NREL PV

Working With Industry

Fall 1995

Planning With Industry

How do we get industry's attention when making plans for in-house research at the National Renewable Energy Laboratory (NREL)? Let us count the ways!

It's fair to say that no two principal investigators at NREL follow exactly the same planning strategy. Their various approaches are based on the number of industry partners, individual personalities, critical issues, and the state of the technology. The PIs are sensitive to these differences and seek approaches best suited for their particular situation.

Conferences, so valuable for sharing information, are also a convenient venue for gathering industry representatives together to get their feedback on project direction and topics. Why not host a dinner meeting to stimulate the flow of ideas from a group of busy people? Responses to questionnaires can also serve a useful purpose in shaping a research program. Of course, various industry players can be invited to a special review meeting. And why not have a small group of NREL researchers take a tour of individual companies instead?

Whatever the approach taken by our principal investigators, they're planning for the same outcome—innovative research and critical support that helps to advance technology in the PV community.

Features

Departments

Meeting Our Customers' Long-Term Needs

An Editorial by Anthony Catalano

Warren Gretz, NREL

Anthony Catalano has been Director of NREL's Photovoltaic Division since 1992.

The National Renewable Energy Laboratory has a unique facility for photovoltaics research and development that supports an experienced, well-qualified staff. Over the last several years, our researchers have often distinguished themselves as leaders for their important work. Our teams in copper indium diselenide, gallium arsenide, amorphous and crystalline silicon, cadmium telluride, and others have all made important contributions, often recognized by their world-record efficiencies or other unique features, such as the improved stability now being seen in amorphous silicon devices. In addition, our dedicated measurements and characterization facilities have served the PV research community by performing more than 10,000 measurements annually. These measurements span the range of properties—from composition and nanostructure to cell and module performance.

These efforts are intended to serve the long-term needs of you, our customers. To ensure that we continue to meet that goal, we have changed the way we plan our internal R&D to reflect the priorities of the PV industry. Over the past 12 months, each of our R&D teams have held meetings to present and discuss our research plans. Our counterparts at universities, industry, and Sandia National Laboratories also attended these meetings, providing their own perspectives and needs. These meetings have enabled us to redesign our efforts and have been enormously helpful, often permitting our people to see their research in a whole new way.

Beyond these planning activities, we have organized nationwide research teams that include not only NREL staff, but also our subcontract researchers in universities and industry. Each team focuses on solving technical problems in a specific area—jointly organizing work, assigning priorities, and distributing duties among participants. The dynamic interchange among the team members ensures that all work remains focused on the mutually agreed upon priorities. This effort began several years ago with our research in amorphous silicon and was inspired by the efforts at AT&T Bell Laboratories through a member of their staff, Dr. Joseph Morabito. The success achieved in this pilot convinced us to extend it to the work in copper indium diselenide and cadmium telluride, as well as environmental, health, and safety issues in thin-film research and manufacturing. We are confident that these self-directed teams will realize the same success.

I hope you will agree with me that these efforts take us well on our way to a true partnership between industry, universities, and NREL.

CdTe Strawman Leads to Two-Year Research Plan

"As we've addressed critical issues and interacted with our industry partners, we've shown that there is something in this whole planning process for them. They really do benefit from these efforts." So says Pete Sheldon, principal investigator for the cadmium telluride (CdTe) team at NREL.

One tangible proof of this statement is a prototype photoluminescence-based diagnostic monitor—the result of a project planned jointly by NREL and Solar Cells Inc. (SCI), of Toledo, Ohio. Under a cooperative research and development agreement, NREL researchers, led by Dean Levi, developed this in-line quality-control monitor, which evaluates the uniformity and quality of CdS/CdTe modules in a production environment.

But let's go back to the overall planning process. Two years ago, Sheldon began a fairly involved process of preparing a fiscal year (FY) 1995 research plan. However, he found that his one-year planning cycle was confining. By laying out a two-year plan—for both FY 1995 and FY 1996—he added vision and continuity to his team's in-house projects.

Sheldon met with all the NREL players, both one-on-one and in groups, to solicit input, ensure buy-in in the process, and make sure the plan would fly when implemented. In this iterative process, critical issues were summarized and a strawman

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***Strawman,** from page 2*

plan was established, which led to a draft Annual Operating Plan (AOP).

The CdTe team wrapped up this hard work with a half-day planning session at NREL. Participants included NREL researchers from the Measurements and Characterization and the CdTe Device Development teams, program managers, and research and development managers from SCI and from Golden Photon Inc., of Golden, Colorado.

During this meeting, Sheldon outlined the critical issues in CdTe research as identified by NREL and served as facilitator as other participants modified the strawman mission statement, technical approaches, and individual objectives in a discussion and mark-up session. The half-day meeting accomplished a lot because of the prior groundwork by both NREL and industry representatives. "By the end of the day," Sheldon emphasized, "we came up with concrete plans, not nebulous thoughts, because people came to the meeting well prepared."

"From this meeting came a list of detailed milestones and a refined AOP, which keep upper management and our industry and university partners informed about where we are and what progress is being made. We refer back to them on a regular basis," said Sheldon.

In the second year of the plan—FY 1996—the CdTe team is using a "tune-up" approach. Rather than going through the rigors of last year's process, Sheldon and his team have continued talks on an informal basis with in-house researchers and industrial partners and used these discussions to refine the FY 1996 AOP. Interaction with the university researchers primarily occurs through the teaming process established by the Thin-Film PV Partnership Program, and specifically, through the CdTe teams formed at the 1st World Conference on Photovoltaic Energy Conversion held last December in Hawaii.

Jim Yost, Jim Yost Photography, NREL/PIX1456

Researcher Dave Albin uses one of the close-spaced sublimation units designed and built by NREL's Cadmium Telluride Device Development team.

The full-blown process will be used next year to develop the FY 1997–FY 1998 plan, with a tune up in FY 1998. So get ready!

For further information, contact Pete Sheldon (303) 384-6533.

Jim Yost, Jim Yost Photography, NREL/PIX1456

This photoluminescence-based unit can monitor the uniformity and quality of CdS/CdTe photovoltaic modules during their production.

The FY 1996 mission statement for the CdTe task was developed with input from key members of NREL's CdTe Device Development team, Measurements and Characterization Branch, program office, and two representatives of the CdTe industry (Scot Albright of GPI, and Peter Meyers, formerly of SCI).

The mission statement focuses on three key goals:

(1) To develop reproducible processes for high-efficiency CdS/CdTe devices;

(2) To explore alternative processes that lend themselves to improved device performance, improved device understanding, improved reproducibility, and/or improved manufacturability;

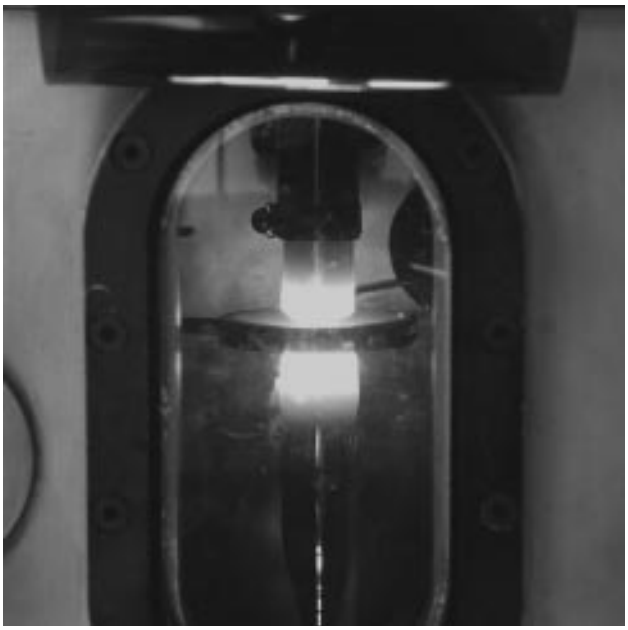
(3) To support industrial partners.

The emphasis of our milestones in FY 1996 has shifted. Last year, our goal was to develop a baseline CdS/CdTe process. This year, we will use the baseline process to explore alternate processes, while maintaining our underlying theme of developing a fundamental understanding of the physics and chemistry of these processes.

Food for (Crystalline Silicon) Thought

Ted Ciszek, principal investigator for NREL's crystalline silicon activities, hosted a dinner meeting at the 5th NREL Workshop on the Role of Impurities and Defects in Silicon Device Processing in August at Copper Mountain, Colorado. Hoping to get industry opinions on NREL's proposed in-house activities in crystalline silicon, he invited research directors and other key personnel from various silicon PV companies. He knew that these people—in spite of their busy schedules—could give him the guidance he needed for his research.

Three years ago, Ciszek began to probe what private industry felt he should be working on. He mailed out a questionnaire and compiled the responses—results that were published in the June 1993 *PV Working With Industry*. This year, he tried a variation on that process by having copies of a questionnaire available at the registration desk at the Impurities and Defects Workshop—but the response was low.



Jim Yost, Jim Yost Photography, NREL/PIX1818

NREL's float-zone system can grow very pure silicon, and very low concentrations of elements such as iron can be introduced to study their effect on PV performance.

The next option was the Copper Mountain dinner meeting. At that gathering, Ciszek presented his research plans to key researchers and research managers from the silicon PV industry. Ted had nine topic areas, but his guests came up with three more topics. Each person then voted for his top three priorities. To Ciszek's surprise, the top recommendation from the group was for a topic not even on the original list. Another topic that he thought would be highly rated appeared at the bottom. Ciszek said, "Obviously, the input from industry was much different than we expected!"

The top three topics involved common problems across many of the industry approaches to silicon growth, as well as direct industry assistance with specific problems. The industry and university representatives ranked thin-film Si research and development at NREL the lowest of any proposed R&D topic. Similarly, NREL's R&D on optical processing was the activity ranked second lowest in industry interest.

Another significant outcome was that industry guests recommended that NREL researchers spend two-thirds of their time on projects that are important to industry and one-third on innovative projects that NREL chooses.

This kind of interaction is vital to making NREL's crystalline silicon research and development relevant to Ciszek's customers. Ciszek said, "The ball is in our court now. We have a much better idea of what they think is important."

For further information, contact Ted Ciszek (303-384-6569).

Budget permitting, NREL's Crystalline Silicon and Advanced Devices team will pursue the following five primary projects for fiscal year 1996:

(1) Investigate the effects and reduction of highly defected "bad" regions in multicrystalline silicon.

(2) Determine the effects of selected relevant impurities and defects on minority charge carrier lifetime and solar cell efficiency through the generation, characterization, and cell diagnostics of controlled samples, and sample distribution to collaborative researchers.

(3) Provide limited, small-scale consultation, analysis, and characterization services, as needed and within resource constraints, to industrial silicon PV companies.

(4) Conduct exploratory R&D in selected silicon growth and processing concepts.

(5) Assess and identify R&D thrust opportunities that have the potential to make dramatic advances in crystalline Si PV technology.

Project Areas 1-3 are designed to meet important R&D needs identified by the silicon industry. Projects 4 and 5 address innovations needed for sustained future technical advancement. Project 5 allows NREL to step back and assess the status of Si PV technology to identify critical areas where successful innovations would have a demonstrably significant impact.

Warren Gretz, NREL

Andrew Gabor, a researcher from Energy Photovoltaics, Inc. (EPV) of Princeton, NJ, works on CIS deposition processes in one of NREL's CIS laboratories, under a cooperative research and development agreement between NREL and EPV.

CIS Team Hits the Planning Road

As the Middle Eastern saying goes, "If Mohammed can't go to the mountain, the mountain will go to Mohammed."

In like fashion, rather than having industry come to the National Renewable Energy Laboratory (NREL), Rommel Noufi and members of his copper indium diselenide (CIS) team have traveled to industry sites to solicit help in planning in-house research. The NREL group wanted guidance in focusing its resources and capabilities. They also wanted the opinions of industry representative's regarding CIS issues and needs.

In the last two years, the CIS team has made a dozen site visits. During these visits, team members briefed industry managers on the status of NREL's CIS work, presented what they thought were critical future R&D directions, and asked for input in setting priorities. Eventually, additional visits made only minimal impact on subsequent plans. At this point, NREL's presentations were very well matched to industry's needs.

Additionally, two research teams were established for CIS that consist of industry, university, and government researchers as part of the Thin-Film PV Partnership Program. One team focuses on the formation of the CIS absorber, while the second is concerned with CIS junctions (see **box**). Some research issues come under the umbrella of these two research teams. Others, though, are included as work to be carried out by NREL's in-house research teams.

Members of the two collaborative teams meet officially twice a year. But to keep up with the latest results and successes, team members use a secure, closed-to-the-general-public electronic bulletin board on the Internet for most communications.

Industry representatives will get a draft of NREL's CIS research plans for the next fiscal year before they become final. However, because of his team's close and regular contact with industry, Noufi expects the research plans proposed by NREL's CIS team to respond to industry's needs. For further information, contact Rommel Noufi (303-384-6510).

The CIS Absorber Team's goals are to:

(1) Correlate absorber properties with substrate properties.

(2) Identify "manufacturing friendly" material diagnostic tools that will lead to improved fabrication controls and reproducibility.

The CIS Junction Team's goals are to:

(1) Define the diagnostic techniques and parameters most useful for junction comparison.

(2) Compare the relative merits of wet and dry processes for forming a CdS buffer layer.

(3) Explore the viability of alternative, Cd-free window layers, including direct ZnO/CIS junctions.

Module and System Workshops Double as Industry Forums

NREL's Module and System Performance and Engineering Project has finally found its new home. Previously spread across some five different locations, almost all work for the project has been (or will soon be) consolidated within the new Outdoor Test Facility (OTF).

So what does project manager Dick DeBlasio plan to do in this new facility? Some of the same things previously done and some new things, too, that are of keen interest to industry. DeBlasio explained, "The project is made up of seven teams. Each team leader puts together a plan for his particular activity or responsibility. These plans are reviewed, usually informally, at the three workshops held each year."

Anywhere from 35 to more than 100 PV experts participate in these workshops that serve as a valuable forum for transferring recent technical information and for interaction among PV experts. In June, PV Standards and Codes are in focus, followed by July's PV Radiometric Measurements workshop. And in September, PV Performance and Reliability, typically the largest gathering, includes such participants from the PV industry as module manufacturers, utility engineers, other testing laboratories, and some international representatives.

"In addition to the regular presentations at the recent Performance and Reliability workshop," Dick continued, "we were able to introduce our proposed FY 1996 plan to 15 experts in the field. Discussions and refinements continued for half a day." Following the meeting, DeBlasio finalized these plans in the project's Annual Operating Plan.

Researchers at the OTF also interact with industry personnel almost daily. So work plans seldom include ideas out of the blue. Instead, team leaders can usually gauge what is of greatest concern to industry throughout the year. Again, ideas are developed through normal dealings with industry people, either through joint projects at NREL, tours, conferences, or other contacts.

Various areas of interest to industry have emerged over time. And the project's scope of work has continued to expand, progressing from qualification testing to characterization of outdoor devices and from testing under accelerated conditions to validation of 1-kilowatt systems. Now, project members are working on module energy rating, encapsulants, and international activities.

NREL becomes involved in many projects through referrals from other clients and associates. But it is crucial to get the PV industry's "new entries" to visit the OTF and talk to NREL's personnel. DeBlasio emphasized, "We want to make sure we support the DOE PV Program, provide necessary services to industry, and are working on important projects both inside our OTF labs and outside in our test area."

For further information, contact Dick DeBlasio (303-384-6760).

Warren Gretz, NREL

The 10,000-ft^2 OTF building was officially
cluster of labs within the building will be fi
foreground are PV modules and systems un

NEWS AT PRESS TIME

dedicated on September 8, and the entire
tted up by mid November. In the
dergoing outdoor testing.

Newark, DE ... AstroPower, Inc., received an R&D 100 Award for their AP-225 solar cell made by their Silicon-Film™ process. These awards acknowledge the 100 technologically most-significant new products of the year as judged by *R&D Magazine*. In a testimony to the U.S. House of Representatives, Dr. Allan Barnett, president of AstroPower, recognized the major role played in the development of this new product by the cost-shared PVMaT program. "This new solar cell, presently in production, was conceived and manufactured under PVMaT. It is a PVMaT product," Barnett stated in his testimony.

Golden, CO ... NREL is again planning the Pageant of Peace PV exhibit at the White House in Washington, D.C. Four PV manufacturers have committed to loan us a total of about 8 kW of PV modules. The power will be used to light the National Christmas Tree in a ceremony scheduled for December 6. An extensive outreach program is planned around the exhibit, including scheduled tours for the public, some trade groups, federal agencies, and VIPs, as well as targeted seminars for the Federal Energy Management Program (FEMP) Renewable Energy Working Group and the National Park Service. NREL will hold an Open House at the NREL Visitor Center in conjunction with the tree-lighting ceremony in Washington.

Golden, CO ... Drs. Dick Ahrenkiel and Al Czanderna of NREL were honored as Fellows at the recent 42nd American Vacuum Society meeting held in Minneapolis, MN. Ahrenkiel received his award for "outstanding and sustained contributions to the study and understanding of electronic materials and the development of innovative characterization techniques that have led to the improvement of semiconductor device performance." Czanderna's award recognized his "pioneering contributions in applied and fundamental surface science, leading to the understanding of adsorption processes, oxidation of thin films, mirror degradation mechanisms, photovoltaic encapsulation reliability, and self-assembled monolayer/metal interfaces."

Newark, DE ... Dr. David Carlson of Solarex was awarded the Karl W. Böer Solar Energy Medal of Merit at a ceremony held at the Institute of Energy Conversion (IEC), University of Delaware, on October 5. Carlson was honored for discovering and developing thin-film amorphous silicon solar cells. The award consists of a medal and $40,000 prize in honor of Karl W. Böer, founder of IEC and distinguished scientist in the field of solar cells. The first awardee, in 1993, of the Solar Energy Medal of Merit was former U.S. President Jimmy Carter.

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

The **DOE, NREL, Sandia, and SEIA Industry Review Team** has visited the following companies involved in PV module manufacturing and related products: **Amonix, ASE Americas, AstroPower, Crystal Systems, Energy Conversion Devices, Energy Photovoltaics Inc., Evergreen Solar, Golden Photon, Iowa Thin Films, IPC, Omnion, SES, Siemens Solar Industries, Skyline, Solar Cells Inc., Solar Design Associates, Solarex, Spire, Trace**, and **UPG**. The team will compile results to develop the next phase of the Photovoltaic Manufacturing Technology **(PVMaT)** program. (Ed Witt, 303-384-6402)

Christy Herig developed a building-integrated PV (BIPV) market research survey for defining and segregating current and potential BIPV markets. The survey, implemented at the **American Institute of Architects** PV for Buildings workshops and to be disseminated to attendees of previous and future workshops, will help the **Pacific Energy Group** of Walnut Creek, CA, develop a BIPV brochure for the AIA. (Christy Herig, 303-384-6546)

Four vaccine refrigerators are on order with **Polar Power, Inc.**, for use in the Hurricane Luis-impacted Virgin Islands. **NREL**'s PV response and selection of the refrigerators was coordinated with representatives from the **Virgin Islands Energy Office**, **DOE**, and **Sandia**, with the support of NREL PV management. A batch of 36 solar lanterns is also being shipped to the Virgin Islands. (Laxmi Mrig, 303-384-6764)

Anthony Catalano, NREL's PV Division director, attended the **EPRI Business Unit Council** (BUC) meeting in Denver, CO, August 28-30. He presented a summary of **NREL**'s and **DOE**'s activities in photovoltaics. Members of EPRI's Solar Power BUC also visited NREL and toured the SERF and Outdoor Test Facility. (Anthony Catalano, 303-384-6446)

In August, **Ernesto Terrado** (Industry and Energy Department), **Anil Cabraal** (Alternative Energy Unit in the Asia Technical Department), and **Susan Bogach** (energy consultant) from the **World Bank** visited NREL for a day-long series of discussions related to NREL's support of a renewable energy study in China by the World Bank. The study is being conducted in partnership with the **State Economic and Trade Commission** (SETC) and the **Energy Research Institute of the State Planning Commission** in Beijing. (William Wallace, 303-384-6476)

In September, **Art Peterson (Niagara Mohawk Power Corp.)** and **John Doty (AWS Scientific, Inc.)** met with **Dick DeBlasio** to discuss module testing to support their **Utility PhotoVoltaic Group** (UPVG) project. Modules from **AstroPower** will be deployed as a 100-kW system for power quality and UPS grid support. NREL will assist in conducting module intercomparison and benchmark testing. (Dick DeBlasio, 303-384-7660)

In September, **Susie Thomas (Virginia Department of Mines and Energy)** met with **Dick DeBlasio** to discuss amorphous silicon module testing and test-method criteria needed for evaluating module performance with regard to the State of Virginia module manufacturing incentive program. (Dick DeBlasio, 303-384-7660)

In September, **Dick DeBlasio**, **Daryl Myers**, **Laxmi Mrig**, and **Christy Herig** attended the **UPVG** Specifications and Engineering Group meeting. Support for developing test conditions for UPVG acceptance testing was provided, as well as standards and codes support. (Dick DeBlasio, 303-384-6760)

Able Engineering of Goleta, CA, is putting GaInP/GaAs cells made by **Spectrolab** into linear concentrators made by **ENTECH** and designing a system to be satellite-mounted. The issue addressed by an **NREL** paper, "The Effect of Chromatic Aberrations on Two-Junction, Two-Terminal Devices in a Concentrator System," is a new one for them, and they contacted NREL regarding how serious a problem it would be for the small linear concentrators they are using. (Sarah Kurtz, 303-384-6475)

The **5th NREL Workshop on the Role of Impurities and Defects in Silicon Device Processing** was held August 13–16 at Copper Mountain, Colorado. Seventy-eight people from the silicon PV industry and other research institutions participated in this workshop, whose theme was Defect Engineering in Solar Cell Manufacturing and Thin-Film Solar Cell Development. A general consensus from industry was that 18% cell efficiencies and < $1/W module costs are achievable with the new silicon technologies already being studied by industry. (Bhushan Sopori, 303-384-6683)

Construction and calibration of the Stand-alone System Test bed (SST) has been completed at **NREL**. This test bed is capable of testing three individual stand-alone systems (nominally 100 watts). System 1 incorporates 4 **Uni-Solar** UPM880 modules, 2 **Trojan** T-105 lead acid batteries, and a **SCI** 12V charge controller. The SST uses a bank of resistive loads to simulate actual load conditions and will help thin-film PV manufacturers test small stand-alone applications under actual outdoor conditions. (Ben Kroposki, 303-384-6170)

The a-Si teaming activity within the **Thin-Film PV Partnership** continues to be extremely helpful in exploring the successful incorporation of the a-Si:H hot-wire (HW) intrinsic layer into n-i-p devices. NREL recently sent a series of partially finished HW structures to **United Solar System Corporation**, Troy, MI, for deposition of ITO top layers, and this collaboration has resulted in high V_{OC}s and device efficiencies exceeding 7.3%. (Richard Crandall, 303-384-6676)

The Environmental, Safety & Health (ES&H) Team of the **Thin-Film PV Partnership** met at NREL in August and was co-chaired by **Paul Moskowitz (BNL)** and **Ken Zweibel (NREL)**. Representatives from most

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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 July through September 1995, we awarded 33 subcontracts (examples listed below) totaling more than $5 million. For fiscal year 1995, we made 171 awards totaling $24.2 million. For further information, contact Kathy Summers (303-384-6595).

Historically Black Colleges and Universities
PV Research Associates Program (9/95–9/96)

Central State University	$22,276
Clark Atlanta University	$77,838
Hampton University	$53,573
Mississippi Valley State	$40,000
Southern University	$20,650
Texas Southern University	$22,616
Wilberforce University	$61,990

Solar Cells, Inc.
Thin-Film CdTe PV Modules
$898,719 (3/95–3/96)

Interstate Renewable Energy Council
Workshop in a Box Video
$50,000 (9/95–4/96)

Pacific Energy Group
Renewables Applications and Economics
$120,000 (8/95–8/96)

Duke University
Impurity Gettering in PV Silicon
$82,801 (7/95–1/96)

Iowa Thin Film Technologies, Inc.
Manufacturing of a-Si on Polymer
$937,375 (7/95–7/96)

Solar Electric Specialties Co.
Advanced Modular PV Power Systems
$155,210 (9/95–9/96)

Omnion Power Engineering Corp.
Three-Phase Power Conversion Systems
$371,873 (8/95–8/96)

U.S. Export Council for Renewable Energy
U.S./Russia Cooperative Program
$85,000 (7/95–2/96)

Evergreen Solar, Inc.
Advanced Polymer PV System
$228,181 (9/95–3/96)

Ascension Technology
Brazil Meteorological Instrumentation
$262,086 (8/95–2/97)
Manufacture of AC PV Module
$189,419 (7/95-1/96)

Siemens Solar Industries
CIS-Based Thin-Film PV Technology
$885,077 (8/95–8/96)

Utility Power Group
AC Solar Tracking Sub Arrays
$492,896 (7/95–7/96)

Trace Engineering
DC to AC Power Inverter
$83,716 (9/95–9/96)

Solar Design Associates
Low-Cost AC PV Systems
$444,858 (9/95–9/96)

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 Leslee Pohle (303-384-6492).

Wohlgemuth, J. Cast Polycrystalline Silicon Photovoltaic Cell and Module Manufacturing Technology Improvements: Annual Subcontract Report, 1 Dec 1993 - 30 Nov 1994. Sept 1995; 32 pp. NREL/TP-411-8244. Work performed by Solarex Corp, Frederick, MD. NTIS No. DE95009285.

Tan, T.; Sopori, B.; Estreicher, S.; Jastrzebski, L. 5th Workshop on the Role of Impurities and Defects in Silicon Device Processing: Summary of Panel Discussions, 13-16 August 1995, Copper Mountain, CO. Sept 1995; 15 pp. NREL/TP-413-20005. NTIS No. DE95009298.

Sinha, K.; Mascarenhas, A.; Kurtz, S. R.; Olson, J. M. Determination of Free Carrier Concentration in n-GaInP Alloy by Raman Scattering. *J. of Applied Physics.* 15 Aug 1995; 78 (4): pp. 2515-2519.

Williamson, D. L. Microstructure of Amorphous-Silicon-Based Solar Cell Materials by Small-Angle X-Ray Scattering: Annual Subcontract Report, 6 Apr 1994 - 5 Apr 1995. Aug 1995; 40 pp. NREL/TP-411-8122. Work by Colorado School of Mines, Golden, CO. NTIS No. DE95009273.

Nelson, A. J.; Gabor, A. M.; Contreras, M. A.; Tuttle, J. R.; Noufi, R.; Sobol, P. E.; Asoka-Kumar, P.; Lynn, K. G. Comparison of Polycrystalline Cu(In,Ga)Se_2 Device Efficiency with Junction Depth and Interfacial Structure. *J. of Applied Physics.* 1 July 1995; 78 (1): pp. 269-272.

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Industry Activity Update, from page 8

CdTe and CIS companies were present **(J. Bohland, SCI; S. Trim, GPI; R. Gay, SSI; A. Gabor, EPV;** and **V. Kapur, ISET)** as well as several ES&H experts and consultants **(H. Steinberger, Fraunhofer Institute; S. Johnson, C. Eberspacher, Unisun; J. Trefny, CSM)**. One finding discussed at the workshop involved studies of module recycling routes. Several proposed approaches led to similar estimated costs of about $\$0.1/W_p$. The next ES&H team meeting will be held during the IEEE meeting in Washington. (Ken Zweibel, 303-384-6441)

Harin Ullal visited **Solar Cells, Inc.** (SCI) in Toledo, Ohio, in August. SCI was represented by **Rick Yocum, Dan Sandwisch, Teddy Zhou, Rick Powell**, and **Rick Sasala**. Recently, a nominal 10-kW thin-film CdTe PV array (the world's largest) was installed at SCI's outdoor test facility in Toledo. Soon, the array will be connected to the Toledo Edison utility grid, and another 10-kW thin-film CdTe array will be delivered to PVUSA. The highest power output for SCI's large-area (7200-cm^2, 8-ft^2), thin-film CdTe module was 60.3 W, verified by NREL. (Harin Ullal, 303-384-6486)

To prepare for upcoming IRP filings and hearings involving regulated utilities in Arizona, **John Thornton** and **Peter Lilienthal** of **NREL**, and **Sam Swanson**, representing the **Land and Water Fund of the Rockies**, visited several utilities in July. The goals were to investigate what PV and other renewable programs these utilities have going and to inform them that NREL can supply up-to-date information for the IRP process. The utilities visited were **Citizens Utilities Co.** (Kingman), **Arizona Electric Power and Light** (Benson), **Tucson Electric Power Company** (Tucson), and **Arizona Public Service Company** (Phoenix). (John Thornton, 303-384-6469)

Harin Ullal and **Rommel Noufi** visited **International Solar Electric Technology** (ISET) in Inglewood, CA, in July and held technical discussions on thin-film $CuInSe_2$ (CIS) technology. ISET was represented by **Vijay Kapur, Bulent Basol, Andy Halani**, and **Craig Leidholm**. Initial discussions were held on the recent CIS team activities, especially on the data presented in the blue book for all the ISET samples submitted as part of the CIS team's research effort. Discussion also focused on the scale-up effort that ISET is currently planning for the manufacture of thin-film CIS-based modules. ISET has fabricated a thin-film CIS solar cell with a total-area conversion efficiency of 12.4%, verified by NREL, using a non-vacuum method to deposit the CIS absorber layer. (Harin Ullal, 303-384-6486)

Tom Surek participated in the annual meeting of the **U.S. Industry Coalition** (USIC), an organization of about 90 U.S. industrial partners specializing in the commercialization of high-technology opportunities from the New Independent States of the former Soviet Union and DOE national laboratories. With funding from USIC, NREL awarded a subcontract to **KVANT** (a Russian State enterprise) and signed a CRADA with **Energy Conversion Devices** (ECD) of Troy, MI, aimed at the start-up of the **Sovlux, Inc.** (Moscow, Russia) a-Si manufacturing facility, owned 50-50 by KVANT and ECD. (Tom Surek, 303-384-6471)

Three members of the **American Yazaki Corporation** visited NREL in July to review the current status of PV. The parent Yazaki Corporation, based in Japan, manufactures wiring harnesses used in U.S. automobiles. A smaller Energy Division, whose primary products are gas-fired air conditioners, wants to expand into residential PV for sale in Japan. The Japanese government is apparently offering special incentives to encourage domestic PV use on residences. **Takashi Ikeda**, General Manager of American Yazaki, stated they want to team up with an American PV manufacturer. (John Thornton, 303-384-6469)

From July through September, **NREL's Measurements and Characterization Branch** evaluated 4770 components, devices, and PV materials for more than 25 research and industry groups for properties ranging from composition and microstructure to cell and module performance. (Larry Kazmerski, 303-384-6600)

In July and August, the **NREL PV Cell Performance Lab** performed 348 one-sun and concentrator I-V, 240 QE, and 78 dark I-V measurements on PV cells for a variety of groups in support of in-house research, contract deliverables, the Thin-Film PV Partnership and PVMaT programs, and the PV industry: **Alpha Solarco, AstroPower, Colorado School of Mines, Colorado State University, Energy Photovoltaics, Georgia Institute of Technology, Golden Photon, Iowa Thin Film, Solar Cells Inc., Solar Engineering Applications, Solarex, Spectrolab, RTI,** and **United Detector Technologies**. International work was for **British Petroleum, EPFL Switzerland, IACS Calcutta India, IMEC** (Belgium), **IES-UPM** (Spain), **INTEC** (Argentina), **University of Utrecht** (The Netherlands), **United Arab University** (United Arab Emigrates). (Keith Emery, 303-384-6632)

In July and August, 384 module measurements were performed outdoors under prevailing clear-sky conditions and on the SPIRE 240 solar simulator. Samples were evaluated from **APS/Chronar/Green Development Corp., ARCO/Siemens, ASE Americas, AstroPower, BP Solar, CEL India, Energy Conversion Devices, Fuji, Golden Photon, Kanaka, Kyocera, NAPSSS, Solar Cells Inc., Solarex, Solems, United Solar Systems Corp/Solvonics**, and **Utility Power Group**. (Keith Emery, 303-384-6632)

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Birkmire, R. W.; Phillips, J. E.; Buchanan, W. A.; Hegedus, S. S.; McCandless, B. E.; Shafarman, W. N. Processing and Modeling Issues for Thin-Film Solar Cell Devices: Annual Subcontract Report, 16 Jan 1994 - 15 Jan 1995. June 1995; 110 pp. NREL/TP-451-8017. Work by the Institute of Energy Conversion, University of Delaware, Newark, DE. NTIS No. DE95009237.

The NREL **Historically Black Colleges and Universities (HBCU) Photovoltaic Research Associates** program got under way this summer and fall. Sixteen undergraduates from seven HBCUs were selected to participate in the program starting in the 1995/1996 academic year. Six of the students received hands-on training in PV in our first summer internship program.

Wilberforce University, in Wilberforce, Ohio, has three students and three advisors in the program. **Tosha Cameron** will study chemical etching of crystalline germanium wafers, and she spent her summer internship at the **University of South Florida**, working with **Professor Don Morel**. **Raymond Haraway** will design, build, and test an automated system for the electrical characterization of photovoltaic devices; he interned at the **University of Delaware** this summer, working with **Professor Robert Birkmire**. **Jeffery Turner** will use the PC1D computer modeling software to perform one-dimensional photovoltaic device analysis on a personal computer.

Clark Atlanta University, in Atlanta, Georgia, also has three students and three advisors participating in the program. **Keenan Goodman** will experiment with silicon and III-V (GaAs, InP) compound semiconductor surfaces. **Leticia Richardson** and **Jason Collins** will use solar monitoring instruments to obtain accurate solar radiation measurements. They will concentrate on learning to calibrate the instruments so they can study the effect of atmospheric variations on radiation measurements.

Southern University, in Baton Rouge, Louisiana, has three students and two advisors participating. The students, **Michael Heard, Charles LeJeune**, and **Paul Hillard** will set up an EXAFS system to study the structures of thin-film samples. Each will have an opportunity to gain hands-on experience with characterization equipment. **Michael Heard** completed a summer internship at NREL where he worked with **Ted Ciszek** to assemble the diffusion furnace.

Central State University, in Wilberforce, Ohio, has one student (**Hakim Evans**) and one advisor participating in the program. Central State has an ongoing international renewable energy research program. Through our program they will be adding PV systems to existing wind experiments. Hakim will travel to Africa to analyze statistical and performance data on the windmill water pumping systems. In the second year of his research, he will integrate solar electricity into the system. Hakim completed a summer internship at **Solar Cells, Inc.**, in Toledo, Ohio, where he learned cell and module characterization and tested alternative lamination-termination processes for **Dr. Ted Zhou**.

Two students (**Brenda Jordan** and **Andre Tuggles**) and one advisor from **Mississippi Valley State University**, in Itta Bena, Mississippi, will participate in the program. One focus will be to set up a PV curriculum at the university. The students will also analyze data from the university's solar radiation station and analyze the data via laptop computers. Brenda interned at NREL this summer with **Larry Kazmerski**, studying Au nucleation on glass and graphite, using an atomic force microscope.

Texas Southern University, in Houston, Texas, will have one student and one advisor participating in our program. **Oral LeFleur** proposed a unique project that could help the PV industry plan for the future. His survey will determine the level of employment the PV labor market will be able to sustain. The analysis will include samples from PV development, basic science, manufacturing, and system products.

Finally, **Hampton University**, in Hampton, Virginia, will use a team approach with a unique architectural project for their research. Three students (**Toren Williams, Natalie Bunkley**, and **Santora McKinney**) and three advisors will conduct a two-year study. They will use existing neighborhood buildings as the prototypical "laboratory" for an architectural design investigation of how PV technology can be applied to both new and existing residential, commercial, and institutional buildings. For each building chosen, the team will investigate the best use of PV devices. Toren interned at NREL in the Buildings Branch with **Paul Torcellini,** analyzing data from existing energy-efficient buildings.

PV Calendar

March 12–16, 1996, *UPVG & Soltech Annual Meeting*. Sponsors: SEIA, UPVG. Location: Palm Springs, CA. Contact: Michelle Birkenstock, SEIA, 202-383-2600.

April 13–18, 1996, *SOLAR 96—National Solar Energy Conference*. Sponsors: Energy Division, NC Department of Commerce, Tennessee Valley Authority, U.S. DOE. Location: Asheville, NC. Contact: American Solar Energy Society, 303-443-3130.

April 14–18, 1996, *ISES/NREL Renewable Energy Conference and Workshop*. Sponsors: NREL, Egyptian Solar Energy Society, ISES. Location: Cairo, Egypt. Contact: Conference Secretariat, ESES, P.O. Box 487 Doki, Egypt.

May 12–17, 1996, *25th IEEE Photovoltaic Specialists Conference*, Sponsors: IEEE, NREL/Washington, D.C. Office. Location: Washington, D.C., Contact: Fran Hodson, 202-651-7518.

June 3–7, 1996, *6th International Energy Forum: Energy Strategies in Developing Countries in the 21st Century—Challenges and Opportunities.* Sponsors: China Association for Science and Technology, International Energy Foundation. Location: Beijing, China. Contact: China International Conference Centre for Science and Technology, Mr. L. Feng, 44 Kexueyuan Road, Shuangyshu, Beijing, 100086, China, Fax: +86-1257-5691.

June 15–21, 1996, *World Renewable Energy Congress IV.* Sponsor: NREL. Location: Denver, CO. Contact: NREL Conference Coordinator, 303-275-4378.

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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