NREL PV

Working With Industry

Fall 1996

Organized for Action

Almost 2000 years before Dilbert, the Roman satirist Petronius is attributed with the cynical insight, "I was to learn later in life that we tend to meet any new situation by reorganizing; and a wonderful method it can be for creating the illusion of progress while producing confusion, inefficiency, and demoralization."

With new situations in 1996, we at the National Renewable Energy Laboratory have seen our share of reorganization. But the directors of our five new "centers" related to photovoltaics don't share Petronius' grim analysis of results. Instead, our PV centers are seeing actual progress. And this progress is coupled with greater clarity of mission, improved organizational efficiency, and higher morale among the researchers.

The five centers—Photovoltaics and Electronic Materials, Performance Engineering and Reliability, Measurements and Characterization, Basic Sciences, and Renewable Energy Resources—can site specific benefits.

For example, one center director emphasizes the greater consensus in his group and between groups as to what they should be doing. Another director points to reduced bureaucratic red tape, thus allowing his researchers to do their work more easily. And other directors see that the division of their centers into functional teams makes sense because they were designed by the people actually involved in research and who are in regular contact with industry needs.

In this issue of NREL's *PV Working With Industry*, we want to provide a picture of the new PV-related centers. And we hope that after this introduction, you'll understand how—through these centers—we can better work for you and with you.

Features

Departments

Focusing on PV's Bright Present and Brighter Future

An Editorial by Tom Surek

Warren Gretz, NREL PIX04236

Tom Surek is the Technology Manager for NREL's PV Program. Photovoltaic research has been his focus for 23 years, with the last 18 years at NREL.

The Photovoltaic Program of the National Renewable Energy Laboratory has entered a very exciting time. After nearly 20 years of research and development, we are seeing a critical transition in the PV industry. No longer are the successes only in the laboratory. Lab-based innovations are now accompanied by first-time manufacturing of new photovoltaic modules and demonstration of new, innovative PV products such as PV roofing modules. Clearly, our developments—the concentrated and consistent efforts of NREL, industry, and universities—are bearing fruit.

As the Technology Manager of NREL's Photovoltaic Program, I serve as the point of contact, linking the Department of Energy and NREL's PV-related "centers." Four of our centers were formed from other existing divisions during NREL's reorganization earlier this year and include the Centers for Photovoltaics and Electronic Materials, Performance Engineering and Reliability, Measurements and Characterization, and Basic Sciences. The fifth center, Renewable Energy Resources, supports the PV Program in the area of assessing the solar resource.

New concepts in the PV wind—to mix renewable energy metaphors—are adding to these exciting times. The recently created National Center for Photovoltaics (NCPV) will be a significant part of the PV Program's effort. The NCPV, coordinated through NREL and in collaboration with Sandia National Laboratories, has as a primary goal to pull together geographically scattered PV initiatives into a single, unified effort. This focusing will encourage the most efficient use of the nation's photovoltaic resources.

The NCPV will allow a more effective means of interacting with other laboratories, industries, and universities that are doing photovoltaics research. We will be able to provide program resources more efficiently to help the U.S. PV industry maintain its worldwide leadership in the technology and the marketplace. And we will be able to reach out better to customers and investors with information and assistance.

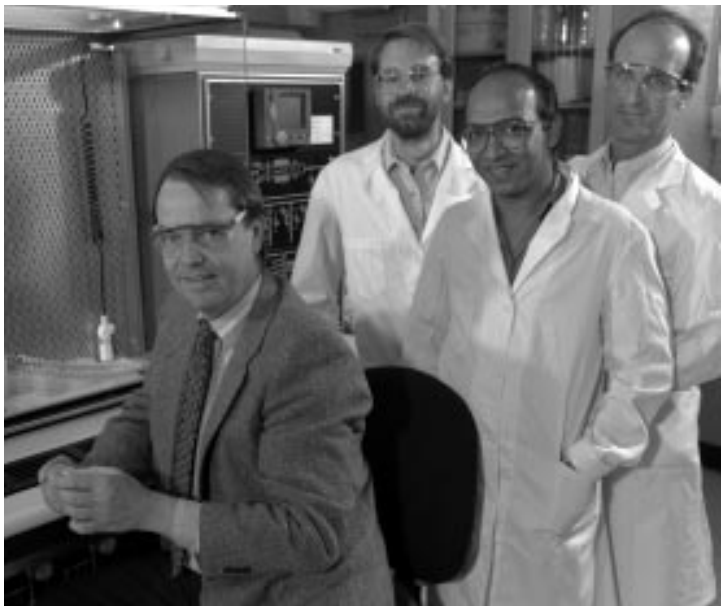
Another goal of the NCPV is to forge additional strategic alliances and partnerships. The stronger links between research facilities will enable cross-laboratory teams to bring complementary capabilities to bear on complex problems. Additionally, connecting related industries will augment the advance of photovoltaics, resulting in new products and applications. This means that, in time, we will see new areas of PV commercialization.

We must emphasize the importance of maintaining balance in the research efforts. We seek to use our resources wisely as we conduct everything from basic and applied research to measurements and testing, from manufacturing research to facilitating marketing and commercialization. Losing sight of any part will cause the PV Program, and the PV industry as a whole, to suffer.

The NCPV is the culmination of many years of PV research. Its existence recognizes NREL's role in the photovoltaics technologies. We can be proud that NREL has played, and continues to play, a strong role in developing these technologies with and for industry.

For further information, contact Tom Surek, 303-384-6471.

Mission Possible: Helping the PV Community



Warren Gretz, NREL PIX04237

Researchers Doug Rose, Ramesh Dhere, and Pete Sheldon (standing, left to right) study cadmium telluride and are part of the Center for Photovoltaics and Electronic Materials directed by John Benner (seated).

"The mission and the people of NREL."

Not surprisingly, that's what has kept John Benner at the National Renewable Energy Laboratory for the last 18 years. Before he became the director this year of the Center for Photovoltaics and Electronic Materials, Benner managed projects in the area of crystalline silicon and advanced devices.

The mission that Benner and his center focus on is: to lead the nation toward a sustainable energy future by developing photovoltaic technologies, advancing related science and engineering, coordinating efforts with NREL's partners, and facilitating utilization and acceptance.

NREL's reorganization earlier this year, which in part reformulated photovoltaic-related activities, helps Benner's center fulfill this mission. Benner expands on how the reorganization has helped create a new, positive environment. "We are striving for consensus decisions rather than engaging in an adversarial process in order to optimize everyone's performance. It's still in a state of development, but we have a clear picture of where we're going."

As a laboratory, NREL is working hard to eliminate barriers. This means taking greater advantage of skills and experience within and across teams—and even across technology centers. In the Laboratory's changing culture, researchers and support people are encouraged to do things that are not specifically in job descriptions; they are also encouraged to share ideas and skills within and between areas. As a result of satisfaction from their jobs and developing new skills, NREL researchers will increasingly benefit their industrial partners.

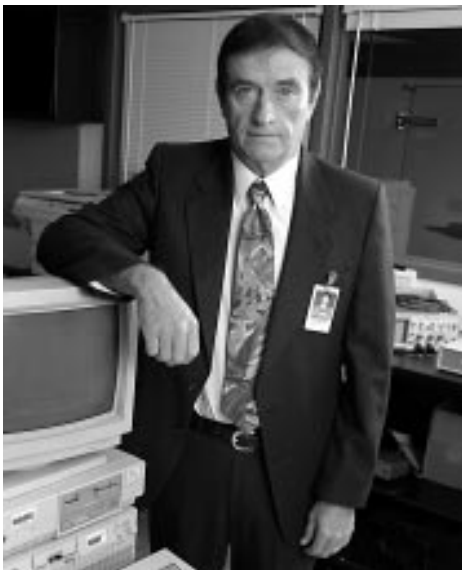
"One of our biggest challenges is keeping up with the success of the photovoltaics industry," Benner said. "Sales have increased by 33% during the past year, and we have had to find ways to improve our contacts. People in industry want to be able to find a specific individual with the background to meet their needs, so we are developing a database of capabilities. We'll make this available to our partners so they know who to contact when they need something."

Another challenge has been streamlining the operation. With about 20% fewer employees than a year ago, Benner's group is still able to meet everyone's needs. Benner wants to assure those people who work with his researchers that his center has retained its core capabilities, even as individual teams continue to streamline processes. "It's too early to measure creativity," he says, "but at least people feel they work in an environment that encourages them to be creative."

Benner is excited about seeing people work in new contexts and about their willingness to share resources and expertise. There will always be challenges at NREL. And a new and evolving organization is helping to meet them.

For further information, contact John Benner, 303-384-6496.

Enhancing Our PV Testing to Support Industry



Warren Gretz, NREL/PIX04235

Roland Hulstrom, director of the Center for Performance Engineering and Reliability, stands next to some of the computers that monitor the performance of PV modules and systems at NREL's Outdoor Test Facility.

As a 19-year veteran of the National Renewable Energy Laboratory, Roland Hulstrom has been involved in a lot of reorganizations. But this one is different, according to this director of the Center for Performance Engineering and Reliability.

"Previously, reorganizations were taken to the first level of management, roughly similar to what is now a center director," he said. "Then that person organized his or her own team at will. Below that organizational level, there was little cohesiveness or agreement."

"Our reorganization earlier this year was completely different," explained Hulstrom. Center members—not just one manager—did a thorough job of looking at their customers and the nature of the work. They interacted with staff members from other centers to determine what the working relationships should be. Finally, they presented their findings to Hulstrom, and together, they came up with a picture of the center.

"It was a real process of self education and self awareness for each staff member," Hulstrom said. "Each person had a big role in making the center happen, and each one understands what it's all about."

NREL's industrial partners have much to gain from this entire process. Previously, each working unit had core competencies. But they weren't always readily available because of technology "silos," a term that graphically describes the stand-alone, non-interactive nature of programs and research that unfortunately may develop within an organization.

Now, when industry partners need help—for example, they want to test a prototype photovoltaic module—Hulstrom's center members can offer a broader set of capabilities. The reorganization expanded the core competencies, and members are aware of related technologies and expertise in other NREL centers. "Silos are the path of least resistance. You just do your own thing in isolation from other groups," said Hulstrom. "The main thrust of the new organization is to break down the barriers. It takes constant effort, but the results are well worth it."

Given that, what does industry need to know in order to do business with the Center for Performance Engineering and Reliability? That we have world-class facilities operated by experienced researchers and technicians. That we are here to collaborate on a variety of projects, to accelerate the development of photovoltaic products. And that, as always, we can be trusted to keep company-sensitive results proprietary.

The Center works with industry on two big challenges: to lower module costs and improve module reliability. At the same time, we must have innovative and timely solutions in research and development to advance photovoltaic technologies and products.

For further information, contact Roland Hulstrom, 303-384-6420.

News at Press Time

NREL, Golden, Colorado—The National Photovoltaics Program now has a site on the World Wide Web. The site, funded by the U.S. Department of Energy and being developed by NREL, contains an extensive introduction to PV technology—from how solar cells work (including the materials used and their interaction with light energy), to how cells are formed into arrays, to applications and uses of the technology. This tutorial on PV technology is currently the largest, most comprehensive one on the Internet. Future development will include an extensive collection of documents, general PV-related information, and links to other PV Internet resources, as well as an overview of the National Photovoltaic Program. The Web site went live on the Efficiency and Renewable Energy Network (EREN) on October 22, and it can be accessed directly at the following address:
http://www.eren.doe.gov/pv

What's in a Name?

Larry Kazmerski's name has not changed at all since last year. But his *group's* name has changed slightly—from the Measurement and Characterization Branch to the Center for Measurements and Characterization.

With such a similar name before and after organizational restructuring at the National Renewable Energy Laboratory, has anything really changed? According to Kazmerski, the center director, there have actually been many changes.

One big change is greater empowering of Kazmerski's staff. "Our researchers can finally deal with their clients—the Department of Energy, industrial partners, whomever—directly," he says. "There are no interfaces, there's no having to go through various levels of bureaucracy, to get something done. Some of these major barriers have been brought down. And as a result, our clients can collaborate with us more easily. It's like we're all part of the same organization."

Kazmerski allows that downsizing—in part due to reduced government funding of renewable energy research and development—has had an effect. But bringing in funding from sources other than DOE will eventually bring in new people. It's a balancing act that's already working. "We always have to ensure we don't detract from our service to DOE. But we're setting up some arrangements, such as cooperative R&D agreements and work for others—that let us enhance our operations," he said.

For example, some staff members are working with companies such as AstroPower and Solar Cells, Inc., to characterize silicon and thin-film PV devices. And the center is working with subcontractors who pay for special projects. "We have the expertise and the facilities to help these companies succeed," Kazmerski said.

He added, "I've been at the Laboratory for more than 19 years, and it's still great to get paid for doing something you like. NREL's a great place to work. There are always challenges, and we have a good working atmosphere for meeting them. And I really think that the job satisfaction here is high, especially as we are able to work more closely and easily with our clients."

Warren Gretz, NREL/PIX04232

Larry Kazmerski (left), director of the Center for Measurements and Characterization, discusses results of scanning tunneling microscopy/atomic force microscopy with researchers Steve Smith, Helio Moutinho, and Leila Cruz.

So what's the greatest challenge? Kazmerski thinks for a second before responding, "For me, perhaps it's running our center in a way that more closely mirrors a private business. This will allow us to better stretch our resources and do more work."

Changing a culture is never easy. But this new center thrives on challenges.

For further information, contact Larry Kazmerski, 303-384-6600.

OSTI, Oak Ridge, Tennessee—The Office of Scientific and Technical Information, through support from the National Photovoltaic Program, has developed a Web site having documents related to photovoltaics. *Photovoltaic Energy—Electricity from Sunlight* is an online document database that contains hypertext, bibliographic citations of current worldwide information available on all aspects of photovoltaics. Topics include amorphous technology, polycrystalline thin films, gallium arsenide, crystalline silicon, concentrator technology, and systems research. Full-text reports are also provided if available. Users can search, retrieve from, and browse the database, which is updated bimonthly to keep PV energy researchers informed on the latest scientific and technical reports in their area. The database can be accessed from the following address: *http://www.doe.gov/phv/phvhome.html*

Getting Down to Basics

Warren Gretz, NREL/PIX04238

The Center for Basic Sciences, directed by Satyen Deb, has expertise in diverse disciplines to support the base of scientific knowledge for renewable energy technologies.

Satyen Deb describes two kinds of basic research, "One kind is compelling, open-ended, and driven by the curiosity of individual researchers, and the other is the directed basic research that serves the needs of specific products or technologies. Both have a role to play, and it is a matter of maintaining the appropriate balance."

Deb, the director of the Center for Basic Sciences, explains that, "...the directed basic research is primarily what the Center does for technologies related to renewable energy." The new center, formerly the Basic Sciences Division, helps to lay the foundation for technologies not yet ready to be commercialized. Its primary objective is to do cutting-edge, long-term, fundamental research—both basic and applied.

In discussing whether the new NREL organization has affected the center's relationship with industry, Deb says, "Many things have not changed. That's partly because the mission is the same, and partly because a lot of the changes we have tried to bring about with the restructuring—dissolving barriers, opening up the opportunity to serve a broader base—are in the process of being implemented."

"However, one key change that should ultimately benefit all of us is a dramatic streamlining of our procurement process," Deb adds. "The increased operational efficiency should reduce the cost of doing business with others."

Despite the overall cuts this year in the funding of renewable energy research and development, the Center for Basic Sciences remains healthy. More than 50 percent of its funding comes from the Department of Energy's Office of Energy Research (OER). And this OER funding to NREL has actually more than doubled during the past 3 to 4 years. "As long as we do good science in support of technology, the customer is happy," Deb said. "This is very important, because it helps us attract and keep talented scientists, who help to advance innovative technologies."

An 18-year veteran of NREL, Deb finds great personal fulfillment and enormous challenges in the field of renewable energy. During his tenure, he has helped build the program from the very beginning. His contribution to the success of this work has included recruiting and hiring of many of the technical staff, as well as expanding and equipping the laboratories. Deb admits he's had a rare opportunity to shape an important program from its inception.

"NREL is reaching adulthood and has a long, productive life ahead. The work we do in the Center for Basic Sciences will contribute to alternative energy for a long time to come."

For further information contact Satyen Deb, 303-6405.

Centers a

Center for Photovoltaics and Electronic Materials
John Benner, x6496

New Business Development Team . . . . . .Dave Ginley, x6573
PV Manufacturing R&D Team . . . . . .Ed Witt, x6402
PV Market Development Team . . . . . .John Thornton, x6469
Clean Room/Device Fabrication Team . . . . . .Tim Gessert, x6451
III-V Materials and Devices Team . . . . . .Sarah Kurtz, x6475
a-Si Team . . . . . .Howard Branz, x6694
CdTe Team . . . . . .Pete Sheldon, x6533
PV Research Partnership Team . . . . . .Jack Stone, x6470
CIS Team . . . . . .Rommel Noufi, x6510
TPV Team . . . . . .Tim Coutts, x6561
Special Projects . . . . . .Dave Ginley, x6573

Center for Performance Engineering and Reliability
Roland Hulstrom, x6420

Engineering and Technology
Validation Team . . . . . .Tom McMahon, x6762
Reliability and Service Lifetime Team . . . . . .Al Czanderna, x6460

Center for Measurements and Characterization
Larry Kazmerski, x6600

Cell and Module Characterization . . . . . .Keith Emery, x6632
Electro-Optical Characterization . . . . . .Richard Ahrenkiel, x6670
Analytical Microscopy . . . . . .Mowafak Al-Jassim, x6602
Surface Analysis . . . . . .Sally Asher, x6450

Resources R Us

The Center for Renewable Energy Resources is an unusual group. This is because it supports all the research technologies at the National Renewable Energy Laboratory: solar, wind, biomass, and geothermal.

As you might imagine, it takes a versatile group of people to span these varied resources. Cécile Warner, the center's director, has a staff whose areas of expertise include engineering, mathematics, physics, economics, natural resources, and meteorology.

Such a melange of talents are needed to cover the duties of the center, which range from analyzing data quality to developing software, evaluating sites to measuring radiometric data. Through its work on the various resources, this group, formed from members of five previous research divisions, facilitates the development and deployment of renewable technologies.

Gathering and analyzing data is important. But the numbers and results must be available to others around the world to be useful. According to Warner, NREL's information is more accessible than ever globally. "Our data are more centralized—and therefore available—we can work better across laboratory lines, and we can manage our programs more efficiently," she said. Her group maintains several Web sites, including the Renewable Resource Data Center (accessed at *http://rredc.nrel.gov*).

When it comes to photovoltaics, the Center's Measurement and Instrumentation team supports the PV Program by calibrating and operating special instruments to measure outdoor solar radiation and meteorological parameters. The spectral content of solar simulators used for indoor testing of PV cells and modules is also measured. The staff helps PV researchers and manufacturers interpret measured and modeled radiometric data for specific applications. And off-site measurements help Department of Energy subcontractors evaluate test results and correct results to standard conditions.

Warner believes that NREL's new organization facilitates greater synergism among the technologies than ever before. "Now that the resource assessment activities are aggregated in one center, we can focus our activities across many renewable technologies," she said. "We can make more efficient use of our satellite and meteorological data sets when we process them, because they often contain data that are applicable to more than one technology. We also have a greater understanding of each others' needs and core capabilities."

For further information, contact Cécile Warner, 303-275-4617.

Warren Gretz, NREL/PIX04234

The facilities of Director Cécile Warner's Center for Renewable Energy Resources include these pyranometers at the Solar Radiation Research Lab atop South Table Mesa in Golden, Colorado.

nd Teams

Center for Basic Sciences

Satyen Deb, x6405

Advanced Concepts . . . . . .Dave Benson, x6462
Biological Sciences . . . . . .Mike Seibert, x6279
Chemical Sciences . . . . . .Art Nozik, x6603
Crystal Growth and Devices/Silicon . . . . . .Ted Ciszek, x6569
Energy Storage . . . . . .John Turner, x6667
Solid State Theory . . . . . .Alex Zunger, x6672
Spectroscopy . . . . . .Angelo Mascarenhas, x6608
Superconductivity . . . . . .Dick Blaugher, x6518

Center for Renewable Energy Resources

Cécile Warner, 275-4617

Measurement and Instrumentation . . . . . .Tom Stoffel, 275-4690
Resource Characterization . . . . . .Gene Maxwell, 275-4688
Data Analysis and Computer Applications . . .George Scott, x6903

(All phone numbers have area code of 303. Prefix is 384 unless otherwise noted.)

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.

In September, **Subhendu Guha of United Solar Systems Corporation** (United Solar) and the Thin-Film Partnership Amorphous Silicon National R&D Team reported a major increase in the world-record, initial, active-area efficiency of a triple-junction amorphous silicon alloy cell—14.5%—a jump from 13.2% and the first major advance in a-Si cell efficiency in several years. Improved efficiency has been a key goal of the a-Si community and the **DOE/NREL Thin Film Partnership National Teams**. A stable-cell efficiency of about 12.5% is expected in upcoming light-soaking tests. According to United Solar, this improvement was possible because of the support received from DOE and NREL under the Thin Film Partnership Program. United Solar will send the light-soaked cell to NREL to verify the cell's record stablized efficiency. **(Ken Zweibel, 303-384-6441; Subhendu Guha, 810-362-3120)**

On June 24-26, representatives of the photovoltaic consensus standards organizations **(ASTM subcommittee E44.09, IEEE Standards Coordination Committee SCC21, and the U.S. Technical Advisory Group, to the IEC Technical Committee TC-82)** met in Winter Park, CO. The purpose was to discuss the status of, revise, and develop standard procedures, test methods, and recommended practices applicable to photovoltaic, industrial, utility, and consumer markets. These forums provide opportunites for the PV standards bodies to meet at a single location. This reduces travel costs and promotes communication and cooperation among the groups. The U.S. Technical Advisory Group TC-82 secretarial reports were presented on the four working group actions at recent previous meetings; technical comments on four IEC standards were generated; the status of four other standards under ballot consideration (including thin-film PV qualification testing) was reported on. IEEE and IEC standards on PV module energy rating methods are under way, along with revision of ASTM spectral response measurement practices. **(Carl Osterwald, 303-384-6630)**

In July, **Robert Hansen of NREL, Tim Ellison of Energy Conversion Devices (ECD), and Joe Wiehagen of the National Association of Home Builders Research Center** tested the ECD batten-and-seam, a-Si:H roofing module system in Upper Marlboro, Maryland. Current-voltage traces were taken at module connections in the attic, despite the extreme heat and humidity, using NREL's DayStar curve tracer. A similar evaluation of the ECD a-Si:H roofing tile system was conducted in Atlanta, Georgia, in August. **(Robert Hansen, 303-384-6364)**

NREL and **EBARA Solar Inc. (ESI)** are both interested in developing silicon materials technology for high-efficiency PV devices. ESI has undertaken an initiative to set up a commercial manufacturing facility for dendritic web silicon ribbons and solar cells, which builds on many years of R&D at Westinghouse Corporation, a large portion of which was DOE funded. **NREL's Crystal Growth and Devices Team in the Basic Sciences Center** has extensive scientific and technological experience in silicon crystal growth and materials characterization. NREL will assist ESI in developing the dendritic web growth process and improving materials properties, to hasten manufacturing readiness for modules that use dendritic web silicon solar cells. **(Ted Ciszek, 303-384-6569)**

The **6th Workshop on the Role of Impurities and Defects in Silicon Device Processing** was held in Snowmass, Colorado, on August 12-14. The workshop—focusing on the technology transition for fabricating high-efficiency, low-cost, commercial solar cells—was attended by 86 participants from photovoltaic and microelectronics industries, and academic institutions throughout the world. The technical progress since the last workshop is staggering. Our understanding is tremendously improved in gettering, low-temperature passivation using plasma-enhanced chemical vapor deposition (PECVD) nitride, and hydrogenation. Multiple groups continue to confirm that optical enhancement of diffusion can have large, beneficial effects. The workshop consensus is that thin wafers are doable and offer significant performance and cost advantages. Most new processes under serious consideration, such as increased use of rapid thermal processing and belt furnaces, appear to have acceptable economics. The tools for continuing the historical continuous improvement in module performance and cost are clearly in place; however, it seems that continued support from government programs such as PVMaT and from the national laboratories are still crucial to the long-range success of the PV industry. **(Bhushan Sopori, 303-384-6683)**

A meeting of the **Thin-Film Silicon Team of the High-Efficiency Photovoltaic Project**, held in Snowmass, CO, on August 11, was attended by 27 participants representing national laboratories, universities, and the PV industry. The purpose was to review team research performed under the Center of Excellence and to enhance interaction between team members at different research facilities. Major issues addressed were: (1) likely structures of thin-film silicon solar cells; (2) material parameters that would yield cell efficiencies in the 13%-14% range; (3) various approaches for controlled nucleation;

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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 1995 through September 1996 (fiscal year 1996), we awarded 209 subcontracts (examples listed below) totaling more than $22.1 million. For further information, contact Tom Surek (303-384-6471).

Golden Photon
Improvement of Near-Term CdTe Processing and Product Capabilities and Establishment of Next-Generation CdTe Technology
$214,265 (8/96–8/99)

Iowa Thin Films
PV Manufacturing Technology Monolithic a-Si Modules on Continuous Polymer Substrates
$265,000 (7/96–10/96)

Siemens Solar Industries
Thin Film PV Partnership Program CIS-Based Thin-Film PV Technology
$216,400 (8/96–10/96)

Silicon Energy Corporation/Utility Power Group
Development of a Low-Cost Integrated 20-kW AC Solar-Tracking Sub Array for Grid-Connected PV Power System Applications
$203,713 (9/95–9/97)

Solar Electric Specialties
Design, Fabrication, and Certification of Advance Modular PV Power Systems
$84,962 (8/96–11/97)

Solar Cells, Inc.
Technology Support for Initiation of High-Throughput Processing of Thin-Film CdTe PV Modules
$82,182 (9/96–11/96)

Texas Southern University
Historically Black Colleges and Universities (HBCU) PV Associates Program
$22,616 (8/96–10/97)

University of Delaware
Processing and Modeling Issues for Thin-Film Solar Cell Devices
$100,950 (9/96–11/96)

University of South Florida
Advanced Processing of CdTe- and Cu(In,Ga)Se_2-Based Solar Cells and Submodules
$59,790 (8/96–11/96)

Publications

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

Basol, B.M.; Kapur, V.K.; Halani, A.; Leidholm, C.R.; Sharp, J.; Sites, J.R.; Swartzlander, A.; Matson, R.; Ullal, H. Cu(In, Ga)Se_2 Thin Films and Solar Cells Prepared by Selenization of Metallic Precursors. *J. Vac Sci and Tech. A, Vacuum, Surfaces, and Films.* July/Aug 1996; 14(4); pp.2251–2256. (International Solar Electric Technology, Inglewood, CA; Colorado State University, Fort Collins, CO; and NREL, Golden, CO)

Birkmire, R.W.; Phillips, J.E.; Buchanan, W.A.; Eser, E.; Hegedus, S.S.; McCandless, B.E.; Meyers, P.V.; Shafarman, W.N. *Processing and Modeling Issues for Thin-Film Solar Cell Devices: Annual Subcontract Report, 16 Jan 1995–15 Jan 1996.* Aug 1996; 111pp. NREL/TP-451-21602. NTIS No. DE96013079. (Institute of Energy Conversion, Univ. of Delaware, Newark, DE)

Coutts, T.J.; Wu, X.; Mulligan, W.P.; Webb, J.M. High-Performance, Transparent Conducting Oxides Based on Cadmium Stannate. *J. of Electronic Materials.* June 1996; 25(6); pp.935–943.

Czanderna, A.W.; Pern, F.J. Performance Degradation, Polymer Encapsulant Degradation, and Estimating Lifetimes for Photovoltaic Modules from Accelerated Testing. Herling, R.J., ed. *Durability Testing of Nonmetallic Materials: Proceedings of the Symposium, 26 Feb 1996, Fort Lauderdale, FL.* ASTM STP 1294. West Conshohocken, PA: ASTM; 1996; pp.204–225.

Dalal, V. *Comprehensive Research on Stability and Performance of a-Si:H and Alloys: Phase I Team Annual Technical Report, 31 May 1994–30 May 1995.* Aug 1996; 45pp. NREL/TP-451-21601. NTIS No. DE96013078. (Iowa State University, Ames, IA)

Deb, S.K. Thin-Film Solar Cells: An Overview. Sayigh, A.A.M., ed. *Renewable Energy, Energy Efficiency and the Environment: Proceedings of the World Renewable Energy Congress, 15–21 June 1996,* Denver, CO. NY: Pergamon; 1996; Vol. I; pp.375–379.

Fernandez, A.M.; Sebastian, P.J.; Bhattacharya, R.N.; Noufi, R.; Contreras, M.; Hermann, A.M. 8% $CuInSe_2$-Based Solar Cell Formed from an Electrodeposited Precursor Film. *Semicond Sci and Tech.* June 1996; 11(6); pp.964–967.

Gessert, T.A.; Mason, A.R.; Sheldon, P.; Swartzlander, A.B.; Niles, D.; Coutts, T.J. Development of Cu-Doped ZnTe as a Back-Contact Interface Layer for Thin-Film CdS/CdTe Solar Cells. *J. of Vac Sci and Tech. A, Vacuum, Surfaces and Films.* May/June 1996; 14(3); pp.806–812.

Continued on page 11

(4) deposition and growth techniques; (5) techniques for characterizing crystalline and a-Si thin films; and (6) defects in the thin films of silicon. Participants agreed that there should be a road map for thin-cell research that would use silicon as the basic material not only for cell development, but also, for understanding interface effects, grain-boundary effects, light-trapping in thin layers, nucleation and growth processes, and grain enhancement. **(Bhushan Sopori, 384-6683; Satyen Deb, 384-6405)**

The 9th PV Performance and Reliability Workshop was held in Lakewood, Colorado, from September 4-6. The more than 100 attendees included people from PV manufacturing, research, and utilities, as well as consumers. Presentations from 25 speakers covered cell, module, and system performance; cell/module reliability; system reliability; and PV applications and field experience. Important topics discussed included: (1) defining service lifetime for PV modules, (2) developing service lifetime prediction models for PV modules, (3) examining and determining failure and degradation mechanisms in PV modules, (4) combining IEEE/IEC/UL testing procedures, (5) AC module performance and reliability testing, (6) inverter reliability/qualification testing, (7) standardization of utility interconnect requirements for PV systems, (8) need for activities to separate variables by testing individual components of PV systems for individual reliability and then to test them in actual system configurations, (9) more results reported from field experience on modules, inverters, batteries, and charge controllers from field-deployed PV systems, and (10) system certification and standardized testing for stand-alone and grid-tied systems. **(Ben Kroposki, 303-384-6170)**

The **NREL PV Advisory Committee** met in September to offer advice on NREL's PV Program activities. The committee included **Charles Backus, Arizona State University; Allen Barnett, AstroPower; David Carlson, Solarex; Ed DeMeo, Electric Power Research Institute; Roger Little, Spire; Fraser Russell, University of Delaware; and Richard Schwartz, Purdue University** (Committee Chairman). NREL personnel gave presentations on the new organizational structure at NREL; introduced the National Center for Photovoltaics (see Editorial in this issue); and reviewed FY 1996 budget expenditures, FY 1997 plans, and planned initiatives. The Committee will be reconstituted this coming year to serve the needs of the National Center for PV. Overall, the committee was positive regarding current and planned activities. **(Jack Stone, 303-384-6470)**

A nominal 1-kW thin-film CdTe PV AC array deployed at **NREL's Outdoor Test Facility** for more than a year has demonstrated excellent stability and robust performance. The modules were supplied by **Solar Cells, Inc.** (SCI), Toledo, OH. This PV array uses frameless modules, which significantly reduce the cost of the modules and systems. Stable PV array performance has also been demonstrated for SCI's thin-film CdTe arrays deployed in Toledo, OH, and PVUSA, Davis, CA. Systems sizes vary from 1 kW to 10 kW. **(Harin Ullal, 303-384-6486; Ben Kroposki, 303-384-6170)**

NREL participated as the U.S. representative in IEA's PV Power Systems Implementing Agreement, Task 7, on "PV in the Built Environment." **The Italian National Utility (ENEL)** hosted the September 25-29 meeting in Rome, Italy. Task 7 provides an international forum to coordinate and promote the development and use of PV systems in buildings and non-buildings applications (other than large, ground-mounted arrays); it should motivate collaboration between PV system specialists, utility engineers, the PV and buildings industry, and other professionals. The meeting included 38 representatives from 13 countries. The United States leads Subtask 3, Non-Technical Barriers, which includes: barriers assessment, economic analysis, evaluation of technical and economic market potential, and strategy development for barrier reduction. **(Roger Taylor, 303-384-6432)**

University Corner

NREL, with support from the **DOE PV Program**, has assisted in developing a renewable-energy pilot project in Ghana to be funded by the **United Nations Development Program-Global Environment Facility**. A PV Program-funded HBCU team from **Wilberforce Univ.** (see next paragraph) conducted a month-long field assessment with logistical and survey support from the **Ghanian Ministry of Mines and Energy**. Data reduction and analysis will provide valuable information for the detailed definition of the project. NREL will continue to work with **Dr. Jerome Weingart (UNDP Senior Consultant)**, the UNDP, Wilberforce University, and colleagues in Ghana to move this project forward. **(Roger Taylor, 303-384-6432)**

As part of the 1996 **Historically Black Colleges and Universities (HBCU) summer intern program**, **Professor Joshua Hill** and **Oral LaFleur (Texas Southern Univ., Houston, TX)** spent 6 weeks at **Port Elizabeth Technikon** (Port Elizabeth, South Africa), training rural South Africans to install and maintain PV systems. **Professor Tuhfeh Habash** and **Tosha Cameron (Wilberforce Univ., Wilberforce, OH)** spent 1 month in northeast Ghana conducting a socio-economic and energy-use study for developing a PV project for the United Nations Development Program. Three students worked at **NREL** on various projects: **Tameka Page (Southern Univ., Baton Rouge, LA)** did cell and module testing; **Danisha Williams (Southern Univ.)** studied flywheel energy storage; and **Natalie Bunkley (Hampton Univ., Hampton, VA)** did research on buildings. **Raymond Haraway (Wilberforce Univ.)** worked with an NREL subcontractor, **Dr. Neelkanthe Dhere** at the **Florida Solar Energy Center**, on module testing. NREL has subcontracts with seven HBCUs to encourage opportunities in PV for selected undergraduates. Sixteen students, under the supervision of 14 professors, are supported by the seven subcontracts during the school year. **Hakim Evans (Central State Univ., Wilberforce, OH)** went to Senegal for 2 months to help install and repair PV facilities for a Senegal renewable energy company. **(Robert McConnell, 303-384-6419)**

A collaboration between the **NREL CIS Team (Kannan Ramanathan and others)** and **Washington State Univ.** (WSU) has achieved an NREL-confirmed CIGS cell with 12.7% efficiency. This cell does not use the CdS window typically used for CIGS cells; rather, it uses two layers of ZnO with different resistivities and a CIGS absorber prepared at NREL. Cell parameters were V_{OC} = 560 mV, J_{SC} = 34.1 mA/cm^2, FF = 66.4%, and cell area = 0.424 cm^2. This tops the previous best ZnO/CIGS cell efficiency of 11.3% obtained when WSU applied this type of contact to a Siemens Solar Industries "double graded" CIGSS absorber. **(Bolko von Roedern, 303-384-6480; Kannan Ramanathan, 303-384-6454)**

Beginning July 1995, **NREL** hosted **Ernest van Dyk of the University of Port Elizabeth (South Africa)** for a 1-year sabbatical involving PV module evaluation, system evaluation, and long-term monitoring. His work included analyzing 1-year's performance of the two 6-kW PV systems on the roof of NREL's Solar Energy Research Facility, and testing PV modules manufactured by Suncorp, a PV module manufacturer in South Africa. The Department of Physics, University of Port Elizabeth, is now in a position to evaluate PV modules and systems using internationally recognized procedures. **(Robert McConnell, 303-384-6419)**

Publications, *from page 9*

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Herig, C. *Photovoltaics Can Add Capacity to the Utility Grid.* Sept 1996; 4pp. DOE/GO-10096-262. NTIS No. DE96000544.

Jung, D.R.; Czanderna, A.W. X-Ray Photoelectron Spectroscopy of Cr/$COOCH_3$ Interfaces on Self-Assembled Monolayers of 16-Mercaptohexadecanoate. *Applied Surf Sci.* 1996; 99; pp.161–168.

King, R.; Stafford, B.; Tamai, G. *Sunrayce 95 Technical Report.* May 1996; 75pp. NREL/TP-411-21098. NTIS No. DE96007868.

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Maruska, P. *High Performance Porous Silicon Solar Cell Development: Final Report, 1 Oct 1993–30 Sept 1995.* Sept 1996; 63pp. NREL/TP-451-21621. NTIS No. DE96013098. (Spire Corporation, Bedford, MA)

Ness, E. *Photovoltaics: Advancing Toward the Millennium.* May 1996; 44pp. DOE/GO-10095-241. NTIS No. DE96000486.

Niles, D.W.; Li, X.; Albin, D.; Rose, D.; Gessert, T.; Sheldon, P. Evaporated Te on CdTe: A Vacuum-Compatible Approach to Making Back Contact to CdTe Solar Cell Devices. *Progress in Photovoltaics: Research and Applications.* May 1996; 4(3); pp.225–229.

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Olsen, L.C. *Investigation of Polycrystalline Thin-Film $CuInSe_2$ Solar Cells Based on ZnSe and ZnO Buffer Layers: Final Report, 16 Feb 1992–15 Nov 1995.* June 1996; 48pp. NREL/TP-451-21406. NTIS No. DE96007923. (Wash. State Univ. at Tri-Cities, Richland, WA)

Sites, J.R. *Device Physics of Thin-Film Polycrystalline Cells and Modules: Annual Subcontract Report, 6 Dec 1994–5 Dec 1995.* Aug 1996; 36pp. NREL/TP-451-21586. NTIS No. DE96013077. (Dept of Physics, Colorado State Univ, Fort Collins, CO)

Smoller, S., coordinator. *NREL Photovoltaic Program FY 1995 Annual Report.* June 1996; 440pp. NREL/TP-410-21101. NTIS No. DE96007869.

Tan, T.; Swanson, R.; Sopori, B. *Sixth Workshop on the Role of Impurities and Defects in Silicon Device Processing: Summary of the Panel Discussions, 12–14 Aug 1996, Snowmass, CO.* Sept 1996; 12pp. NREL/SP-413-21640. NTIS No. DE96013101.

Williamson, D.L. *Microstructure of Amorphous-Silicon-Based Solar Cell Materials by Small-Angle X-Ray Scattering: Annual Technical Report, 6 Apr 1995–5 Apr 1996.* Aug 1996; 30pp. NREL/ TP-451-21584. NTIS No. DE96013075. (Colorado School of Mines, Golden, CO)

PV Calendar

November 19–22, 1996
14th NREL/Sandia Photovoltaics Program Review Meeting. Location: Lakewood, Colorado. Contact: Joan Ross, NREL. Phone: 303-275-4321. Fax: 303-275-4320.

March 3–5, 1997
Solar Electrification 1997. Location: New Delhi, India. Contact: Dr. Dilawar Singh, Perth, Western Australia. Phone: +619-321-7600. Fax: +619-321-7497. E-mail: case@wantree.com.au

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

May 1–2, 1997
Solar Thin Film Photovoltaic Symposium, and 25th IEC Anniversary. Location: Newark, Delaware. Contact: Institute of Energy Conversion, University of Delaware, Newark, DE. Fax: 302-831-6226. E-mail: IEC25th@mvs.udel.edu

May 18–21, 1997
The Third Thermophotovoltaics (TPV) Conference. Location: Colorado Springs, Colorado. Contact: Tim Coutts, phone 303-384-6561, e-mail tim_coutts@nrel.gov

June 23–25, 1997
PV Standards and Codes Forum. Location: Golden, Colorado. Contact: Carl Osterwald, NREL. Phone: 303-384-6630.

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

July 22–24, 1997
International Symposium on Advances in Alternative/Renewable Energy, ISAAE '97. Location: Johor Bahru, Malaysia. Contact: the Secretariat, ISAAE, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Locked Bag 791, 80990 Johor Bahru, Malaysia, Attn: Mrs. Ani Idris/Mr. Othman Ayub. Phone: 60-7-5504758/5504577. Fax: 60-7-5566159. E-mail: Othman@FKJ.UTM.MY

September 29–October 3, 1997
26th IEEE PV Specialists Conference. Location: Anaheim, California. Contact: Paul Basore. E-mail: p.basore@unsw.edu.au

The purpose of this quarterly report is to encourage cooperative research and development by providing the U.S. PV industry with information on the activities and capabilities of the laboratories and researchers at NREL.

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