# Pulling Out All the Stops

The trail of April's NCPV Program Review, SOLTECH 2000, and Earth Day activities is still fresh. The energy in evidence at those events is still palpable.

The U.S. PV industry does indeed seem to be pulling out all the stops.

True, some NCPV attendees questioned whether the accelerated 25% annual growth rate presented in the *Report of the PV Industry Roadmap Workshop* is overly ambitious. But more thought that this goal is achievable. The actual growth rate of U.S. PV production, 20% when averaged over the last five years, will do that to a person.

The article on page 6 of this issue of *NREL PV Working With Industry* offers a summary of the PV Industry Roadmap Workshop. The goal, targets, and end points are in place, but extremely important details, such as implementation steps, must be addressed to produce an actual roadmap. There's talk of convening a meeting to do just that at the IEEE PV Specialists Conference in September.

In the meantime, there's a way to stay on top of PV news as it unfolds (see the NCPV Hotline article on page 3). There's also an interesting way to look at—and contribute to—milestones of the PV Program's Five-Year Plan (see page 4). And, finally, there are two new solicitations for current *and* future NCPV partners to review (see page 10).

In closing, let us point out that the roadmap article is illustrated with road signs—with nary a "stop sign" among them. It shows that we at NREL have also gotten with the Program. Full speed ahead.

NREL PV

Working With Industry

First Quarter, 2000

## Features



## Departments

# Competing in the Big Race

***An Editorial by Roger Little***

Spire Corporation/PIX09111

*Roger Little is President and CEO of Spire Corporation and a member of the NCPV Advisory Board.*

*Contact Roger Little at 781-275-6000*

Running a PV company takes serious stamina. To beat your competitors, you must run hard and fast toward the finish line. Along the way, you must push yourself and maintain an exhausting pace. You also must dodge obstacles at every turn.

I found an ideal way to train for the difficult task of running a PV manufacturing equipment company by training for and competing in the Iron Man Triathlon. A typical competition begins with a 2- to 3-mile swim in the ocean, followed by a 100-mile bicycle race, and concludes with a 25- to 30-mile run. To win an Iron Man Triathlon, you need to develop all three of these areas of physical skill.

If the PV industry wants to win the race of technology development and commercialization, it will need to develop the high-priority areas outlined in the NCPV's Five-Year Plan and the PV Industry Roadmap.

The NCPV developed its Five-Year Plan to help guide DOE's R&D efforts over the next five years. It did a great job helping the PV industry put its Roadmap together in a timely fashion and getting it in sync with its own Five-Year Plan.

The PV Industry Roadmap is a significant document. It marks the first time in history the PV industry has its own map to guide its business efforts toward a common goal. This is significant because participants are the best people to choose an industry's directions and goals. I think that's very important.

Knowing what's important for the PV industry has helped keep me focused for over 20 years. I first began working in PV back in the 1970s with the Spire Corporation, which was involved in PV for space applications. When the OPEC Oil Embargo struck this country during that time, Americans had to wait in long lines to buy gasoline. Spire got involved with bringing PV space technology down to Earth to help provide alternative forms of energy and make the United States less dependent on foreign oil. Many oil companies at that time were investing in PV. Spire chose the path of making the equipment that makes PV modules. That's been our role ever since.

As President Ronald Reagan took office, research budgets were slashed. At that time, I was on the Secretary of Energy's Advisory Board and was asked to help formulate a DOE PV Program at a time when the White House was only interested in basic research. That meant our research focus had to be advanced technology that was not available on the current market. Because of this, the program was driven toward higher efficiencies and the development of new materials.

The DOE PV Program developed along programmatic lines similar to the ones that exist today, such as module R&D and thin-film R&D. The major elements of our early plan persist in today's plan and much progress has been made in technology development. But excelling in technology development alone won't carry us across the finish line. In addition to focusing on technology development, the PV industry needs to expand its goals to include other areas, such as increasing public awareness about PV, developing new markets, and contending with international competition, all of which are addressed in the PV Roadmap.

I still compete in triathlons. I'm still looking for that finish line. Like triathlons, developing and marketing PV technologies is an endurance event—except that there is no finish line in sight! As business grows, opportunities grow, and the race gets longer! The Five-Year Plan and PV Industry Roadmap will help us stay on track and get closer to that finish line.

## PV Web Sites

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

**National Center for Photovoltaics** ..... *www.nrel.gov/ncpv*
World Class R&D • Partnering and Growth • Information Resources

**The Center for Basic Sciences** .....*www.nrel.gov/basic_sciences*
Capabilities • Optoelectronics • Crystal Growth and Devices

**Measurements and Characterization** .....*www.nrel.gov/measurements*
Virtual Lab • Capabilities • Doing Business • Data Sharing

**Million Solar Roofs** .....*www.eren.doe.gov/millionroofs*
Initiative Goals • Scope • Solar Technologies • Solar Registry

**Photovoltaic Manufacturing Technology** .....*www.nrel.gov/pvmat*
Overview • Partners • Fact Sheets • News and Events • Contacts

**PV Silicon Materials Research** .....*www.nrel.gov/silicon*
Thin-Layer Si Growth • Research with Industry

**Surviving Disaster with Renewables** ..*www.nrel.gov/surviving_disaster*
Renewables to the Rescue • NREL's Work • Solar Recovery

# *The NCPV Hotline*
# It's Here, It's Fast, It's Free!

If you were a subscriber to the National Center for Photovoltaics (NCPV) Hotline, you'd know a lot. And you'd know it instantly, as soon as the news is available.

You'd know which company recently installed a building-integrated PV system—New England's largest—for the U.S. Coast Guard offices in downtown Boston (PowerLight Corporation). You'd know how much Japan's Sanyo Electric Company is investing to boost its production of solar batteries (33 billion yen). And you'd be able to identify which national symbol is housed in a pavilion powered by Green-e certified renewable power (the Liberty Bell).

The NCPV Hotline has relayed these and dozens of other PV-related news items recently. Introduced in September1999, the hotline is the brainchild of NREL's Jack Stone. Stone recognized that the PV community needed a handle on the ever-expanding arena of PV progress, including the events and developments happening in the United States and around the world that propel this progress. Because e-mail is the fastest way to collect and relay information, that was the medium chosen for the hotline.

"So far, the hotline contents have been relatively uncensored," says Stone. "We depend on the good judgment of the contributors to separate fact from rumor."

It's easy to sign up for the hotline—and membership costs nothing: Just submit your name, organization, and e-mail address to Jack Stone (jack_stone @nrel.gov). Removing your name from the list is just as easy: Simply send Stone an e-mail making that request.

Stone notes that people joining the NCPV Hotline should be willing to contribute, as well as receive, important news items. Every contributor is credited, and feedback (positive or negative) is welcomed. Subjects covered in the hotline include important research results, new PV products, measurement techniques and results, codes and standards, company news (e.g., new production facilities), and government program budgets.

"We're not looking to replace any of the excellent PV newsletters and magazines—our niche is in rapidly communicating the latest PV news to PV specialists around the world," says Stone. NREL does not guarantee the accuracy of the material transmitted or posted, but makes every effort to control quality. Submission of material to NREL is considered as permission given to forward the material to our mailing list and post it on the NCPV Web site.

Speaking of the NCPV Web site, that's the place to find an archive of the latest hotline news items (at *www.nrel.gov/ncpv/hotline.html*). The NCPV Hotline is one of the many ways that the NCPV promotes the overall visibility of PV technologies and makes it easier for national and international stakeholders to get access to the information they need.

*Contact Jack Stone at 303-384-6470*

# Measure for Measure—a Bolder,

## A Five-Year Plan that's *bold*? A Five-Year Plan that's a *two-year plan*? *Yes*, on both counts.

### Short

Consider the approach we used for the National PV Program Plan published last fall. Rather than spend 20 pages up front summarizing and discussing themes, and providing guidance, we boldly cut, cut, and cut some more. The result is a plan of 16 parsimonious pages—most of which is actually dedicated to the status, plans, and milestones of the PV Program's research and technology tasks. This approach, along with the document's theme and layout, makes it easy to read and to find what you're looking for.

### Sweet

Consider the theme, *Photovoltaics — Energy for the New Millennium*, under which we assert that photovoltaics is good for our nation's energy supply, good for our economy, good for our environment, and good for our future. These are bold assertions. But if you understand anything about the technology and the industry, if you know anything about the recent growth history of the market, and if you look at any of the growth scenarios we paint, these are assertions that the Program and the PV community can back up.

We believe so strongly in this theme that we are making it a centerpiece for the National Center for Photovoltaics and the DOE National PV Program. In the coming months, you'll see it carried forward in presentations, exhibits, posters, and displays. We hope that the simple message and image it creates will become imbued in the minds of the PV community, national and local leaders, and most of all, the public.

BP Solarex/PIX09057

*BP Solarex, a partner in the DOE National PV Program, is testing these new "Apollo" cadmium-telluride PV modules at its facility in Fairfield, CA. The arrays are tied to the local utility grid. A milestone for the PV Program's Thin-Film task is to demonstrate 10%-efficient commercial CdTe modules by 2004.*

### With Meat

But where's the meat? It's in the description of and planning for the research and technology tasks. Every program task has identified at least one milestone for each year of the plan. Some tasks even identify more than one milestone for some of the years.

Most of the milestones are stated in ways that allow us to easily determine whether or not a milestone has been met. This is not so much a departure from the past as it is a refinement toward better metrics.

**By the Number.** In some cases, we stated milestones with numbers. For example, the Thin-Film task listed these expectations for cadmium telluride (CdTe) technology:

- Demonstrate 17%-efficient CdTe cell and support the transition of CdTe to multimegawatt production (2002)
- Demonstrate 10%-efficient commercial CdTe module (2004).

This approach has several advantages. First, we can tell whether a milestone has been met… or how close we've come. This quantitative approach also often provides insight on *why* a milestone wasn't met, *what* barriers are yet to be overcome, and *how* to revise the milestone. In addition, it provides insight on the status and direction of the technology.

**Yea or Nay.** We also made the milestones measurable by stating them in ways that makes their achievement precisely verifiable. Such is the case with the High-Performance task, which set these milestones:

- Initiate projects targeting a doubling of PV performance from 1999 commercial levels (2000)
- Demonstrate feasibility of a three-junction device for 38%-efficient solar cell under concentration (2002)
- Demonstrate achievement of voltage addition in four-junction device (2004).

The first thing to notice about these statements is that the technology has come a long way. We have met many of the performance challenges of most present device materials and configurations—especially the high-efficiency, two-junction devices—and are ready to push the technology to the next level. The next thing to notice is that the first and third milestones above are presented as definite yes/no propositions: We either *have* initiated projects or we *haven't*. We either have a working four-junction device that achieves voltage addition or we don't. But the statement in the second bullet seems somewhat ambiguous, primarily because of the word "feasibility." However, if this word is defined properly (such as having three separate working devices that an acceptable mathematical model demonstrates would achieve 38% efficiency in a tandem configuration), a definitive yes/no proposition results.

# Shorter Plan

**Slippery slopes?** We can make the same type of assessment with milestone statements such as:

- Identify promising PV options for future R&D (Basic and University Research task—2004)
- Publish comparison of module energy-rating methods (Module Performance and Reliability task—2001)
- Assess viability of dye-sensitized solar cells (Basic and University Research task—2001).

The first two statements seem straightforward. We either *identify* or not, *publish* or not. But what about "assess viability" in the last bullet? The term "viability" can escape the trap of ambiguity as long as there are appropriate criteria for determining when a cell is viable. We may be standing on a slippery slope, however, when we use terms such as "assess," for there may be no way to pin down when or how something has been assessed, unless that assessment is performed according to approved methods and is documented.

Compound milestone statements may seem to make the terrain even more slippery:

- Develop *and* implement an electro-optical-based diagnostic compatible with manufacturing environments (Measurements and Characterization task—2001)
- Help develop and publish a qualification standard (IEEE 1513) for concentrator modules (Systems Engineering and Reliability task—2000).

Meeting such milestones requires satisfying both elements, as well as dealing with ambiguities such as what it means to *develop* or *help* to develop something. With the proper analysis, however, these ambiguities dissolve. For example, in the first bullet above, if we implement a diagnostic, presumably we have also developed it—so the only element to satisfy is the implementation. Similarly, for the second bullet: If we are part of a team that is developing a standard, then we are *helping*. Consequently, if we publish the standard, the milestone will be met.

In the final assessment, you will see that the great majority of the milestones are measurable, even though they may be couched in terms that do not indicate measurability at first glance.

On this and other matters regarding the usefulness of the Five-Year Plan, we welcome additional opinions and insights from our industry and university partners (who contributed mightily to developing this Five-Year Plan). Your input should lead to an even better plan for the next cycle, which begins anew very soon.

## The Two-Year Cycle

How soon? The Program Integration task has a milestone to issue a revised Five-Year Plan at the beginning of 2002. This means that we must begin to address the issues, develop a theme, and revise the milestones in less than a year.

This is also new. Prior to this, we have kept to a five-year cycle for the Five-Year Plan. Changing this to a two-year cycle will keep the planning closer to the pulse of the technologies, priorities, growth, competition, and funding. And it will present us with more timely feedback, allowing us to more readily measure the progress and to revise and fine-tune milestones accordingly.

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

Jim Yost/PIX07103

*An early candidate for in-line diagnostics is this NREL-developed technique—radio-frequency photoconductive decay. It quickly and easily measures the minority-carrier lifetimes of wafer material, an important characteristic indicative of material quality.*

# A Map for the Long Road Ahead

You think navigating the information superhighway on the Internet is tough? Try plotting a course for the PV industry! As difficult a task as it seems, members from all areas of the U.S. PV industry got together last year and began work on a roadmap to accomplish just that. When the roadmap is completed, the PV industry will take its product into the marketplace with a map to stay on the right track, prepare for rough areas ahead, and help go the distance.

The U.S. PV industry has already come a long way. It's in the lead when it comes to PV technology and manufacturing, but staying there requires strategic planning for the long journey ahead—overcoming market barriers, increasing production, accelerating research and development of new technology, and bringing down costs. The recently released *Report of the PV Industry Roadmap Workshop* outlines the goals and strategies for industry and its R&D partners through 2020. Among these goals is a 25% yearly PV manufacturing growth rate over the next 20 years. At that rate, the PV industry will approach $10 billion a year, creating tens of thousands of jobs and enormous environmental benefits.


## Ambitious PV Goals

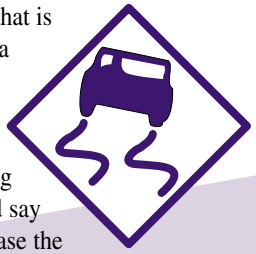
The PV industry has deliberately set ambitious goals for itself. To help industry reach these goals, the National Center for Photovoltaics (NCPV), which helps guide the PV R&D program of the U.S. Department of Energy (DOE), is facilitating the continued development of the roadmap. The NCPV Advisory Board, which includes representatives of major U.S. PV manufacturers, utilities, and universities, serves as the Roadmap Steering Committee. NCPV Director Lawrence Kazmerski applauds the industry effort. "The roadmap is aimed at preserving the U.S. lead in PV technology, manufacturing, and jobs," he says. But he also warns, "Unless we invest more toward the roadmap goals, we will lose out on all three areas."

Reaching these goals requires development of the following four high-priority research and technology transfer areas identified by the Workshop.

### *Markets and Applications*


The main focus here is educating the public about PV by conducting consumer education programs, adding photovoltaics to school science curriculums, and becoming more involved in the political arena. The Workshop report states that education of the consumer is needed because people aren't aware or don't understand how PV benefits them, how PV systems work, how they perform over time, and how they are maintained. Consumers need to be "sold" PV products just like any other product.

More involvement in the political arena by the PV industry is important because many political challenges still lay ahead. Mike Davis, President and CEO of Kyocera Solar, Scottsdale, AZ, and an NCPV Advisory Board member, says one of those challenges is improving the PV industry's credibility in Washington. For one, the people making decisions in Washington believe much of the information presented by DOE regarding energy and global climate change and air pollution is based on politics. Davis says DOE needs to close the credibility gap and get public policy moving in the same direction as renewable energy. One way to do that is to consistently put solar energy in a larger context with other forms of energy, such as fossil fuels, when talking about bettering the environment, creating jobs, and securing our energy future. However, he did say that the NCPV has helped to increase the PV industry's credibility by producing consistent and accurate information.



### *PV Components, Systems, and Integration*

This part of the roadmap involves the future fabrication, installation, and servicing of PV systems in home-retrofit applications and new-home construction for both stand-alone and grid-connected PV systems. Most of the problems in this area are technology related, but customer and public policy issues also cause some problems. For example, existing systems experience some reliability problems and are not yet maintenance free, despite claims to the contrary.

Reducing the high cost of PV modules is a high priority. Lowering the cost of modules will reduce overall system costs, increasing market potential. But lowering cost should not be the only focus here. The plan states that people who buy PV for non-economic reasons, such as improving the environment or living a grid-free lifestyle, should not be overlooked.

Research, development, and demonstration needs include the development of improved, reliable systems and components with lower installed costs that require less maintenance than units sold today. Future PV systems will need to be sold in "refrigerator-like" packaged systems. They will also need to be "market ready" with a utility infrastructure capable of supporting "plug and play" applications.

### *PV Manufacturing*

PV manufacturing concerns are very important to industry. Among the most important is the need for an increased collaboration between the PV industry and government to develop manufacturing partnerships. These partnerships will allow manufacturers and PV vendors to work together to develop the next generation of equipment. This information can then be shared to improve the industry

as a whole. Right now, lack of support for advanced equipment development and lack of knowledge of high-throughput processes are two major stumbling blocks for the PV industry.

Expanding the collaboration between the PV industry and government will also help to guide research activities at national labs and universities for the long term. "Obviously then, NREL's PV Manufacturing R&D project is a top priority for us," says Roger Little, President of Spire Corporation, Bedford, MA, and an NCPV Advisory Board member. When it comes to technology development, companies generally seek to develop technology that will pay off quickly, he says. "Long-term research and development planning is NREL's job."


The roadmap is a first step toward an improved industry/government collaborative because it puts everyone on the same page, says Little. The roadmap goal, targets, and and end points were generated with as much input from industry as its creators could get to provide a coherent report to present to DOE to align with its Five-Year Plan.

### *Fundamental and Applied Research*

Government and university researchers are constantly seeking new materials and processes to improve the industry as a whole. Although many advances have been made, PV material costs are still too high and material efficiencies still too low. Furthermore, government funding has been inadequate to surmount these problems. Research focus for this area was divided into four broad categories:


**Evolutionary R&D—**The high costs of module materials and encapsulation processes were given top priority. To overcome these problems, research of new materials will be needed to reduce production costs. The Workshop calls for more research in areas such as EVA (ethylene vinyl acetate), chemical tempering of glass, thin semiconductor materials, optimized transparent conducting oxide, and alternative substrates.

**Leapfrog R&D—**To make the leap from today's PV technologies to those of tomorrow, the roadmappers gave top priority to developing materials and devices conducive to high efficiencies and low-cost systems. R&D on manufacturing throughput was also labeled high priority.

**Manufacturing Infrastructure and R&D—**Increasing throughput and yield also ranked as a high priority, along with issues facing thin-film manufacturability. The highest ranking need in this category was to address throughput issues by conducting R&D on automation, process control, high-speed processes, and scale-up.

**Institutional R&D—**High-ranking priorities include inadequate support from government for R&D and unclear selection criteria for resource allocation. More support from government is needed here.

## Getting Government Support

When it comes to getting more funding from government, NCPV Director Larry Kazmerski says the PV industry will have to work within the current policy structure, which is not the same as Japan's or Europe's. That difference in structure is clearly reflected in the year 2000 PV budget for three large PV manufacturing countries: Japan's PV budget is $456 million and Germany's is $260 million (R&D and Roofs program combined)— compared with a PV budget of only $65 million for the United States.

Part of the U.S. policy structure is a shortsightedness resulting from political concerns, Kazmerski says. Politicians need to see results quickly to appeal to their constituencies and tend not to think long term. The PV community needs to become more aggressive in selling the further development of PV to the public and to politicians to get people thinking more than one or two years down the road, he says.

## A Map with Purpose

The PV Industry Roadmap will set the stage for PV technology development and market growth for the next 20 years. It will outline marketing, R&D, and manufacturing strategies to help the PV industry reach its 20-year goal of installing 7 gigawatts per year of U.S.-produced PV systems worldwide, with 3.2 megawatts installed in the United States alone, during 2020. It will also serve as a guide to help the PV industry keep on the right track to reach its ultimate vision: "To provide the electrical-energy consumer with competitive and environmentally friendly energy products and services from a thriving United States-based solar-electric power industry."

*Read the report of the U.S. Photovoltaics Industry PV Technology Roadmap Workshop on the NCPV Web site at www.nrel.gov/ncpv. Hard copies of the report are available via e-mail to pvsac@sandia.gov*

*Larry Kazmerski has written an article for* Compound Semiconductor Magazine *(May issue) on the PV Industry Roadmap and its effect on the compound semiconductor industry.*

*For more information, contact Larry Kazmerski at 303-384-6600.*

*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.*

**United Solar** and **Energy Conversion Devices** (ECD) achieved a **Thin Film PV Partnership** Annual Operating Plan "Control Milestone" by fabricating 9%–10% stable cells at 4–10 angstroms/sec. To manufacture a-Si cells cost-competitively, deposition rates must be increased from the current 1–3 angstrom/sec level without compromising typical efficiency. ECD's 8.8% cell was made at 10 angstroms/sec, and **United Solar's** 10% cell was made at 4 angstroms/sec. The cells were light-soaked by the manufacturers and verified at **NREL**. Their progress satisfies a FY 1999 "Control Milestone" that had been rescheduled for March 2000. Contact: **Ken Zweibel, 303-384-6441**

About 35 researchers from the four Amorphous Silicon National Subteams attended the **12th Amorphous Silicon Guidance Team and Technical Team Meetings** held at NREL January 10-11, 2000. NREL scientists **Howard Branz, Harv Mahan, Qi Wang,** and **Dick Crandall** gave presentations at the **Metastability and Midgap Alloy Team** meeting. Wang also addressed the **Wide-Gap and Open-Circuit Voltage Team** meeting. Industry and academic researchers were particularly interested in our hot-wire research results. Wang described the recent record for all-hot-wire devices grown at 18 angstroms/sec. Mahan described materials research on ultrahigh deposition rate hot-wire films grown at 70–150 angstroms/sec. The **Amorphous Silicon Team** agreed to significantly restructure its subteams. The following "umbrella" areas were identified by the team as key issues: (1) increased deposition rates of the intrinsic layers without loss in stabilized performance; (2) improved performance of low-bandgap materials, including microcrystalline Si films; (3) fundamental aspects of metastability; and (4) high-performance and device-integration issues. Future team meetings will include collaborative subteams/working groups to address issues falling within these umbrella areas. Among the meetings' industry participants were **BP Solarex, United Solar,** and **Energy Conversion Devices**. Contacts: **Bolko von Roedern, 303-384-6480,** or **Howard Branz, 303-384-6694**

A record attendance of about 70 people representing academia, **NREL**, and the thin-film PV industry attended the **11th National CdTe R&D Team Meeting** that was held at NREL, Golden, CO, January 27-28. **First Solar**, Toledo, OH, reported on the progress made in setting up their multimegawatt manufacturing plant in Toledo, OH. The first depositions of the semiconductor films (CdS, CdTe) were made in the new coater by the vapor transport deposition method, an extremely rapid process. All other equipment for module fabrication is in place and is undergoing debugging. **BP Solarex**, Fairfield, CA, reported on its two thin-film CdTe products, namely, 40 W (14"x61") and 70 W (24"x61"), with a corresponding aperture-area efficiency range of 8.0% to 8.5%. The highest-wattage module achieved by BP Solarex is 72.2 W, which is the highest wattage for any monolithically integrated thin-film module in the world. BP Solarex also reported on the stability of its thin-film CdTe PV systems deployed in Fairfield. Much meeting time was devoted to discussing the stability of thin-film CdTe devices, modules, and arrays. The role of Cu was discussed in great detail. There was much discussion on various back contacts as they relate to performance and stability of devices. Various modes and mechanisms responsible for stability were also reported. Detailed modeling efforts were presented. Electronic structures of II-VI semiconductors, the polycrystalline nature of the material and its superior performance as compared to single-crystal CdTe, and the various analytical tools used for characterization of CdS and CdTe films were presented in detail. This is an excellent forum for CdTe specialists to exchange ideas, discuss various viewpoints, and design new experiments for the future. This should help the thin-film CdTe PV industry in its commercialization effort in the near future. Contact: **Harin Ullal, 303-384 6486**

**First Solar's** new CEO, **Bob Baumgartner**, and **Steve Johnson**, VP for Business Development, met with **NREL's Tom Surek, Larry Kazmerski, Pete Sheldon, Rommel Noufi,** and **Tim Gessert** in late January to discuss their company's commercialization plans and collaborations and contracts with NREL. Also discussed at the meeting was industry's need for continued support by NREL and **DOE** and the current PV budget at the federal level. Contact: **Ken Zweibel, 303-384-6441**

**NREL** personnel working at the **Outdoor Test Facility** (OTF) reported to and assisted the Russian manufacturer **Sovlux** (a joint venture with **Energy Conversion Devices**) in determining an optimal process recipe and process window for manufacturing a-Si PV modules with higher stabilized efficiency. OTF personnel are charged with stability and environmental qualifications testing of Sovlux PV modules. More than 30 large- and small-area PV modules were received in 1999 by OTF personnel for performing these tests, with the overall goal of assisting manufacturers to improve their product. OTF light-soaking tests recently concluded on 13 small-area modules and entailed indoor light exposure in the Atlas 1600 controlled climate chamber for 600 hours at 1-sun intensity and nominally 47°C. Modules stabilized

*Continued on page 11*

# 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 1999 through March 2000, we awarded more than $15 million to new and existing subcontracts (examples listed below). For further information, contact Ann Hansen (303-384-6492).*

**AstroPower, Inc.** (2/00–9/00)
Silicon-Film™ Solar Cells by a Flexible Manufacturing System
$574,872

**BP Solar Inc.** (1/00–9/00)
Apollo Thin-Film Process Development
$211,750

**Colorado State University** (1/00–9/00)
Device Physics of Thin-Film Polycrystalline Solar Cells
$64,309

**Crystal Systems** (12/99–9/00)
Production of Solar-Grade (SoG) Silicon by Refining of Liquid Metallurgical-Grade (MG) Silicon
$215,000

**PowerLight Corporation** (2/00–9/00)
PowerGuard® Advanced Manufacturing
$223,743

**Syracuse University** (1/00–9/00)
Electroabsorption and Transport Measurements and Modeling Research in Amorphous Silicon-Based Solar Cells
$37,500

**Texas Tech University** (2/00–4/03)
Research in Hydrogen Passivation of Defects and Impurities in Silicon
$109,405

**United Solar Systems Corp.** (2/00–9/00)
High-Efficiency Triple-Junction Amorphous Silicon Alloy Photovoltaic Technology
$528,000

**University of Delaware** (12/99–9/00)
Optimization of Processing and Modeling Issues for Thin-Film Solar Cells
$400,000

**University of South Florida** (3/00–5/03)
Characterization of Defects in PV Crystalline Silicon
$60,000

**Utility Power Group, Inc.** (1/00–9/00)
Development of a Fully-Integrated PV System for Residential Applications
$342,835

# Publications

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


**Ahrenkiel, R.;** et al. *CuPt-B Ordered Microstructures in GaInP and GaInAs Films*. February 2000; 9 pp. NREL/CP-520-27699. Presented at the Materials Research Society Fall Meeting, 29 November–3 December 1999, Boston, Massachusetts.

**Birkmire, R. W.;** et al. *Optimization of Processing and Modeling Issues for Thin-Film Solar Cell Devices: Final Report, 3 February 1997–1 September 1998*. February 2000; 62 pp. NREL/SR-520-27929. Work performed by University of Delaware, Newark, Delaware.

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# University Corner

*"It works it works it works!!! How exciting!"*

That's how **Cornell University** student **Dan Allen** expressed his enthusiasm for his PV project assignment—to make a working Graetzel solar cell. The Graetzel cell was named after its inventor, Michael Graetzel of the Swiss Federal Institute of Technology. Graetzel cells use a light-sensitive dye bonded to a semiconductor to move an electron and create a positive charge that is discharged through an electrolyte. **Sayten Deb**, Director of **NREL's Basic Sciences Center**, actually discovered the photoelectrochemical phenomenon, but Graetzel improved on it by using nanoparticles of $TiO_2$ (anatase) sensitized by Ru-complex dyes and achieved greater stability and a higher efficiency of 11%.

Cornell University is a partner in the DOE PV Program. Professor **Dieter Ast** of Cornell's Materials Science and Engineering Department likes to find new ways to teach students about the structure and electronic properties of defects in semiconductors. His aim is to help students understand the relationship between the atomic structure of the defect and its electronic properties. Recently, Ast challenged his students to choose a topic for one of his design courses, and all the students voted for the Graetzel cell.

During the course of this project, Allen wrote an e-mail to his professor: "It works it works it works!!! How exciting! It looks like I am getting an open-circuit voltage in the dark of 0.02 V and an open-circuit voltage of 0.32 V in the light. For current, I am getting a short-circuit current of 0.1 mA in the dark and 0.6 mA in the light. I'm using a 90-W light source through a 633-nm monochromatic filter to yield a 25-mW/cm$^2$ light source on the sample. These figures aren't the world's best, but hey, we have only begun."

Cornell/PIX09126

*Cornell student Dan Allen hooks up his Graetzel cell for testing in front of the class.*

Judgment day was Friday, April 21, when Professor Ast measured all the cells. Two-person teams of students (15 teams in all) brought their Graetzel cells to class. They put them on the overhead projector (which corresponds roughly to 20% of full sunlight) and hooked them up to a large digital ampere meter to measure the short-circuit current.

The winners were **Panitarn Wanakamol** and **Yana Masushita**. Their cell delivered 1.62 mA. The lowest current measured in class was 0.26 mA. The two students with the lowest current, however, got high marks from their fellow classmates for an inventive short video about Graetzel cells that was a great hit. Contact: **Dieter Ast, 607-255-4140**

# News at

## Important New PV Solicitations Launched

The NCPV recently announced two new solicitations, both of which are posted on the NCPV Web site (*http://www.nrel.gov/ncpv/solicitations.html*).

Letters of Interest are due June 12 for **High Performance PV**. This is a new activity for the PV Program—one that seeks to double the efficiencies of key technologies. The two areas of interest are: (1) Thin-Film Multijunctions and Concentrators; and (2) High-Efficiency III-V Multijunctions for Concentrators. The solicitation complements work being planned by NREL internal research. It is also a 2-year Phase I ("Identifying Critical Pathways") of a planned 10-year program, with projected funding of about $10 million per year. The 2010 targets of High-Performance PV are to demonstrate a 20%-efficient multijunction thin-film minimodule; demonstrate a 20%-efficient single-axis concentrator using a potentially low-cost thin-film cell; and demonstrate the translation of III-V cell results to a pre-commercial concentrator module of 33% efficiency. These targets define the kind of activities that are likely to be carried out during the 10-year program. Contact: **Vicki Riddell, 303-384-7457; e-mail: vicki_riddell @nrel.gov**

Proposals for **Photovoltaic Technologies Beyond the Horizon** are due June 15. The basic research in this project is directed toward generating inexpensive electricity from sunlight. The solicitation is open to universities, colleges, and U.S. companies. Although highly diverse responses are acceptable and encouraged, several areas are of particular interest to the PV Program. These areas, not in priority order, include: dye-sensitized solar cells, single-crystal or large-grain thin films (e.g., GaAs or 1 to 30 microns of Si) on low-cost substrates, innovative PV concentrators, organic solar cells, solar cells based on novel ternary semiconductors, solar cells based on nanocrystalline particles or other quantum confinement concepts, new multijunction concepts, innovative device structures, hybrid device technologies, innovative or improved characterization techniques, and other promising, nonconventional PV materials and technologies. Contact: **Liz Surek, 303-384-7354; e-mail: elizabeth_surek@nrel.gov**

*Industry, Continued from p. 8*

after about 200 hours of exposure. The better stabilized-efficiency values were in the 5.8% range (aperture area). The environmental-qualifications testing of the large-area modules entails running through IEEE 1262 sequences and is nearly completed, as well. Contact: **Joe del Cueto, 303-384-6104**

**Keith Emery, Tom Moriarty, Scott Ward,** and **Dan Friedman** at **NREL**; **D. Lillington** at **Spectrolab**; and staff at **Fraunhofer Institute for Solar Energy Systems** (ISE) in Freiburg, Germany, have been comparing multijunction concentrator cells to increase understanding and confidence in multijunction concentrator measurements. A GaInP/GaAs/Ge triple-junction concentrator cell, manufactured at Spectrolab and measured earlier at NREL, was independently measured at ISE. ISE's measurements fell within 0.2% of NREL's—substantially closer than the estimated uncertainty of ± 6%. A $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ cell fabricated at ISE was also evaluated. ISE reported 31.3% at 300 suns, and NREL reported 30% at 300 suns. The difference in efficiency versus concentration data is due to ISE measuring a 4%-higher 1-sun current than NREL. Contact: **Keith Emery, 303-384-6632**

**BP Solarex**, Fairfield, CA, has recently fabricated a world-record, thin-film CdTe module with an aperture-area (4874 $cm^2$) conversion efficiency of 10.8% and power output of 53.9 W. This is the highest efficiency for any thin-film CdTe module in the world. There were several modules measured in the efficiency range of 10.2% to 10.8%. The results were verified by **NREL's OTF** staff. The previous world record was held by **Matsushita Battery**, Japan, with an aperture-area (5432 $cm^2$) efficiency of 9.7%. BP Solarex deposits its CdTe absorber film by the electrodeposition technique, whereas Matsushita Battery uses the atmospheric pressure close-spaced sublimation method. Interaction with NREL scientists and the **National CdTe R&D Team** have contributed to the progress in this emerging thin-film PV technology. BP Solarex has also meet its Phase III milestone a year ahead of schedule. The **Thin Film PV Partnership Program** and NCPV commends the Apollo Team on this excellent result. Contact: **Harin Ullal, 303-384-6486**

Measurements at **NREL** of **United Solar System Corporation's** large-area (0.93 $m^2$) US-64 model amorphous silicon (a-Si) triple-junction PV modules demonstrated the maturity of high-efficiency a-Si PV technology. Two modules have been deployed in the array field at NREL's **OTF** since February, 1997. On March 20, 2000, the modules were measured on the NREL large-area continuous solar simulator and revealed efficiency values measured at standard reporting conditions (SRC) of 7.26% and 7.18%. Output powers were 67.3 and 66.6 watts, respectively. The measurements were taken immediately after the expected end-of-winter cyclical nadir in performance, which is observed in a-Si technology modules deployed in cold climates. The measurements represent the minimum performance at SRC expected from modules throughout the rest of the year. During the summer, module performance will likely be higher by a few percent relative to the values noted above. The US-64 modules are rated at 64 watts of power at SRC. Data collected on these two a-Si modules show that the stabilized power rating is fairly conservative, unlike that of most other commercially available modules of amorphous, crystalline, or polycrystalline silicon technologies. Contact: **Joe del Cueto, 303-384-6104**

*Publications, Continued from p. 9*

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**Young, D. L.;** et al. "Density-of-States Effective Mass and Scattering Parameter Measurements by Transport Phenomena in Thin Films." *Review of Scientific Instruments*. February 2000; 71(2); pp. 462–466.

# PV Calendar

**June 10–15, 2000,** *FEMA 2000: Technology Partnership for Emergency Management Workshop and Exhibition*. Sponsor: NREL. Location: Colorado Springs, CO. Contact: Wendy Larsen, NREL. Phone: 303-384-6497. E-mail: wendy_larsen@nrel.gov.

**June 16–21, 2000,** *SOLAR 2000: Solar Powers Life—Share the Energy*. Sponsor: American Solar Energy Society. Location: Madison, WI. Contact: ASES. Phone: 303-443-3130. Web site: *www.ases.org/conference/solar2000.htm*

**July 1–7, 2000,** World Renewable Energy Congress 2000. Sponsor: WREN. Location: Brighton, United Kingdom. Contact: Ali Sayigh. Phone: +44.1189.611364. Web site: *www.wrenuk.co.uk/brighton/brighton.html*

**July 30–August 4, 2000,** *13th International Conference on Photochemical Conversion and Storage of Solar Energy (IPS-2000)*. Sponsor: NREL. Location: Snowmass, CO. Contact: Barbara Ferris, 303-275-3781. Web site: *www.nrel.gov/ips2000*

**August 13-16, 2000,** *10th Workshop on Crystalline Silicon Solar Cell Materials and Processing*. Sponsor: NREL. Location: Copper Mountain, CO. Contact: Bhushan Sopori. Phone: 303-384-6683.

**August 23–24, 2000,** *IEEE SCC21 P1547 Standard Development*. Conference focuses on an interconnection standard for distributed electric power systems. Sponsor: NREL. Location: Golden, CO. Contact: Cricket Pierce. Phone: 303-275-4326.

**September 17–22, 2000,** *28th IEEE PV Specialists Conference*. Location: Anchorage Hilton, Anchorage, AK. Contacts: Ajeet Rohatgi. Phone: 404-894-7692. Or John Benner. Phone: 303-384-6496. Web site: *http://ieeepvsc.nrel.gov/pvsc28home.html*

**October 2–5, 2000,** *UPVG Photovoltaic Experience Conference 2000*. Location: Baltimore, MD. Sponsor: Utility PhotoVoltaic Group. Contact: Tina Schneider, Phone: 202-857-0898. Web site: *www.upvg.org/upvg/upex2000*

**October 2–6, 2000,** *American Vacuum Society, 47th International Symposium*. Sponsor: AVS. Location: Boston, MA. Contact: AVS. Phone: 212-248-0200. Web site: *www.vacuum.org/call/default.html*

**November 27–December 1, 2000,** *Materials Research Society 2000 Fall Meeting*. Sponsor: MRS. Location: Boston, MA. Contact: MRS Headquarters. Phone: 724-779-3003. Web site: *www.mrs.org/meetings/fall2000*

**December 4–7, 2000,** *Village Power 2000: Empowering People while Building Markets*. Sponsors: NREL, World Bank, Winrock International. Location: World Bank HQ Building, Washington, DC. Contact: Barbara Ferris, 303-275-3781. Web site: *www.nrel.gov/villagepower*

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.

**Robert McConnell** .....303-384-6419
PV Program Communications

**Tom Surek** .....303-384-6471
Technology Manager, Photovoltaics

**Lauren Poole** .....303-384-6624
Writer, Editor

**Susan Moon**.....303-384-6631
Writer, Editor

**Gary Cook**.....303-275-3659
Writer

**Jim Miller**.....303-384-6595
Graphic Designer

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**PV Program**
1617 Cole Blvd. Golden, CO 80401-3393

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