more than a series of canned presentations. So panelists first presented a 10-minute review of the issues, roles, and priorities determined for their topic area. An hour-long discussion then followed, with questions and comments directed not only to the panelists but to the rest of the audience as well. DOE and national lab staff paid close attention to a lively exchange of information and opinions. After all the panels had been covered, each panel spent about two hours over lunch coming to a consensus on key issues, roles, and priorities. These summaries were presented by an individual from each panel and capped by a one-hour discussion in which all participants attempted to pull together the central themes and issues that emerged over the two days.

ernment Listens

Participants from DOE and the labs hope to hold meetings like this regularly, either annually or in conjunction with the DOE PV Program Review Meeting, to monitor changes in the critical issues and solutions coming out of the PV community. The result should be to make the NCPV a more responsive group of participants in the development and deployment of photovoltaic technologies.

One issue raised at the workshop was industry representation on an NCPV Advisory Board. Attendees submitted a long list of qualified candidates. Working with that list, government members of the NCPV plan to invite several individuals to join the Board and attend its first meeting in the Fall. The purpose of the Board is to provide guidance on the concerns in the various sectors of the PV industry to the NCPV Operations Office.

The information shared at the workshop is summarized in a report that participants say will definitely not be relegated to the back of a filing cabinet. The NCPV has already listened closely to one workshop recommendation and responded by including external reviewers in assessments of NREL's and SNL's internal programs. In August, NREL and SNL team leaders and program managers presented their R&D task plans, budgets, and resource needs to the NCPV Operations Office. Two workshop attendees were among those who reviewed the proposed R&D tasks.

Plan for the Future

The information and ideas gleaned from the workshop are being combined with the task plans to come up with a solid NCPV Annual Operating Plan for Fiscal Year 1998. This operating plan should help to lead the national laboratories in R&D activities that better serve the needs of the entire PV community.

For more information about the NCPV or the annual operating plan, contact John Benner at 303-384-6496 or at bennerj@tcplink.nrel.gov.

Panelists for NCPV's Workshop on Strategic Directions for the PV Program

PV Market Development and Conditioning

Mary Shaffner (facilitator)	Solar Energy Industries Association
Don Osborn	Sacramento Municipal Utility District
Rose McKinney-James	Corporation for Solar Technology and Renewable Resources
Michael Eckhart	Management and Financial Services
Clay Aldrich	Siemens Solar Industries

PV Systems Integration and Applications Development

Chuck Backus (facilitator)	Arizona State University
Edward Kern	Ascension Technology
Steven Strong	Solar Design Associates
Steve Chalmers	PowerMark Corporation

Balance-of-Systems Component Engineering and Development

John Wiles (facilitator)	Southwest Technology Development Institute
Hans Meyer	Omnion Power Engineering Corp.
Christopher Freitas	Trace Engineering
Michael Stern	Utility Power Group
Gerard Ventre	Florida Solar Energy Center

PV Module Manufacturing and Process Development

Clay Aldrich (facilitator)	Siemens Solar Industries
Roger Little	Spire Corporation
Allen Barnett	AstroPower, Inc.
Brian Huff	Automation & Robotics Research Institute, University of Texas at Arlington
William Bottenberg	Photovoltaics International

Applied Research and Exploratory Development

David Carlson (facilitator)	Solarex
Tim Anderson	University of Florida
Subhendu Guha	United Solar Systems Corp.
Dan Sandwisch	Solar Cells, Inc.
Roy Gordon	Harvard University
Ajeet Rohatgi	Georgia Institute of Technology

Fundamental Research and Innovation

Alan Fahrenbruch (facilitator)	Stanford University
Robert Birkmire	Institute of Energy Conversion, University of Delaware
Fritz Wald	ASE Americas
Richard Schwartz	Purdue University
Vikram Dalal	Iowa State University
Robert Gay	Siemens Solar Industries

Other Industry Invitees

Todd Foley	BP America Inc.
Vijay Kapur	International Solar Electric Technology
Ron Kenedi	Photocomm, Inc.
Mohan Misra	ITN Energy Systems
Jawid Shahryar	Solec International, Inc.

The Paperless Lab: Getting

NREL's Center for Measurements and Characterization has more than 25 experts who measure and characterize almost 15,000 PV materials, cells, or modules each year. This group has always served many people in the PV community—and has served them well.

But NREL can now offer even better service, not just in the quality and range of measurements, but in the ability to shorten the turnaround time. One of the research scientists in this Center, David Niles, has worked with others to develop a quick, easy, and secure way to transfer data electronically to customers. This capability—available through the Center's Website at http://www.nrel.gov/measurements—especially improves NREL's interactions with external collaborators.

Sending data via the Website is easier and faster than faxing, e-mail, and the U.S. postal service. Niles, who specializes in electron spectroscopic analyses, says, "Information in the form of 'images' represents the highest demand for data transfer. But many of our state-of-the-art techniques, such as the large-area laser scanner, produce image files that may be too large to transmit via e-mail. So the transfer via our Website on the Internet works perfectly."

The Measurements and Characterization group has been experimenting with this concept since last fall. After some initial trial runs, the Center decided to purchase a separate server—located in Niles' office—specifically to maintain the security of the data. The mechanism developed was a cooperative effort among the Measurements and Characterization group, NREL's Information Technology team and Communications Center, Apple Corporation, and several DOE subcontractors involved in collaborative research with NREL.

Some industry researchers have been concerned about the security of the transactions. But according to Niles, this concern, although understandable, is unfounded. "We've definitely erred on the side of over-security," says Niles. "Several private consulting firms have set up a big-dollar challenge to anyone who can hack into the operating system. But the system has no features you can break into, so you're forced to enter through the 'front door' with an ID and password." For high security, there is also a feature that disables the system at the third failed attempt to log on.

Some people have also wondered if data can only be transferred using a Macintosh computer. "The transfers are not specific to platforms," says Niles, "so you can access this option via the Internet whether you're a PC, UNIX, or Macintosh user." The mechanism is designed to integrate AppleTalk, FTP, and HTTP services.

A third typical concern relates to data formats. Jamie Norris, a Web developer helping Niles, explains, "Although you are not restricted, we recommend certain formats like GIF (Graphic

News at Press Time

NREL's III-V Team Wins Technology Transfer Award

The III-V Materials and Devices Team at NREL has received an award for excellence in technology transfer from the Federal Laboratory Consortium (FLC). The award was presented to **Jerry Olson, Sarah Kurtz, Daniel Friedman, Alan Kibbler,** and **Charlene Kramer** for the development and transfer of the technology for a tandem solar cell for powering satellites. The tandem cell, which uses two cells grown monolithically as one device, has a record-setting 25.7% (AM0) 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 FLC represents more than 600 federally funded laboratories. *For more information, contact Jerry Olson at 303-384-6488.*

Data from Us to You Electronically

Interchange Format) and JPEG (Joint Photographic Experts Group) because Netscape has internal translators for them. Most of our customers use Netscape and this is where we've put most of our efforts." These concerns and others are discussed more fully in a Frequently Asked Questions section on the Website. One caveat: you may need to learn a little more about Netscape than you currently know to take full advantage of this data-transfer mechanism. But as Niles concludes, "Short-term pain for long-term gain!"

So what's next? The main goal is to get more external clients and NREL researchers aware of this capability and its benefits. Besides cleaning up any bugs in the current system, Niles is working on a screen-dump option so that data will not need to be converted. When perfected, this will provide almost real-time collaboration at a distance and will be especially useful for customers who are knowledgeable about specific techniques.

For further information, or to set up a password, contact David Niles at 303-384-6624 or Larry Kazmerski at 303-384-6600. Also check the Website at http://www.nrel.gov/measurements.

Jim Yost Photography/PIX01663

David Niles, here using an X-ray photoelectron spectroscopic unit, can send analytical data and interpretations to customers quickly and securely via the Internet.

Announcing a New Renewable Energy Journal

Larry Kazmerski is the Editor-in-Chief of a new quarterly international journal published by Elsevier—*Renewable and Sustainable Energy Reviews*. The journal will publish specially commissioned review articles designed to bring together under one cover current advances in the field of renewable and sustainable energy sciences. The articles will concisely summarize recent work, providing sufficient detail for a non-specialist in the general field to gain an understanding of the state of the art without having to go to the original papers. The first issue, available in September, includes a review paper by Kazmerski entitled, "Photovoltaics: A Review of Cell and Module Technologies." *For more information, contact Larry Kazmerski at 303-384-6600.*

PV Optics Software by NREL Wins R&D 100 Award

R&D Magazine has selected NREL's "PV Optics" software as an R&D 100 winner for 1997. Developed by **Bhushan Sopori, Jamal Madjdpour, Todd Marshall,** and **Chris Gaylord**, "PV Optics" models the light-trapping of any solar cell or module, telling not just how much light will be absorbed, but also, what wavelengths and at what depth. Using wave theory as well as ray optics, it accurately accounts for thin layers and metal backings, neither of which could be handled by any previous model. The award ceremony will be at the Museum of Science and Industry in Chicago in September. *For more information, contact Bhushan Sopori at 303-384-6683.*

Standards and Codes Make Life Easier for PV Stakeholders

People who buy, use, and sell photovoltaic energy systems and PV power have at least one thing in common.

Consumers need to feel assured that the product they're buying will live up to their expectations for quality and performance. Utilities need to know that they won't encounter power quality problems and hit other snags when residential customers use a PV system connected to the power grid. And manufacturers need to have their products certified both nationally and internationally, so they can stay competitive in expanding markets. The common element in all these needs: standards and codes.

Where It Began

Consumers, utilities, and manufacturers can all thank a group of dedicated individuals and organizations who have been working hard for years to help meet the need for PV standards and codes. The group began its work about 20 years ago. In 1977, the U.S. government recognized the need to establish a "consensus approach" in uniformly evaluating the performance of terrestrial PV components and systems. Several early documents, though not prepared using a formal consensus process, included input from more than 100 individuals from industry, government laboratories, and academia.

These early documents gained wide acceptance and prompted the establishment of a strong organization of technical groups that now write consensus standards. The major organizations actively working on PV standards and codes today include the Institute of Electrical and Electronics Engineers (IEEE), the American Society for Testing and Materials (ASTM), the International Electrotechnical Commission (IEC), the National Fire Protection Association (NFPA), and Underwriters Laboratories (UL).

Domestically, IEEE and ASTM began working on PV performance consensus standards in 1978, and UL began safety standards work in 1984. Internationally, standards development activities formally began in 1982, when the IEC formed a technical committee on Solar Photovoltaic Energy Systems. The Solar Energy Industries Association currently coordinates a Secretariat position and a Technical Advisory Group, with funding from the Department of Energy through the National Renewable Energy Laboratory (NREL).

Where We Are Now

After nearly 20 years of work, standard methods and practices continue to be essential for a maturing PV industry. A major effort by the PV community during the last 3 years has been to revise electrical safety codes. The importance of establishing consensus standards to commercialize PV is evident in the continuing activities of IEEE, ASTM, IEC, UL, and NFPA, which have provided the technical basis, knowledge, and expertise for revising the National Electrical Code.

Another major effort has been to establish a PV module certification and laboratory accreditation activity in the United States. The PV community participated in an NREL-funded study conducted by Arizona State University to develop the criteria and implementation approach for PV module certification and laboratory accreditation. Testing requirements were based on ASTM and IEEE PV standards. PowerMark Corporation, a not-for-profit certification body, was formed in 1996 to provide assurances to purchasers and users on module quality through product labeling. As a third-party organization, PowerMark licenses manufacturers to use a certificate of conformity based on both U.S. and international consensus standards. Testing criteria for module qualification are in accord with IEEE and IEC standards. In July 1997, Arizona State's PV Test Laboratory became a fully accredited PowerMark laboratory for testing and certifying PV modules—the first U.S. PV module commercial testing laboratory to be so recognized.

Global issues are crucial in today's standards community. The international PV community believes that accelerating the commercialization of PV depends on being able to certify PV systems to ensure product quality and safety. One solution is PV GAP—the Global Approval Program for PV—whose mission is to be "a global, PV-industry-driven organization that strives to promote and maintain a set of quality standards and certification procedures for the performance of PV products and systems, to ensure high quality, reliability, and durability." Products displaying the PV GAP "Quality Seal" should enjoy a significant marketing advantage.

NREL has played an active role in standards and codes work by sponsoring the PV Standards and Codes Forum. In June, forty participants representing U.S. PV manufacturers, users, testing laboratories, and the

national laboratories met in Winter Park, Colorado, at the fifth annual forum. It allowed all organizations involved in developing PV standards and the National Electric Code to meet together; later, working groups from IEEE, ASTM, and IEC discussed individual documents.

Where We're Headed

During the forum, the IEEE Standards Coordinating Committee 21 (IEEE SCC21) participants reviewed a draft Project Authorization Request (PAR) 1479, "Recommended Practice for the Evaluation of Photovoltaic Module Energy Production." This document presents a method of determining the energy output of a PV module under reference weather and load conditions. This standard will give customers information about how much energy their modules will produce under certain conditions.

Two new draft projects were also proposed at the IEEE SCC21 meeting. For the first project, an IEEE PAR for PV system test standards must be established; the project will focus on developing a U.S. standard on PV system-level testing to assist in developing an international standard. The outcome will be a standard establishing small-system testing procedures and requirements needed by users, manufacturers, and commercial testing laboratories. This standard is needed for PV system certification by accredited testing laboratories.
A second project, proposed by the PV Concentrator Alliance (see p. 11), will develop a standard for PV concentrator qualification testing. Once the project is approved, the working group will develop an IEEE consensus standard that references the IEEE document on module qualification tests and Sandia's test procedure for concentrators.

The forum also involved ASTM subcommittee E44.09 participants, who reviewed an existing standard for spectral response measurements of solar cells and two new draft standards. One is a field insulation resistance test for arrays and the other is a test method for multi-junction PV devices. After reporting on activities of the U.S. Technical Advisory Group for IEC Technical Committee 82 working groups, the Technical Advisory Group reviewed several draft standards: a classification scheme for solar simulators, energy ratings for PV modules, module safety testing, and on-site measurements of current-voltage characteristics.

All this work should help meet the needs of everyone in the PV community. Consumers will gain confidence in the performance and safety of PV products. Utilities' concerns will be allayed by standards that help to break down infrastructure barriers to interconnection. And manufacturers will have a stronger competitive position in the global energy market.

For more information, contact Dick DeBlasio (303-384-6452), who is Chairman of IEEE SCC21 and is on the Board of Directors of PowerMark and PV GAP. Or contact Carl Osterwald (303-384-6764), the Chairman of ASTM E44.09.

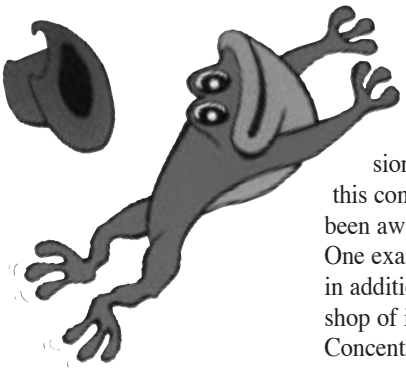
Steve Rummel, NREL/PIX04569

The testing of module performance and durability, both outdoors and indoors at NREL's Outdoor Test Facility, supports groups developing PV standards and codes.

Conferences Galore — Both New and

Every event needs a symbol to add dignity to the proceedings. The **First Conference on Future Generation Photovoltaic Technologies,** held in Denver, Colorado, on March 24–26, was no exception. With apologies to Mark Twain, and to symbolize technologies poised to make dramatic progress in the short term, the symbol for this conference was a leaping frog. The proud winners of "Calaveras Awards for Leapfrog Technologies" can attest to the event's success.

But the "froggy conference" did have a more serious side. NREL hosted 120 researchers from 9 countries; discussions focused on recent achievements of PV technologies that have the long-term potential to simultaneously achieve high efficiency and very low cost. For this conference, "future generation PV technologies" were those not in production and not expected to enter production soon because additional research, development, and innovation is needed.



There were 38 oral presentations in 6 sessions, and 12 posters. Many of the concepts at this conference were proposed decades ago, but have been awaiting enabling technologies or innovation. One example is PV concentrator technology, which, in addition to a special luncheon session, had a workshop of its own following the conference (see Concentrator Alliance, p. 11.).

A conference highlight was the report of almost 11% conversion efficiency and the discovery of a new dye for the so-called Graetzel cell. Graetzel reported that seven industrial organizations are working to bring this solar cell to market. Conference proceedings will be published by American Institute of Physics in September. *For more information, contact Bob McConnell at 303-384-6419 or at robert_mcconnell@nrel.gov.*

The TPV community was well represented at the **Third NREL Conference on Thermophotovoltaic Generation of Electricity,** held May 18–21 in Colorado Springs, Colorado. The 123 attendees included researchers, systems engineers, potential users, and participants from federal and state agencies and universities. They discussed all aspects of TPV electricity generation—combustion processes, emission of radiation, spectral control, conversion of radiation into electricity, systems engineering, and practical experience.

One outcome of the conference was a sense of agreement among the community that TPV appears to be developing rapidly and that there is a real need for systems demonstration rather than R&D into the individual components of a TPV system. TPV systems have a number of potential outstanding advantages in military applications and other markets, and demonstration of systems is likely to encourage prospective users to support the field more enthusiastically.

In addition to eight general sessions, the conference featured a special session led by Holly Thomas of NREL. Attendees discussed issues around a coordinated national TPV plan, including a proposed structure for a national TPV program. The objective of the national program would be to raise the general awareness of the potential for TPV technology and to facilitate cooperation among researchers, system developers, component manufacturers, and funding sources to rapidly develop a robust U.S. industry. The program would be conceived from the needs of the market, with development focused to support the market-identified requirements, so that advancements would be rapidly used by industry. Conference proceedings will be published by American Institute of Physics in September. A fourth TPV conference is planned for October 12–15, 1998, at the Adams Mark Hotel in Denver. *For more information, contact Tim Coutts at 303-384-6561 or at tim_coutts@nrel.nrel.gov.*

The annual **PV Performance and Reliability Workshop** was organized and sponsored by Sandia and NREL, and hosted by the South West Technology Development Institute on August 5–6, 1997, in Las Cruces, New Mexico. The focus of the workshop was to identify performance and reliability issues that are having an impact on the value of the technology, establish the benefits of improving performance and reliability in the highest impact areas, and develop a constituency that will actively participate in implementing solutions. More than 125 participants attended the 2-day meeting, which included more than 20 presentations and summary discussions by all. Emphasis was placed on the reliability of systems and balance-of-systems (BOS), the safety and performance of systems and BOS, and field experience.

Conference goers identified and addressed some major areas of concern for the PV community, including battery applications in PV system design, inverter failures in the field (prototype vs. commercial products), the need for accelerated and environmental testing of BOS, and standard system design vs. standard system performance testing. A presentation on the Million Roofs program, given by Jeffrey Mazer from DOE, developed further interest and discussion on utility interface standards (IEEE 929),

Old — Provide Valuable Tech Transfer

UL requirements, NEC codes, building code requirements, and module and system safety and performance certification.

A major benefit to all attending the workshop was learning about recent developments, interacting on concerns regarding fielding systems and lessons learned, and exploring where the industry and laboratories can help each other. The next workshop is planned for November 1998, hosted by the Florida Solar Energy Center. *For more information, contact Dick DeBlasio at 303-384-6452 or at deblasid@tcplink.nrel.gov.*

The **7th Workshop on the Role of Impurities and Defects in Silicon Device Processing** was held in Vail, Colorado, on August 11–13. Seventy-six researchers and scientists from the United States, Japan, Germany, the Netherlands, and Belgium attended. The theme was "R&D Issues to Support 1 GW/yr Goal by the Year 2010."

Like the previous workshops, this one revealed a wealth of pertinent information. The projected PV energy production costs, based on silicon technologies, are believed to be at $1.78/W at a 100-MW factory level using current technologies.

Process equipment and diagnostic/monitoring tools for 1 GW/yr production are basically unavailable. PV-specific equipment must be developed, which will require some standardization of the material, similar to that of the integrated-circuit industry. The PV industry needs mapping-type tools.

The processing required to reach 18% or higher efficiencies requires fundamental approaches of impurity and defect manipulation after the material growth. Much has been accomplished in the last 5 years, but a major hurdle remains in developing efficient methods to dissolve precipitated impurities from the defect clusters, with some novel approaches being pursued.

Although tremendous progress has been made in applying gettering and passivation to solar cell processing for fabricating higher-efficiency cells, details of these processes are still obscure. Systematic studies are needed.

Thin-film Si cells offer a tremendous potential. Some of the recent results show that very high current densities can be obtained from thin (about 3-μm) layers of microcrystalline Si cells, possibly indicating higher absorption than in crystalline Si. *For further information, contact Bhushan Sopori at 303-384-6683 or at soporib@tcplink.nrel.gov.*

The Concentrator Alliance Warms Up

The **Workshop for the PV Concentrator Industry,** requested by DOE and held last March following the Future Generation PV Technologies conference, drew dozens of representatives from industry—14 companies overall—and government organizations. This was the first time since the Sandia Program review meetings that the concentrator industry had met together, and most of the participants were surprised at the number of companies that are still pursuing concentrator PV. Fairly recently, large companies (BP Solar and Honda) have shown interest in developing concentrator technologies.

Concentrator systems have evolved during the past decade to meet different market opportunities. Products now include concentrator systems as small as 230 watts, hybrid systems providing both heat and electricity, and several innovative nontracking or minimal-tracking systems. Research and development sponsored by government (DOE), the utility industry (Electric Power Research Institute), and private companies has helped to create a nascent concentrator industry, ready to advance to large-scale commercial deployment of concentrator PV systems.

For more information, contact Sarah Kurtz (303) 384-6475.

This workshop spawned a meeting of the minds and mutual interests, leading to the formation of the PV Concentrator Alliance. The alliance is an industry group of companies pursuing the commercialization of concentrator PV components and systems. Memberships and associate memberships in the alliance are open to all companies and persons in government, universities, and nongovernmental organizations who share these goals.

Warren Gretz, NREL/PIX00183

This PV concentrator tracking system is currently deployed at PVUSA in northern California.

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.

During **NREL**-led trade missions to India in 1995, **Omnion Power Corporation** was introduced to **NEPC-Micon**, a half-billion-dollar company. The introduction led to an agreement between the companies to establish a joint venture in renewable energy. Both PV and wind systems are being pursued, with Omnion supplying their power conditioning systems to the projects. Over the next 4 years NEPC plans to invest an additional $150 million in solar generation. It is expected that Omnion will provide the majority of the power conditioning equipment. The first result of this joint venture is a 100-kW PV plant located on existing wind farms. The PV plant was recently inaugurated by **Indian Minister Dr. S. Venugopalachari, Ministry of Power and Non-Conventional Energy Sources, Government of India**. NEPC presently has 750 MW of wind systems installed in the Tamil Nadu area of India. This joint venture is an excellent example of how private-sector companies working in partnership with the U.S. government can develop a win-win situation to do business in the international sector. Contacts: **Jack Stone, 303-384-6470 and Harin Ullal, 303-384-6486**

The first CdTe Module Accelerated Life Test meeting was held at **NREL** in February. Key participants included **T. McMahon, G. Jorgensen, K. Zweibel, H. Ullal, NREL; P. Meyers, ITN/ES; S. Albright, Golden Photon, Inc. (GPI);** and **R. Powell, Solar Cells, Inc., (SCI).** Two levels of accelerated testing were considered: The first level—standardized screen tests, requiring a small number of test objects to accelerate and isolate failure modes—would need to be conducted on modules or special cell/device structures. For characterization, we will select a sensitive, easy-to-measure parameter derived from standard light and dark current voltage data for each test to monitor each failure mode. The screening tests must assist in defining acceleration constants for models used in life prediction tests. Also, we must not screen for failure modes that won't occur in the field. The second level of accelerated testing will be module lifetime prediction tests appropriate for CdTe, requiring a large number of test objects for service life prediction. These will follow at an appropriate time. Contacts: **Tom McMahon, 303-384-6762 and Harin Ullal, 303-384-6486**

NREL staff members **B. von Roedern** and **T. Surek** made site visits to the **Sovlux** plant in Moscow, Russia, and held meetings in February with Sovlux management and staff; staff from **Energy Conversion Devices (ECD)** also participated. Sovlux is a joint venture between the Russian State organization **KVANT** and ECD. In Moscow, they are operating a triple-junction amorphous silicon line to produce a-Si PV modules. NREL is supporting Sovlux with a subcontract under the **Newly Independent States/ Industrial Partnering Program (NIS/IPP)** managed by the **United States Industry Coalition (USIC)** for **DOE**.

NREL is also engaged in a CRADA with ECD to support the development of Sovlux' PV modules. After our discussions, it became clear that the two areas where NREL could provide the most crucial support are module testing and the evaluation of encapsulation materials. To compete on the world market, the Russian thin-film PV modules must pass all accelerated testing sequences. NREL is conducting most of these tests, not to establish pass-fail criteria, but rather, to assist the module manufacturers to identify the causes of problems. Further, Sovlux is planning to switch certain U.S.-made encapsulation materials to Russian-made ones. NREL's expertise in polymer chemistry should be valuable in determining the suitability of those materials for PV module encapsulation. Contacts: **Bolko von Roedern, 303-384-6480 and Tom Surek, 303-384-6471**

The **Electric Power Research Institute (EPRI)/ Department of Energy (DOE)** Photovoltaic Application Experience Workshop in Denver, CO, was organized by **Frank Goodman** of EPRI to review PV application and experience, identify problem areas, and identify opportunities for cooperation and collaboration to address the needs. The workshop had 27 attendees from utilities, module manufacturers, system integrators, **Environmental Protection Agency**, **Western Area Power Administration**, **Utility PhotoVoltaics Group**, **NREL**, and **Sandia**. **Holly Thomas** of NREL moderated the session on Interconnection and Safety, and NREL's **Dick DeBlasio** provided additional comments and supporting discussion on topics such as testing, standards, certification, and product definition. Results of the workshop will be summarized in a report published by EPRI. Key issues, their relative priority, and who should be take a leadership role in resolving them were identified for the topics of Interconnection and Safety, PV Products, Operating Requirements, and Project Planning, Procurement and Installation. Contacts: **Holly Thomas, 303-384-6400 and Dick DeBlasio, 303-384-6452**

NREL's CdTe team has initiated a project to develop high-performance transparent conductive oxides (TCOs) that could replace the conventional SnO_2 layer in a CdS/CdTe device structure. One promising candidate is cadmium stannate (Cd_2SnO_4), which has several significant advantages over conventional

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Recompeting the Thin-Film PV Partnership Program

The recompetition of the entire subcontracted thin-film R&D program is under way. On May 15, in accordance with the FY 97 Annual Operating Plan milestone schedule, letters of interest (LOI) for the 2nd Thin-Film PV Partnership were mailed to 131 requesters. This recompetition covers the entire DOE Thin-Film Program at NREL, including R&D and Technology Partnerships in CIS, CdTe, a-Si, and film silicon.

The awardees of the LOI will join with NREL in-house researchers to make up the four National Teams (CIS, CdTe, a-Si, and ES&H). Depending on the results of the LOI, another national team, "Film Silicon," may be formed from among the awardees. An unusual aspect of this round of the LOI is that EPRI is cosponsoring it with funds of between $300 and $1,000 K for a Special Topic in Very High Efficiency CIGS-Based Multijunctions. This private funding of additional R&D successfully leverages the federal investment in thin-film PV. The DOE portion of the funding forms the backbone of the LOI and is expected to be about $11 to $13 M per year for 3 years. Corporate partners must cost share between 10% and 40% (but some have proposed 50%), depending on the kind of award and on whether they are a small or large business.

The response to this solicitation has been strong. More than 60 proposals were submitted by the U.S. PV thin-film industry and the various university groups. The U.S. DOE/NREL dollar amount requested is $77 M, with the subcontractor contribution being $36 M. The total amount for the 3-year program is $113 M. Both external and internal reviewers are being used in the evaluation process. Announcement of awards is scheduled for early November 1997. *For more information, contact Ken Zweibel at 303-384-6441.*

Request for Proposals Issued for PVMaT Phase 5

The announcement for a PVMaT (Photovoltaic Manufacturing Technology) Phase 5 request for proposals (RFP) was published in Commerce Business Daily on May 15. The RFP, issued on June 30, solicited research and development proposals from members of the photovoltaic and related industries. Planned for $8 M, the goal of the RFP is to advance PV manufacturing technologies, reduce PV manufacturing costs, improve PV product performance and reliability, and provide a foundation for private expansion of U.S. commercial PV-production capacities.

Areas of interest include, but are not limited to, issues such as improving module-manufacturing processes; system and system-component packaging, system integration, manufacturing and assembly; product manufacturing flexibility; and balance-of-systems development including storage and quality control, with the objective of improving the manufacturing process. Proposals must demonstrate significant cost reductions in manufacturing systems/system components and delivered power or services to users. As with the previous PVMaT solicitations, this will be a cost-shared partnership between DOE and industry. Proposals were due by September 9, 1997. After the evaluation process, contracts will be awarded in early FY 1998. *For more information, contact Ed Witt at 303-384-6402.*

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).

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University Corner

NREL signed a subcontract with the **Institute of Energy Conversion (IEC), University of Delaware**, in February. This subcontract supports IEC to continue its research on thin-film PV devices based on a-Si:H, CdTe, and $CuInSe_2$. The 4-year, $4.7 million subcontract covers work from February 1997 to February 2001. IEC's subcontract, "Optimization of Processing and Modeling Issues for Thin-Film Solar Cell Devices," is funded by NREL's Thin Film PV Partnership. DOE has designated IEC as a **University Center of Excellence for PV Research and Education**, headed by **Dr. Robert Birkmire**. For many years, NREL has contributed the largest share to IEC's budget. IEC celebrated its 25th anniversary in May with a Thin Film Photovoltaic Symposium, also hosting a meeting of all three **Thin Film PV Partnership National R&D Teams**. Contact: **Bolko von Roedern, 303-384-6480**

In February, **Texas State University (TSU)** dedicated a 4-kW PV R&D laboratory at its School of Technology campus in Houston, Texas. The system consists of 4 kW of **Solarex** modules, two **Ananda** power controller systems, a **Trace** inverter, a battery bank, and a variety of ac and dc appliances. **Marshall Blalock, Jr. (Solarex Southwest PV Systems, Inc.)** was the system contractor. The system was jointly funded by **Houston Lighting and Power** ($135,000) and the **Electric Power Research Institute** ($105,000). Project consultants included **Andries Van Der Linde** and **Johann Niehaus**, **Port Elizabeth Technikon** (Port Elizabeth, South Africa). **TSU Professor Joshua Hill** and **HBCU PV Associate Oral La Fleur** worked at Port Elizabeth Technikon last summer, supported by NREL HBCU funding, on a training program for PV system installers. The PV R&D laboratory supports TSU's developing program to encourage undergraduates to explore challenging career options in PV. TSU has one of NREL's smallest HBCU contracts, but has been extremely successful in leveraging its funding to obtain additional support for educational PV projects. Contact: **Robert McConnell, 303-384-6419**

Physics Today, American Physical Society's monthly magazine, published news about a collaborative research project between the **NREL Amorphous Silicon Team (R. Crandall and E. Iwaniczko)** and the **Cornell Physics Department (R. Pohl and X. Liu)**. The same NREL hot-wire a-Si:H that has improved, stable properties compared to other forms of a-Si:H also exhibits dramatically reduced vibrational damping. The damping study, together with NMR and X-ray absorption results, suggests increased structural order that may contribute to the improved stability of hot-wire material. Contact: **Richard Crandall, 303-384-6676**

Publications, Continued from p. 13

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Industry Updates, Continued from p. 12

TCOs. It is more conductive, more transparent, has a lower surface roughness, is patternable, and is exceptionally stable. The team has integrated this compound into a device and produced the first ever Cd_2SnO_4-based CdS/CdTe polycrystalline thin-film solar cell with an efficiency of 14.0%. These promising results have generated significant interest from industry with requests from **Solar Cells, Inc. (SCI), Golden Photon, Inc. (GPI),** and **ANTEC** for Cd_2SnO_4 coated substrates. Cd_2SnO_4 material was provided to both SCI and GPI for evaluation. Contacts: **Peter Sheldon, 303-384-6533 and Xuanzhi Wu, 303-384-6552**

The **Gas Research Institute (GRI)** is developing software entitled "Binmaker" that provides access to and analysis of TMY2 data for energy analysis by heating and air-conditioning engineers. The software will provide bin type data that gives the number of hours in the year that certain meteorological conditions (dry bulb and humidity ratio primarily) are met. **Bill Marion** of **NREL** discussed with **GRI's Doug Kosar** the development of TMY2, the data, and their intended use and application with respect to GRI's software.

The TMY2 data set consists of one year (365 days) of hourly typical meteorological year (TMY) data for 239 locations in the United States and its territories. The data set was completed by NREL in 1995 by using solar radiation and meteorological data for the period 1961-1990. TMY2 data are intended for use in computer simulations of solar energy conversion systems and building systems to facilitate performance comparisons of different system types, configurations, and locations. GRI will package its software and the TMY2 data on CD-ROM and make it available to heating and air-conditioning engineers for a small fee to cover the distribution costs. GRI's anticipated 10,000 to 20,000 users within the first couple of years will greatly expand the use of the TMY2 data sets and yield improved energy analyses. Contact: **Bill Marion, 303-275-4620**

The Solar Spin project had its first implementation meeting. A Memorandum of Agreement between **DOE** and **NASA** was signed January 1997 to integrate commercially available renewable energy sources with new advanced flywheel energy storage systems. Participants included **Henry Chase, US Flywheel Systems; Byron Stafford, NREL; Jim Dunn, NASA's Center for Technology Commercialization; Bob Beaman, NASA Goddard Space Flight Center; Dave Christer, NASA Lewis;** and **Joe Obermann, Unique Mobility.** This project will characterize the electrical interfaces between the flywheel system's motor controller, input power sources (PV, wind), and the electrical power output (dc or ac) on commercially ready or prototype flywheel systems. This project is focused on complete energy storage systems with 2-5 kWh energy capacity and up to 1 kW peak power output. Applications requiring more energy or power would use several flywheels in parallel, much like battery systems. This meeting solidified the working relationship between NASA and NREL acting on behalf of DOE, along with two flywheel manufacturers. Two major areas of the Solar Spin project still under development are defining the electrical inputs and outputs of flywheel systems of interest to this project, and defining and implementing the remaining project. Contact: **Byron Stafford, 303-384-6426**

The **Lockheed-Martin/NREL** CRADA work at Lockheed-Martin (Scaled-up CIS-based solar cells on flexible substrates) has produced devices with efficiencies exceeding 6%. Even though the efficiency value is not high (as compared to our record devices), its merit is three fold: (1) such devices come from a sample that is 12-in x 12-in, i.e., uniformity is not an issue in the Lockheed sputtering approach, (2) such devices are not manufactured in the standard moly-coated soda-lime glass but rather, in a lightweight, flexible substrate (Upilex) that is amenable to both space and terrestrial applications, and (3) such devices are $CuInSe_2$ (no Ga or Na). The importance of these results to NREL is that it has met the expectations from Lockheed regarding the technical support required from the **NREL** CIS Team. The 6% number was an internal LM milestone needed to demonstrate/validate their approach. This is an example of a highly productive technology transfer work from the CIS Team to U.S. industry. Contacts: **Miguel Contreras, 303-384-6478 and Rommel Noufi, 303-384-6510**

In May, **Hal Post (Sandia), Linda Neilson (Utah Office of Energy Services),** and **John Thornton (NREL)** met with the **2002 Winter Olympics (Salt Lake City)** project managers or representatives for the speed skating, luge and bobsled, and hockey venues, as well as the new student housing. Typical of most major construction of this sort, utilities are being provided and power requirements are immense; PV does not appear to be cost-competitive as a main source of power. There are opportunities in which PV can be used as an educational tool, that-while not competitive with the grid-will have tremendous public exposure. There are also many opportunities requiring small, mobile, grid-independent or emergency power sources for applications such as security or lighting in which PV will be highly cost-effective. Contact: **John Thornton, 303-384-6469**

PV Calendar

October 20–24, 1997, *American Vacuum Society 44th National Symposium*. Sponsor: PEUG, AVS. Location: San Jose, CA. Contact: Keith Mitchell. Phone: 212-248-0325 Fax: 212-248-0245.

October 28–30, 1997, *Utility PV Experience Conference & Exhibition 1997*. Sponsor: UPVG. Location: Albuquerque, NM. Contact: Erin O'Donnell. Phone: +1-202-857-0898 Fax: +1-202-223-5537.

November 10–12, 1997, *World Photovoltaic Power '97*. Sponsor: Gorham Advanced Materials. Location: San Diego, CA. Contact: Chris Jones. Phone: 207-892-5445 Fax: 207-892-2210.

March 21–25, 1998, *3rd International Conference of Solar Electricity: PV and Solar Thermal Technologies*. Sponsors: Government of Sharjah, NREL, others. Location: Sharjah, UAE. Contact: Fuad Abulfotuh, NREL. Phone: 303-384-6601 Fax: 303-384-6604.

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

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.

September 14–16, 1998, *15th NREL/SNL PV Program Review Meeting*. Sponsors: NREL, SNL. Location: Denver, CO. Contact: Mowafak Al-Jassim. Phone: 303-384-6602.

October 12–14, 1998, *4th Conference on Thermophotovoltaic Generation of Electricity*. Sponsor: NREL. Location: Denver, CO. Contact: Tim Coutts. Phone: 303-384-6561.

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

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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