SOLAR ELECTRICITY

the power of choice

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Features

Departments

National Center for Photovoltaics
Phone: 303-384-NCPV
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Reporting on solar electricity research and related activities from the National Renewable Energy Laboratory and its partners within the National Center for Photovoltaics

Through the Looking Glass

Through the looking glass of September 11, there came another world. A world that in many respects looks the same, but never will be. A world that just doesn't *feel* right… that somehow needs adjusting.

Not all of the changes are bad. Strangers and shopkeepers seem friendlier. "I'm proud to be an American" is more than just a song. Most rewarding is that our heroes are real—and they are among us.

The National Center for Photovoltaics Program Review Meeting was held in Lakewood, Colorado, in mid October. In many ways, this meeting seemed like the 16 that came before it. Researchers, technicians, and managers from the government labs, universities, and private-sector companies that comprise the PV program discussed progress toward higher efficiency cells and more streamlined manufacturing. The growing market for solar electricity was applauded.

In another way, however, this meeting differed greatly from those in the past. In reflection of the national mood, there was a sense of determination in the room that was nearly palpable. The solar electricity community has always known that it was engaged in work that is crucial to our national security. Communications satellites and space travel depend on solar electricity. The U.S. military uses solar electricity extensively for its operations.

But, suddenly, the need for solar electricity to be a significant contributor to the national electricity grid became real. Our nation needs to generate electricity from domestic resources—and the United States has plenty of sunshine. Solar electricity needs to be brought on line in significant amounts. We need a national commitment to make this happen. More than ever, solar electricity needs to be part of the solution. Not all of the changes are bad.

Solar Electricity Has So Much to Offer

An Editorial by Kannan Ramanathan

Warren Gretz, NREL

Kannan Ramanathan chaired the recent National Center for Photovoltaics Program Review Meeting. He is both a research scientist and the leader of the Copper Indium Diselenide Team, and has been with NREL for 16 years.

Contact Kannan Ramanathan at 303-384-6454.

As a research scientist in the field of solar electricity, I see no shortage of encouraging developments. I know we are making key breakthroughs in our understanding of new material systems for photovoltaic technologies. Collaborations among universities, national labs, and private industry are stronger and more productive than ever before. The need for the fruits of our research has never been more pronounced.

All of the above—and much more—was in evidence at the recent Program Review of the National Center for Photovoltaics, held in Lakewood, Colorado, in October.

It is not often that one gets a chance to chair a technical meeting or a conference, much less that of the NCPV Program Review. The chance was mine this time, and I found able partners in Sally Asher, my co-chair, and in an enthusiastic program committee. We opened our preliminary discussions with a quest for a "theme" for this meeting. It became clear that we must highlight our R&D and emphasize our pride in it. Our program is stronger than it has ever been, and we manage our resources to bring out the best science, engineering, and product development.

The events of September 11 did concern all of us. Some people questioned whether we should hold the meeting at all. But when President Bush and Secretary of Energy Abraham encouraged the nation to conduct business as usual, we made the decision to move ahead. Interestingly, none of the non-NREL attendees expressed any concern about the domestic situation. They took this in their stride and traveled to be here. Many made important presentations and stayed for the entire meeting. This demonstrates their commitment, and they have our gratitude.

I hope the meeting reflected a sense of pride and success. We were able to include more oral presentations than in previous years. About 90 papers were presented as posters during two days. The proceedings were prepared ahead of time and given to the participants in a CD format at the meeting. The painstaking work of Sally Asher and the NCPV Communications Team made this happen. Our thanks are also extended to the NREL Conferences Team, and particularly, to Barbara Ferris.

The opening plenary session set the stage for the meeting. Larry Kazmerski, Bob Birkmire, Dave Carlson, and John Benner spoke to the diversity and strength of our program. Other highlights of the meeting were the technical presentations, the panel discussion on the PV industry Roadmap, and the Rappaport Award presented to Jack Stone. NCPV staff from Sandia National Laboratories organized an excellent oral session dedicated to PV systems engineering R&D and the important work being done in this field. Richard King gave his perspective of solar and PV development in the context of energy throughout the ages. Jim Rannels brought some exciting news, announcing that an independent panel of experts had reviewed the DOE PV Program and rated it outstanding in every aspect.*

Overall, this was a successful meeting, and it was especially important for the solar electric community to gather at this time and renew friendships and collaborations. As I sat and listened to the presentations, I was reminded anew that we in the NCPV have so much to bring to the energy security table. We all know that solar electricity is an elegant technology that generates electricity at the place where it's needed. And that place is at our Lab in Golden, Colorado… across the United States… and around the world.

*See *www.nrel.gov/docs/gen/fy02/nn0088.pdf* for the complete *2001 Peer Review of the U.S. Department of Energy Photovoltaics Program.*

The Shift to Renewables

"Let's Make It Revolutionary Rather than Evolutionary"

The opening session of the NCPV Program Review Meeting ended on a high note with Jack Stone's acceptance of the Paul Rappaport Award for his service to the field of photovoltaics. Stone is a former professor of electrical engineering at Texas A&M University and a 24-year-man and principal scientist in the photovoltaics program of the National Renewable Energy Laboratory.

Citing the tragic events of September 11, Stone's remarks centered on our nation's energy security. He called the shift from a fossil-fuel to a renewable-energy economy virtually inevitable in the long run, and proposed that the shift be "revolutionary rather than evolutionary."

Warren Gretz, NREL

Lloyd Herwig (right), the first Paul Rappaport honoree, congratulates Jack Stone, who received the fourth award at the NCPV Program Review Meeting in October.

"We call photovoltaics the power of choice, but it could be the power of significant amounts," he said. "It's time to usher in a more decentralized approach to electricity generation. Renewable energy represents terror-proof distributed generation."

Stone said that much of our nation's infrastructure appears to match airline transportation systems in terms of vulnerability. Bridges, dams, highway tunnels, and electricity supply head up the list of systems especially open to terrorist attack. These are highly concentrated assets in relatively small areas—much like the World Trade Center towers. Multi-megawatt electrical generation is tied up in dams, nuclear generating stations, and power plants fired by coal and gas that are difficult to protect.

Natural gas has been identified by the U.S. electricity industry as a "bridging" fuel between coal and renewables and/or nuclear. And, although it's true that natural gas burns cleaner than coal and has no long-term disposal problems, there's one obvious problem: the supply is finite. Furthermore, it is possible that the United States could become dependent on foreign supplies before the eventual preferred fuels are available to provide energy in significant quantity.

Stone's suggestion is to move toward a hydrogen economy as quickly as possible. The scenario would be to produce hydrogen from the electrolysis of water, with the electrolysis powered by photovoltaics. Many arguments have been advanced stating that solar energy is too dispersed to be a significant contributor. Actually, very conservative calculations show that the sun shining on a photovoltaic system within a 100 by 100 mile square can provide all of the energy required by our country. Most probably, concentrator photovoltaic systems in the desert areas of the United States would produce the hydrogen, which could be piped or stored for later use. Hydrogen is an ideal fuel because of its very high energy content, coupled with its clean burning characteristics—the only byproducts are water vapor and heat. There is no hydrogen cartel! Hydrogen generation can be geographically distributed. And hydrogen fuel cells can power transportation.

So what needs to be done? Stone cited the 1960s, when the United States made a commitment to put a man on the moon by the end of the decade—and did it. In 2002, a similar national commitment to fully developing photovoltaic and hydrogen power *would* accomplish our objective. It *would* put the United States in position to control our energy destiny. Along with this, the photovoltaic industry needs a substantial increase in production capacities. And photovoltaic research must continue to make advances in improved performance, reduced cost, and increased reliability.

This growth will require increased government and private investment in the technologies. The current U.S. Department of Energy photovoltaics budget is not sufficient to get the job done on an *accelerated* schedule. Remember, we need *revolutionary*, not evolutionary, approaches. The path described in the U.S. PV Industry Roadmap is evolutionary. Clearly, the goals of this plan can be placed on a revolutionary track with an appropriate commitment to larger funding from the U.S. government.

September 11 was a wakeup call, which, no matter how tragic, *will* be overcome. The task at hand—securing our nation's energy future—must start *now*. It's time to learn from this experience, move ahead, and provide truly significant amounts of solar energy.

For more information, contact Jack Stone at 303-384-6470.

Putting Our Heads Together

A prominent energy advisor recently blasted the photovoltaics community for not thinking big enough. In part to counter such a charge, the final session of this year's NCPV Review Meeting focused on the PV Industry Roadmap and the opportunities and challenges facing the PV industry. The forum was chaired by Roland Hulstrom and consisted of a five-member panel of U.S. PV industry representatives: Paul Maycock (PV Energy Systems), Theresa Jester (Siemens Solar Industries), Dave Carlson (BP Solar), Ray Hudson (Xantrex Technology, formerly Trace), and Ron Kenedi (Kyocera Solar).

Paul Maycock emphasized that the grid-connected PV market has yet to become "real," meaning that it remains highly subsidized and uneconomic on its own. It is improving though. For example, in 1996, the 70,000 Roofs program in Japan was subsidized 50%, to buy $11/W systems down to $5.50/W. The present subsidy is 10%, to get to the same $5.50/W system cost. Maycock also insisted that we must sell the tremendous values of PV beyond the price, such as modularity, fuel diversity, nonpolluting technology, and many others.

Terry Jester discussed the basic process flow and issues involved in Siemens Solar Industries' manufacturing lines, both for crystalline silicon and thin-film CIS production. Regarding thin films, Maycock earlier mentioned them as remaining a real "possibility" for the next 3 to 5 years. The need is for bigger plants to manufacture thin films—plants with capacities larger than just 10 or 25 MW.

Dave Carlson noted that the recent growth of PV sales of about 40% per year has been fueled by government subsidies. To have sustained annual growth above 25%—which is the growth curve considered in the Roadmap and equates to a doubling of capacity every 3 years—prices will need to drop more rapidly. And sustained invesments in PV will require profitable operations.

Carlson also showed an "experience curve" for PV prices, with PV module prices (in $/$W_p$) plotted against cumulative PV sales (in MW_p). Extrapolating the resultant curve predicts a PV-module selling price of $1.05/$W_p$ in 2020 if cumulative sales reach 88 GW_p. He also pointed out that, in time, PV will become a commodity, dominated by materials costs.

The PV industry must continue to address new, developing markets. As an example, Carlson discussed building-integrated PV and compared standard architectural windows to PV windows (same as standard windows, but with a PV coating). The PV window should cost only about 25% more than the standard window, have similar distribution and installation, and have relatively low balance-of-systems (BOS) costs, leading to a cost below $1 per watt.

Ray Hudson spoke about BOS, which he said is typically considered "all that other stuff," though he likes to consider it the heart of the system, or "everything else required to make PV power usable." Xantrex is involved in three markets: distributed power (solar); high-volume mobile power (cars, trucks); and high-quality programmable power (DC power supply).

Dave Carlson of BP Solar spoke during the second plenary session of the NCPV Program Review Meeting, and also participated in the panel discussion on the PV Industry Roadmap.

Several issues in the BOS arena were outlined. First, the trend is toward integrating more of the components into the inverter. Second, all states and utilities need to adopt codes and standards so that not every system is custom. Third, the performance/efficiency curve can be improved, realizing that there is a trade-off between cost and efficiency. Hudson summed up his remarks by saying that many "inverter problems" are actually problems with system design and application, e.g., a poor match of array and inverter.

Finally, Ron Kenedi provided the perspective of a systems integrator. He painted a profile of "early adopter" customers as those who fear rising utility rates and blackouts, are "meter watchers," and are financially able to afford a higher-priced system. But he emphasized that we need to move beyond such early adopters to a larger customer base.

To do so, performance must match expectation. Early adopters must be convinced if the larger customer base will be convinced. Predictable power losses must be sorted out from variable losses, such as those caused by dirt on modules. We must be able to explain to customers why their actual power production is less than the nameplate rating, perhaps by giving a range of expected power. We must overcome the performance perception barriers of grid-tied systems. And finally, industry must increasingly consider product aesthetics, financing, and ease of installation.

Following the opening comments by each panelist, the floor was open for questions, answers, and comments. The gist of several key exchanges follows.

- PV may have difficulty in the market competing against other energy options based on price alone. But taking into account PV's total set of values can often more than meet competitive challenges. We must emphasize such values, educating the public and letting consumers know why they should get excited about this technology.
- It may be time to "freeze" the development of thin-film manufacturing and start producing a significant amount of product. But ultimately, this is a business, not a technology, decision.
- Module makers can develop their products in such a way to help the BOS people improve reliabilities. One means would be to produce modules with higher voltages, which can especially be done with thin films.
- We must accelerate the time frame in which PV will have a significant impact. The PV story must be told more broadly, with PV products becoming more visible and being marketed more concertedly (as with some developers in California, who are building solar-powered homes as their standard model). Solar electric systems must get beyond the perception of just being "gadgets," and instead be known as significant contributors within our nation's energy portfolio.
- The R&D PV community cannot live on 2- to 4-year promises, which is the typical political time frame. We need sustained funding at adequate levels. (See article on next page.)
- We must continue to expand our partnership with other industries and agencies. For example, the PV industry has partnered with Alcoa, the National Association of Home Builders, and the International Brotherhood of Electrical Workers in the buildings arena. Also of interest is that this meeting attracted the interest of General Electric, who sent a representative from GE Corporate R&D.

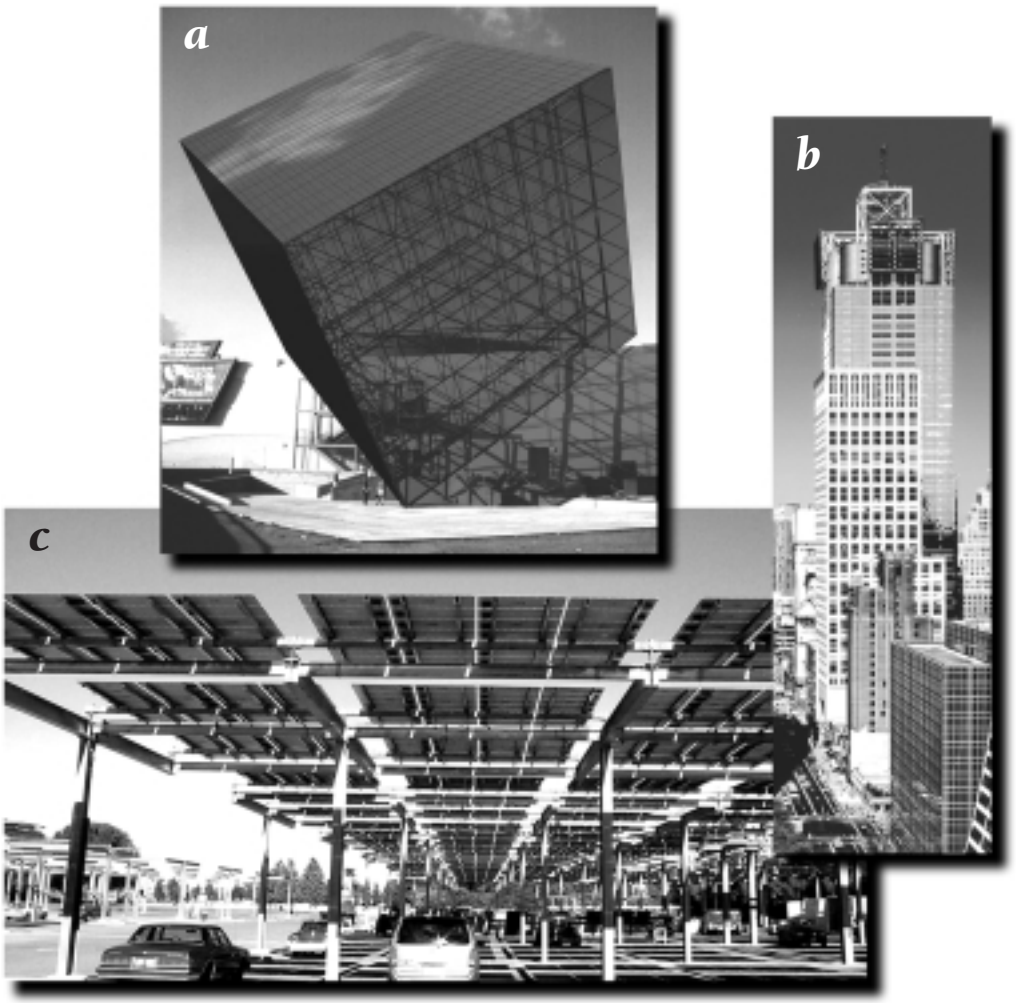
The panelists and audience agreed that much more discussion and action are needed as members of the PV industry are stretched to "think bigger." But this session at the Review Meeting was a good step in that direction.

The PV Roadmap panelists and their audience stressed the importance of raising the visibility of PV products. The projects pictured here do just that.

(a) About 500 thin-film Millennia PV modules from BP Solar were used on the Solar Cube, which stands 135 feet tall on top of the Discovery Science Center in Santa Ana, California. Solar Design Associates designed, engineered, and constructed the 20-kilowatt, grid-connected array. (Solar Design Associates, Harvard, Massachusetts/PIX09334)

(b) The upper stories of the 4 Times Square Building in New York City feature a "skin" of thin-film PV panels that replace traditional glass cladding material. The PV curtain wall extends along sections of the 35th to 48th floors on the south and east walls of the tower, making it a highly visible part of the midtown New York skyline. (Andrew Gordon Photography and Fox and Fowle Architects/PIX09052)

(c) The PV system at the Cal Expo parking lot in Sacramento generates about 540 kilowatts of electricity, enough to power about 180 homes. The solar arrays serve as an oasis of shade for 1,000 cars in a desert of scorching blacktop. (Kyocera Solar/PIX09435)



Boost the Investment, Reap the Return

"It's no longer business as usual," said Larry Kazmerski at the National Center for Photovoltaics Program Review Meeting. He was referring to events of the past 18 months—the electricity supply problems in California, terrorist activities, and a renewed focus on energy security—and how the PV community could mount a response.

Kazmerski said that tripling the current DOE PV budget would accelerate the projections of the U.S. PV Industry Roadmap dramatically, meeting in 2015 the roadmap's 2020 expectation of 3.2 gigawatts of new installed, domestic solar electricity. This number could approach 10 gigawatts by 2020, which is more than three times greater than the original target. Such an initiative would require a modest investment—merely one-quarter the level of Japan's 2002 PV budget.

"We can answer the mandate from the President's National Energy Policy, which calls for increasing America's use of renewable and alternative energy. We can do more in bringing closer the time that PV will make a real impact," he said.

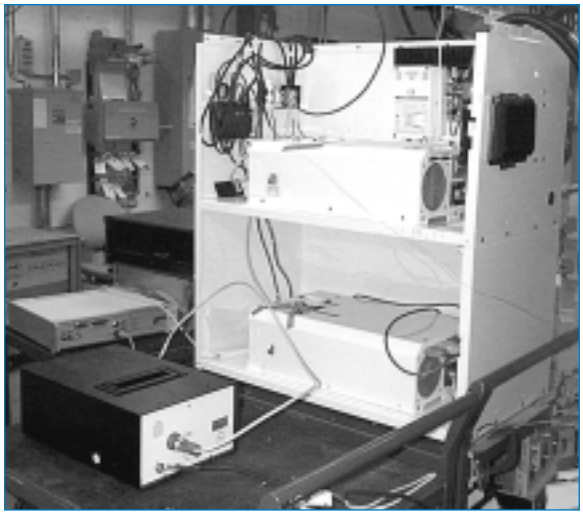
The NCPV director spelled out ways this investment could be spent with the potential for greatest return. With that in mind, the editors of this newsletter wondered how others in the PV community would spend increased funding in PV research and development—and what this could mean for advancements in solar research.

When we asked for input, several messages rang out clearly. Our respondents need research dollars to gain a deeper understanding of the processes that create a successful solar device—and to continually reduce the cost of the end product. They want to find ways to manufacture that device more expeditiously. Finally, they want to marry that device to a system that works over the long haul. But perhaps we should let them speak for themselves.

Paul Klimas, Manager, PV Program and Renewable Energy Systems, Sandia National Laboratories

If the DOE PV Program increased funding to my organization threefold, we would spend the money on an accelerated PV System Reliability Program and on developing a plug-and-play PV Alternating Current Building Block. Obviously, funding levels will affect advancements in solar research. The question is, whose advancements will make it to the marketplace first and secure the competitive advantage? We hope that it will be those developed in this country.

The two areas above are the areas of emphasis. The first has been neglected and can quickly deliver economic advantages to U.S. industry. The second will open new and large markets for whoever develops the technology.



In the area of PV system reliability, engineers at Sandia National Laboratories evaluated seven grid-tied inverters and nine inverters in off-grid configurations last year. These evaluations helped PV manufacturers develop new products.

Peter Meyers, Director of Research, First Solar

Increased funding would help us gain a detailed understanding of film growth and processing for our specific process. This multi-tiered investigation would include materials science, device physics, and identification and quantification of mechanisms related to device-fabrication procedures. Then we'd explore additional device fabrication and processing procedures and alternative device structures. After that, we'd look into third-generation solar power conversion concepts.

It is hard to quantify the effects, but funding is an enabler of improved solar cell and module technology. PV has not yet realized its full potential. Because profitability of PV companies is elusive, funding enables commercial enterprises to invest in programs that will ultimately lead to increased availability of solar power. Much more could be done to accelerate progress, and funding is a limiting factor.

First Solar opened this high-volume PV manufacturing plant in Toledo, Ohio, in 2000. When fully operational, it is expected to produce 100 megawatts per year of thin-film, cadmium-telluride modules.

An additional area to those cited above is energy storage. PV is not a complete solution. On a minute-by-minute, hour-by-hour, or day-by-day basis, stand-alone PV is an unreliable power source. PV will find market acceptance only when it becomes part of a complete, uniquely PV source of low-cost power on demand. Developing the "PV solution" will go a long way toward promoting future investment in PV technology.

Peter P. Bihuniak, Vice President of Technology, BP Solar

If funding were increased significantly, we would increase efforts on relatively short-term issues, with an emphasis on manufacturing technology. Improvements to in situ sensors, process control algorithms, and overall equipment efficiency will have the greatest short-term impact on cost/price reductions and product-reliability enhancement. Further, increased spending could be directed toward an improved overall package. That is, encapsulation, wiring, framing, and power-conditioning (specifically inverters) cost reduction and reliability/warranty enhancement. Another relatively short-term concern is the continued availability of cost-effective PV silicon. The industry has grown on the availability of "scrap" materials. Sustaining a 25% annual growth rate requires a solid foundation of available raw materials.

I realize I haven't mentioned ongoing efforts in efficiency improvement. While I think this work should continue, especially in thin films (especially degradation phenomena), I strongly believe manufacturing enhancements will have the greatest impact in the next five years.

Ray Hudson, Vice President of Advanced Development, Xantrex Technology

We at Xantrex believe strongly that the many successes that have been achieved in the development of solar cells and modules have the industry well positioned to focus more on complete systems. Traditionally, the key system components have been referred to as "balance of system" (BOS) components, and relatively little emphasis has been placed on R&D in this area. Going forward, significant development (not basic research) activities in the BOS area can greatly improve the performance of PV systems. Xantrex believes that the development of integrated systems that match all required components for an optimal system is a key to reducing the complete PV cost of electricity. Through development of standard systems that can be distributed, installed, and maintained through traditional electrical-supply channels, PV can achieve broader adoption in the marketplace.

The major areas of research and development that should be emphasized are reducing system cost, increasing system efficiency, and improving reliability. For example, the reliability of PV inverters can be increased through engineering developments (such as accelerated life testing) to better complement the long lifetime of PV modules. Opportunities also exist for adding value to PV systems through additional functionality such as backup, demand management, and operation with other generation sources. These recommendations are in the context of moving toward the system view described above, which is a real key to making solar the electricity source of choice.

Ajeet Rohatgi, Director, DOE Center of Excellence in PV, Georgia Institute of Technology

At Georgia Tech, we would use extra funds to hire a new faculty member in PV, several graduate students, and two or three high-caliber research engineers. Next, we would make our lab facilities more state of the art and add some new ones. Then we would look for ways to enhance education in PV by offering more classroom and hands-on training courses. This might include offering a freshmen-level course on renewable technologies to attract students early on to this field.

Increased funding would have a significant impact on the quality of our research, because it is the higher quality people who demand more stability and higher paying jobs. It would allow us to add more manpower to do the technology development for the next-generation silicon solar cells. It would enhance our characterization and fabrication capabilities and increase our depth of research. Most of all, it would bring much-needed higher quality graduate students to PV, who are now somewhat reluctant to come to a group with a history of unstable funding.

I would like to see more R&D in the area of silicon PV, with the emphasis on very high efficiency (18%–20%) silicon solar cells that are thinner and easier to manufacture. This will require improvements in screen-printing technology and paste, texturing

(Continued on page 11)

Ajeet Rohatgi/PIX08532

A Georgia Tech graduate student performs minority-carrier lifetime measurements by the photoconductive decay technique—important research for improving the quality of PV cells.

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.

Cominco, located in Ontario, Canada, is the world's largest zinc-mining company and the fourth largest zinc-metal refiner in the world. As part of its mining and refining operations, Cominco sells various metals and coproducts such as zinc, copper, lead, silver, and gold, along with specialty metals such as germanium and indium, to organizations worldwide. Cominco is currently evaluating the PV industry for potential business opportunities. When representatives from Cominco visited **NREL** in June, discussions were held on the **NCPV** evaluating Cominco-developed semiconductor materials such as CdTe, CdS, and ZnO for solar-cell fabrication. Cominco is planning to visit the U.S. PV industry and discuss industry needs in the near and long term. The visitors were given a tour of the SERF building and OTF. Several brochures and papers were provided to the visitors. Contact: **Harin Ullal, 303-384-6486**

BP Solar has fabricated a world-record monolithically integrated thin-film module (0.87 m^2) with a power output of 90 W. This has been independently verified by the **Outdoor Test Facility** staff at **NCPV/NREL**. This is the highest module power output for any thin-film module in the world. The CdTe film is deposited by the electrodeposition method, whereas the CdS is deposited by the CBD technique. Thin CdS, 0.05 micron thick, is used in the module fabrication. Collaborative research with the **Institute of Energy Conversion**, **NCPV CdTe Team**, the **Measurements and Characterization group**, and the **National CdTe R&D Team** have helped to improve the state of the art. Extensive research is under way for reliability testing both indoors and outdoors as part of product development. Contact: **Harin Ullal, 303-384-6486**

Siemens Solar Industries has boosted its sales of thin-film CIGSS modules to 500 kW/year. Several products are being offered with nameplate ratings of 5 to 40 W. The products are well received in the marketplace and meet their nameplate ratings. SSI is currently ramping up its manufacturing line for multi-megawatt production in the next few years. Several CIGSS systems varying in size from 1 to 17 kW are being field-tested at various locations worldwide. **NREL** and the **Thin Film PV Partnership** have supported the R&D activities of CIGSS at SSI for the past several years. Contact: **Harin Ullal, 303-384-6486**

Earlier this year, the **Iowa Department of Natural Resources** (DNR) requested technical assistance from NREL for its PV Advisory Board. Iowa organized this Board to support its work under a **Million Solar Roofs** award received last year. The Board, consisting of representatives from education, system installers, municipal and investor-owned utilities, construction engineers, builders, and realtors, met this summer to review preliminary results from a six-state survey about PV perceptions in the regional building community. When finalized, the Iowa-DNR plans to release the study results, and will define a plan to increase the use of PV in the region. Contact: **Holly Thomas, 303-384-6400**

Global Solar Energy (GSE), a joint venture between **Tucson Electric Power** and **ITN Energy Systems** (ITN/ES), has improved its large-area (64.4 cm^2), lightweight, flexible CIGS solar cell efficiency to 9.2%. The CIGS is deposited by the physical vapor deposition method. The cell parameters are: J_{sc} = 28.97 mA/cm^2, V_{oc} = 0.55 V, FF = 0.575, and the cell structure is ITO/CdS/CIGS/Mo/SS. In addition, GSE has fabricated a lightweight, flexible CIGS module with a conversion efficiency of 8.29%. The improvement is mainly due to better uniformity of the absorber film over large areas and more precise control of CIGS stoichiometry over this area. GSE has collaborated with ITN/ES, the **Institute of Energy Conversion**, the **NREL CIS Team**, the **Measurements and Characterization group**, and the **National CIS R&D Team**. Further process optimization could result in lightweight, flexible, thin-film CIGS solar cell efficiency of 10.0% in the near future. In addition to applications for power packs for the **U.S. Army and Marines**, these flexible CIGS cells can be embedded in roof shingles. Contact: **Harin Ullal, 303-384-6486**

With the growing market for PV products attracting their interest, key business and technical members of **GE Central Research** recently visited **NREL**. In addition to obvious connections with power electronics (inverters, controllers) and hybrid systems (with diesel, natural gas turbines, etc.), GE is also interested in entering module production, using its manufacturing and high-technology capabilities. Research to date has caused GE to favor thin films as a higher-potential option for future multi-GW annual production. The visit included extensive discussions on all aspects of PV. At the conclusion of the meeting, GE stated its appreciation for the **DOE/NCPV Program** for "developing new technologies that GE could pick and choose among for further development." Contact: **Ken Zweibel, 303-384-6441**

On a recent visit to the **NCPV**, **First Solar** staff brought **NREL** management up to date on the progress of introducing CdTe modules in large volume. Specific issues were discussed concerning their multi-MW plant in Toledo, OH. Through the **Thin Film PV Partnership National CdTe R&D Team**, First Solar maintains a focus group that supports the transition to first-time manufacturing. In addition, they have close collaborations with NREL's **Characterization and CdTe Teams**. These collaborations were discussed, and plans were developed for further technical collaborations focusing on feedback control of manufacturing processes. NREL's **Xuanzhi Wu**, who (with the CdTe Team) is the current world-record holder in CdTe cell efficiency (16.5%), presented material on cell efficiency, an innovative way to manufacture CdTe modules, and a recent invention for replacing the conventional thin CdS heterojunction. The remainder of the meeting concerned policy issues. First Solar believes that PV can play an anti-terrorism role by significantly upgrading the robustness of the

(Continued on page 11)

Subcontracts

Subcontracted research with universities and industry, which is often cost-shared, is an important part of NREL's PV Program. From October 2000 through September 2001, we awarded more than $24 million to 184 new and existing subcontracts. Examples are listed below.

Colorado School of Mines, Golden, CO
Studies of Basic Electronic Properties of CdTe Solar Cells

Colorado State University, Fort Collins, CO
Device Physics of Thin-Film Polycrystalline Solar Cells

Colorado State University, Fort Collins, CO
Stability, Yield, and Efficiency of CdTe PV Devices

Spectrolab, Inc., Sylmar, CA
High Efficiency, Low Cost III-V Concentrator PV Cell and Receiver Module

University of Central Florida, Orlando, FL
CIGSS Thin Film Solar Cells

University of Delaware, Newark, DE
Processing, Materials, Devices and Diagnostics for Thin Film PV

University of Florida, Gainesville, FL
Identification of Critical Path in the Manufacturing of Low-Cost High-Efficiency CGS/CIS Two-Junction Tandem Cells

University of Illinois, Champaign, IL
$Cu(In,Ga)Se_2$ Heterojunction Solar Cells for Extreme High Efficiency Photovoltaic Concentrators

University of South Florida, Tampa, FL
Development of a II-VI Based High Performance, High Band Gap Device for Thin Film Tandem Solar Cells

University of Toledo, Toledo, OH
High Efficiency and High Rate Deposited Amorphous Silicon-Based Solar Cells

University of Toledo, Toledo, OH
Fabrication and Physics of High-Efficiency CdTe Thin Film Cells

Washington State University, Pullman, WA
Alternative Buffer Layers and Device Mechanisms in CIS-Based Solar Cells

Xantrex Technology, Inc., Vancouver, British Columbia
PV Inverter Products Manufacturing and Design Improvement for Cost Reduction and Performance Enhancement

Publications

Research papers, technical reports, and patents are one of NREL's most valuable contributions to the PV community. NREL researchers and subcontractors publish some 300 papers annually in scientific journals and conference proceedings. Listed below are a few examples (see ***www.nrel.gov/publications*** *for more). When possible, we choose publications that relate to articles in the current issue.*

R.K. Akrenkiel, R. Ellingson, W. Metzger, D.I. Lubyshev, W.K. Liu. "Auger Recombination in Heavily Carbon-Doped GaAs," *App Phys Lett*, 78(13), 2001, 1879–1881.

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The **Thin Film Partnership** began its subcontract recompetition in early FY 2001 with a Letter of Interest mailed to more than a hundred recipients. Reviews were completed in June, and a competitive range was developed in July 2001. With the substantial help of the NREL Subcontracts Administrator, **Vicki Riddell**, we have now awarded the first two of about 35 potential contracts, meeting our AOP Key Milestone for August 2001. The first two 3-year subcontracts were made to universities (**Colorado State University** and **University of Toledo**) for work to support CdTe and CIS development. Numerous other contracts are in various phases of negotiations and will be awarded in September-December 2001. Contact: **Ken Zweibel, 303-384-6441**

The **University of Delaware's Institute of Energy Conversion** (IEC) achieved a 16.9% efficiency for a thin-film solar cell using a new Cu(InAl)Se_2 absorber layer in place of the Cu(InGa)Se_2 layer in other high efficiency chalcopyrite-based solar cells. **NREL** confirmed that the co-evaporated thin-film solar cell prepared at the IEC reached 16.9% efficiency (V_{oc} = 0.621 V, J_{sc} = 36.0 mA/cm^2, FF = 75.5%, cell area = 0.471 cm^2). This cell constitutes a world-record efficiency for this aluminum-alloy absorber and shows that IEC continues to be a global leader in $CuInSe_2$ and other thin-film solar cells. Research at IEC on Cu(InAl)Se_2 is being done in collaboration with **Global Solar Energy** and **ITN Energy Systems** under a **NIST Advanced Technology Program**. IEC's role in the program, to develop the technology for a wide-bandgap Cu(InAl)Se_2 solar cell that could be used in a tandem solar cell, has drawn from its expertise and capabilities developed as a Center of Excellence supported by NREL and the **Thin Film PV Partnership**, and opens a new avenue toward the goals of the **High-Performance Photovoltaic Program**. Contact: **Bolko von Roedern, 303-384-6480**

Three new collegiate teams have been selected to compete in the 2002 **Solar Decathlon** in Washington, D.C., based on the review and acceptance of their proposals to the Solar Decathlon RFP. The new teams are: **University of Delaware, Auburn University,** and **University of North Carolina—Charlotte**. As with the original 11 teams accepted to the competition, each new team will receive $5,000 to begin their Solar Decathlon project. The Solar Decathlon is a national collegiate competition to design and build the most efficient and attractive 100% solar-powered house. The Solar Decathlon will involve architecture and engineering students in the design and construction of residential solar energy applications. In late September 2002, each team will transport its home to Washington, D.C., and erect it on the National Mall, temporarily transforming the Mall into a bustling community of solar-powered homes. Teams will have several days to assemble their modular homes before the judging begins. Each 500-square-foot house must have sufficient solar energy for heating and cooling, must have hot water for cooking and washing clothes, and must generate electricity for lights, appliances, computers, and an electric car. The winning entry will blend aesthetics and modern conveniences with maximum energy production and optimal efficiency. All entries will test a variety of skills and disciplines, and the entries will be judged on a number of criteria including: design, space heating, space cooling, lighting, communications, hot water, refrigeration, appliances, transportation, and presentation. Student teams from the following 11 schools were previously selected to participate in the Solar Decathlon:

Carnegie Mellon University, Pittsburgh, PA
Crowder College, Neosho, MO
Texas A&M, College Station, TX
Tuskegee University, Tuskegee, AL
Virginia Tech, Blacksburg, VA
University of Colorado at Boulder, Boulder, CO
University of Maryland, College Park, MD
University of Missouri—Rolla, Rolla, MO
University of Puerto Rico—Mayaquez, Mayaquez, PR
University of Texas at Austin, Austin, TX
University of Virginia, Charlottesville, VA

Contact: **Cecile Warner, 303-384-6516**

News at Press Time

Contreras' Work among the Most Cited

Science Watch keeps track of the most frequently cited publications in all areas of science (e.g., medicine, chemistry, physics). In the publication's September/October 2001 issue, an article authored by Miguel Contreras and colleagues within the National Center for Photovoltaics at NREL made the top ten list of "What's Hot in Physics." The article "Progress Toward 20% Efficiency in Cu(In,Ga)Se_2 Polycrystalline Thin-Film Solar Cells," was number seven on the list and originally appeared in *Progress in Photovoltaics*. So far, the article has 95 citations, but this number is still growing. "The reason for the strong interest in my work is because the efficiency is the highest reported for thin films, which are now established as serious competitors for silicon," said Contreras. He is honored to make the list, "not only because it is an impartial evaluation of my work, but because it also reflects on the quality of the research here at NREL." Contact: **Miguel Contreras, 303-384-6478**

NCPV Lauded for Advancement of Power Technologies

The National Center for Photovoltaics received three awards from the Office of Energy Efficiency and Renewable Energy's Office of Power Technologies (OPT) 2000 Research and Development Awards Program. This is the first year for these awards. They are intended to recognize the exceptional talent working to advance OPT technologies. Several of the DOE National Labs and Operations Offices submitted nominations for the awards. The three award categories are Research Leadership, Young Investigator(s), and Research Partnerships. NCPV staff, Yanfa Yan and Tihu Wang, received two of the five Young Investigator Awards. The Thin Film PV Partnerships project, involving NREL's Ken Zweibel, Harin Ullal, and Bolko von Roedern, received a Research Partnerships Award. Zweibel said that the entire Partnership team, in-house as well as subcontractor, contributed to the worthiness of this award. An award ceremony will take place at DOE on December 13. Contact: **Ken Zweibel, 303-384-6441**

Boost the Investment, Continued from p. 7

and light trapping, selective emitters, and front and back passivation on low-cost materials. Some funding should be used for silicon feedstock research and thin-film silicon. Research on copper indium diselenide (CIS) cells would also benefit from a boost in funding.

Angus Rockett, PV Principal Investigator, Professor of Materials Science, University of Illinois

We would do three things. First, we would hire an electron microscopist postdoc or two, or bring in a senior microscopist on sabbatical, to conduct highly detailed measurements of CIS solar cell materials to learn what distinguishes a good material from a poor material at the atomic scale. This would include studying the atomic-scale structure of good and bad devices to learn what makes a good device good. Second, we would improve our solar cell fabrication and testing facilities so that we could produce our own devices quickly and efficiently. Finally, we would take the time to do the detailed and fundamental studies of materials and devices from a range of laboratories, which we have not had the luxury to do recently.

Increased funding would affect advancements in solar research dramatically. Solar cells are poised for major advances in impact and industry scale. Significant advances at this point will accelerate technology deployment, increase the rate at which manufacturing volumes rise, and increase the profitability of fledgling companies. Strong basic research will provide the foundation for industry success in both the near and long term.

Industry Activity, Continued from p. 8

U.S. electric utility grid. This would be done through distributing power production to the user, rather than centralizing it in large, but vulnerable, facilities (as is done today). In addition, the growth of natural gas as the fuel of choice in the U.S. electricity production will lead to eventual shortages, price spikes, and new imports (via LNG), which will add to our foreign dependence. PV deployment would minimize this need for new natural gas. First Solar will be working on these issues and will present its views to the federal government (including **DOE**) in the near future. Contact: **Ken Zweibel, 303-384-6441**

The **DOE Five-Year PV Program Plan** lists a milestone in 2001 to "assess viability of dye-sensitized solar cells." An assessment report meeting this milestone was recently completed and sent to DOE. The assessment reviews the work of more than a dozen of the world's leading researchers in the field, and is based on a framework developed by the Netherlands Agency for Energy and Environment (Novem). The report concludes that the dye solar cell has the potential for becoming a cost-effective means for producing electricity, capable of competing with available solar electric technologies and, eventually, with today's conventional power technologies. But it is a relatively new, and therefore high-risk, technology and faces many hurdles on the path to commercialization. The dye-sensitized solar cell is a nonconventional solar electric technology that gained the attention of the photovoltaic community with the appearance of a 1991 publication in *Nature*. Many governments, including the United States, consider it to be good policy to support high-risk technologies having the potential to compete with more mature technologies. Another policy consideration is the demonstrated interest of private industry, both in the United States and abroad. At least five companies have worked on or expressed interest in developing the dye cell technology. **DuPont** recently received a **Beyond the Horizon** award for developing a solid-state electrolyte for the dye solar cell. In another show of interest for the technology, Xcel Energy, a large public utility, recently awarded $0.9 million over 3 years to Don Selmarten's group at NREL for dye-cell R&D. With these policy considerations met, the results of the Novem assessment, the excellent research taking place worldwide, and the relatively small U.S. funding allocated for this technology, the report concludes with the recommendation to increase government support for further research and development of the dye-sensitized solar cell technology. The report will soon appear in the international journal, *Renewable and Sustainable Energy Reviews*. Contact: **Robert McConnell, 303-384-6419**

NREL and **Siemens Solar Industries** (SSI) were recently honored at the annual awards banquet of the **Federal Laboratory Consortium** (FLC). They were selected for the 2001 **Outstanding Technology Development Award in Environment** as a result of R&D on "Caustic Waste Reduction and Material Recovery in Photovoltaics Manufacturing." This work was performed under the **Photovoltaic Manufacturing Technology Project** (PVMaT) as part of the SSI subcontract, entitled "Specific PVMaT R&D on Siemens Cz Silicon Product Manufacturing." The two organizations were represented by **Ed Witt**, Project Leader for Photovoltaics Manufacturing R&D at the National Center for Photovoltaics at NREL and **Theresa Jester**, Director of Engineering and Development for SSI. The award was described in the FLC summary provided at the presentation: "The U.S. photovoltaics (solar cell) industry is a rapidly growing sector, in response to the need for alternative energy sources, particularly in third-world countries. Silicon solar cells dominate the market and are produced using wire saws to slice silicon ingots into individual wafers. A slurry mixture of silicon carbide and oil is used in the process and a mixture of caustic chemicals is employed in the cleaning and etching of the wafers. The National Renewable Energy Laboratory and Siemens Solar Industries have developed a technique for reprocessing the oils and solvents to reuse the vital materials and reduce the caustics in the waste stream. The results have been dramatic: in two years, the amount of caustic wastes entering the environment has been reduced by nearly 80%." Contact: **Ed Witt, 303-364-6402**

PV Calendar

April 1–5, 2002. *MRS Spring Meeting*. Sponsor: Materials Research Society. Location: San Francisco, CA. Contact: *www.mrs.org/meetings/spring2002/cfp*

April 22–April 26, 2002. *International Conference on Metallurgical Coatings and Thin Films—ICMCTF 2002*. Sponsor: Advanced Surface Engineering Division of the American Vacuum Society. Location: San Diego, CA. Contact: *www.vacuum.org/icmctf/icmctf.html*

May 17–25, 2002. *29th IEEE Photovoltaics Specialists Conference*, Location: New Orleans, LA. Contacts: John Benner, 303-384-6496, or Dr. Rajeewa Arya, 757-566-8770. Web site: *www.ieee.org/pvsc*

May 19–22, 2002. *First International Conference on Solar Electric Concentrators (in conjunction with the 29th IEEE Photovoltaic Specialists Conference)*. Location: New Orleans, LA. Contact: Robert McConnell, 303-384-6419 or bob_mcconnel1@nrel.gov.

June 15–20, 2002. *Solar 2002, Sunrise on the Reliable Energy Economy*. Organizer: American Solar Energy Society. Location: Reno, Nevada. Contact: *www.solarenergyforum.org*

August 6–9, 2002. *5th International Meeting on Electrochromism*. Location: Golden, Colorado. Contact: Megan Maguire, 303-275-4321.

This quarterly report covers solar electricity research and related activities from NREL, Sandia National Laboratories, and their partners within the National Center for Photovoltaics (NCPV). These partners include the DOE University Centers of Excellence for Photovoltaics at the Georgia Institute of Technology and the University of Delaware's Institute of Energy Conversion, and the Regional Experiment Stations at the Florida Solar Energy Center and the Southwest Technology Development Institute.

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