2000 and Beyond: Our Time to Shine

Last June, 44 intrepid souls met in Chicago for the U.S. PV Industry Roadmap Workshop. They represented industry, academia, and government research programs. There were no crystal balls on the premises, but those in attendance pooled their expertise and looked 20 years into the future, setting a target for where the U.S. PV industry wanted to be at that time—and what it needed to do to get there. Of course, they didn't always agree on strategies.

The *PV Industry Roadmap* that came from the workshop and earlier gatherings is profiled in this issue. The roadmap focuses on developing the PV market here at home—and doing that will enhance business for everybody. Naturally, this includes PV manufacturers, but it also includes integrators, installers, and distributors. The latter three groups stand to benefit greatly from a steady stream of domestic business.

The roadmap shows decision-makers in Congress and the Executive Branch that the PV industry takes its mission seriously. And once the potential of the PV industry is understood—once it's clear that its success is concomitant with cleaning up the environment, creating domestic jobs, and securing an onshore energy supply—then federal support for PV technologies will cease to be a partisan issue. Poll after poll shows that the average citizen understands this already. The general public wants solar energy, and the PV Roadmap is all about making that happen.

Another important document described in this issue is the *National Photovoltaics Program Plan*, also called the five-year plan, which will be distributed in January, 2000. This plan was built here at NREL, with input from the PV community as in past years. But it's shorter, with enhanced graphics and design to better communicate the Program's ideas and plans. The goals are clearly stated, the R&D milestones are definitive. With the level of feedback we received—and applied—every step of the way, we are confident that the plan will serve as a relevant and measurable guide for the Program.

The *PV Industry Roadmap* and the *National Photovoltaics Program Plan* are complementary, with the former charting a course for PV to command a larger share of the energy market, and the latter detailing the R&D accomplishments needed to make that journey possible. Together, they describe how the PV community and its stakeholders can make the upcoming century "our time to shine."

NREL PV

Working With Industry

Third Quarter, 1999

Features

Departments

The PV Roadmap Leads Us Home

An Editorial by Allen Barnett

AstroPower/PIX08370

Allen Barnett is President of AstroPower, Inc., which is currently the largest U.S.-owned PV manufacturer and fifth largest in the world. Active in PV research and development since 1975, Barnett pioneered the development and manufacture of thin, crystalline silicon solar cells on low-cost substrates. He holds thirteen patents and has received six R&D 100 awards for new industrial products. He serves on the Solar Energy Industries Association Board and on the National Center for Photovoltaics Advisory Board.

Contact Allen Barnett at 302-366-0400 x166

The photovoltaic solar market continues to be robust, with the fastest growing segment being grid-connected applications. These applications are projected to grow at 40% per year over the next five years. Unfortunately, most of the present growth comes from Europe and Japan.

In Europe, the will of the people has rapidly translated into favorable government policy, particularly in Germany and Switzerland and more recently in the Netherlands and Spain. The primary driver is concern for the environment. In Japan, concern for the environment and the desire for energy independence drive the policy.

For the U.S. PV industry to sustain itself globally, it must have a substantial domestic market, particularly for grid-connected applications. And while we've seen improvements in this arena, we're still grappling with market barriers relating to electric utility regulation and tax policy. One reason that Congress has not yet resolved these issues is the lingering skepticism about whether solar electric power can supply a significant amount of energy to meet demand.

We in the PV community know that it can. *The PV Industry Roadmap demonstrates that there is a clear path to providing 15% of the new electricity generating capacity expected to be required in the United States in 2020.*

Providing this capacity requires only the type of support that any emerging industry needs to penetrate an established market. For example, net metering legislation has been enacted in 30 states, which is good, but it also means that there are now thirty different sets of regulations that the PV industry and utilities must contend with. The federal government must step in to homogenize the state net metering laws so that PV technologies can plug into the grid as easily as telephones, an area in which Congress also mandated national interconnection standards.

Tax policy is the most unfair situation, because the lion's share of incentives goes to conventional energy industries, which are mature technologies in mature markets. Intangible drilling costs, depletion allowances, and special treatment on coal royalties are just a few examples of costs that amount to billions of dollars worth of tax subsidies per year.

Consider some of the incentives provided to just one industry—nuclear energy. Many of the present U.S. plants are being sold at $0.05 or less for every $1.00 of value on the books. The new owners, freed of the capital cost, can now produce low-cost electricity in competition with renewables and other fully taxed forms of electricity. Who paid for the $0.95 of lost capital value? The answer is the U.S. taxpayer, who paid for much of that in increased federal, state, and local taxes. This tax "benefit" to the nuclear industry will cost tens of billions of dollars. To add insult to injury, the nuclear industry is currently lobbying for two proposed tax law changes that will lead to an increased taxpayer burden of more than $1 billion over the next ten years.

In the meantime, the emerging solar electric industry has asked for a five-to-ten-year residential investment tax credit that's levelized at $50 million per year. Even this small amount would provide great incentives—but it has not been approved.

Clearly, some incentives for the solar electric power industry are in order. Congress is not driving new, clean domestic energy technologies for several reasons, including: (1) lack of technical expertise by a significantly smaller group

Continued on page 10

PV Web Sites

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

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

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

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

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

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

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

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

The PV Roadmap
Accelerating the Growth of U.S. Industry

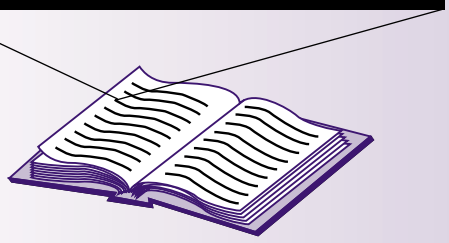
As far as anyone knows, the sun will still be shining on January 1, 2000. And if that's the case, PV systems within the United States will still be producing some 150 megawatts of electrical power. But the U.S. PV industry and the broader PV community want more.

How much more? A document called the *PV Industry Roadmap* spells it out. The goal is "For the domestic photovoltaic industry to provide up to 15% (about 3,200 megawatts) of new U.S. peak electricity generating capacity expected to be required in 2020."

Developing a national PV strategy is imperative. It's clear that the U.S. edge in solar-electric RD&D, once so strong as to seem unassailable, is growing softer by the year. Foreign governments and industries have seized on the strategic and economic importance of PV technologies—recognizing them as highly marketable commodities for an electricity hungry world. The U.S. *must* respond in kind to maintain its international leadership position.

There's much at stake. PV is an emission-free electrical generation technology that is critical to our nation's energy security, strategic technology, and long-term economic growth. As a "distributed" generation source, this technology acts as a network, making it much less susceptible to large-scale outages. PV mitigates our dependence on foreign energy supplies, while providing distinct benefits to the domestic economy.

Photovoltaic Industry Roadmap *n* (1999) **1** : a detailed plan, culminating in 2020, to guide PV technologies in capturing an ever-increasing share of the domestic and international energy market **2** : a set of strategies to implement that plan developed by representatives from industry, academia, and the national laboratories **3** : a new approach for the PV industry—one that borrows from other successful, high-tech industries in their transitions to mass production and commercialization.



Delivering the Goods

The roadmap focuses on putting the domestic PV industry in the position to deliver U.S. citizens the clean solar energy they're clamoring for… in a form that's both affordable and reliable. And this PV industry—now on the threshold of mass production and commercialization of technologies so vital to the national interest—needs a map to guide the process. Otherwise, where will all the solar-grade silicon come from? How about the skilled labor pool needed to fabricate PV cells… the integrators and distributors to deliver product to the marketplace… the technicians to maintain the PV systems once installed? These are just a few of the questions that the roadmap seeks to answer.

This initial roadmap is evolving into a full roadmap to guide PV research, technology, manufacturing, applications, markets, and policy through 2020. The next step is to build details around the framework, specifying the short- and mid-term goals and objectives and the technology pathways to meet the long-term goals. The success in 2020 of achieving the vision and these goals will be a *hundredfold* growth—over 1999 levels—in domestic markets and the U.S. industry. The roadmap will set the stage for further ramping up of the use of this valuable renewable resource beyond 2020, providing significant portions of U.S. and world electricity generation by an environmentally clean, reliable, and competitive energy source.

The Starting Point

The need for a PV roadmap has long been recognized, but it's difficult to pin down when the formal process actually began. A good guess is July of 1997, when 45 members of the PV community met in Denver for the Workshop on PV Program Strategic Directions, sponsored by the National Center for Photovoltaics (NCPV). The group comprised representatives from private industry, utilities, academia, and the national labs—NREL and Sandia National Laboratories. This workshop ushered in the NCPV Advisory Board (see

Continued on next page

sidebar on page 5 for current board members) and the concept of Technology Development Areas, around which the roadmap is fashioned.

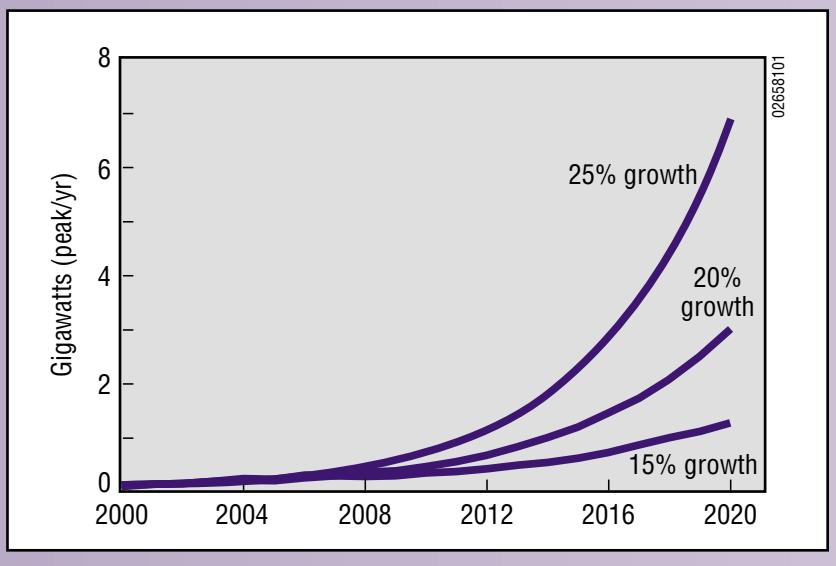
Roadmapping—and the need for a national PV strategy—were discussion topics at the first meeting of the NCPV Advisory Board, held in Denver in May of 1998. Later meetings of the board and other interested members of the PV community succeeded in building consensus for the goals and strategies of the roadmap.

Here's where the roadmap stands now. The vision, goals, projections, and major concepts or strategies have been agreed upon. The four strategies are to:

- Maintain the U.S. industry's worldwide technological leadership
- Achieve economic competitiveness with conventional technologies
- Maintain a sustained market and PV production growth
- Make the PV industry profitable and attractive to investors.

So important are these strategies that they merit some discussion. Maintaining U.S. technological leadership is deemed essential for both economic competitiveness in PV markets and for PV to reach its potential within the national energy portfolio. Sound and well-conceived programs, including both national lab and university participation, and *sustained* funding are critical to making that happen.

"The Vision is 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."



Whether the PV markets continue to grow at their historical rate (from 15% to 20% per year) or at the roadmap's accelerated rate of 25%, PV will provide the nation with a large amount of electricity by 2020. Under the roadmap scenario, half of U.S. PV production will be shipped to domestic markets at that time, supplying about 3.2 gigawatts, or 15%, of America's added generation capacity.

An ongoing strategy is to continue to expand the range of applications in which PV is cost-competitive with conventional technologies, with emphasis on grid-connected power systems. During the past 25 years, the cost of PV has come down by several orders of magnitude. Based on the actual cost of electricity at the point of use, current PV systems are within a factor of 2–2.5 for distributed generation such as residential rooftops. Enormous markets will open up for PV as this number achieves parity with conventional technologies.

The third strategy, maintaining a sustained market and PV production growth, will allow the industry to approach $10 billion per year—creating thousands of high-value jobs and enormous environmental benefits within the 20-year time frame of the roadmap.

None of the above can be realized without success of the fourth strategy. The aggressive growth of the PV industry outlined in the roadmap will require considerable private investment—and foundational funding is required now to make that happen. With this roadmap, the industry will be profitable, the investments of the private sector will be secured, and the nation will have an industry that clearly leads the world in production, deployment, technology, and domestic economic benefit.

Goals and Projections

The roadmap's goals relate to two major industry target areas:

- Total installed (annual) production capacity—This will be at least 6 gigawatts of power (GW_p) shipped worldwide by the U.S. industry during 2020, of which 3.2 GW_p will be used in domestic installations. The installed volume will continue to increase, exceeding 25 GW_p of domestic photovoltaics during 2030. In 2020, the cumulative installed capacity in the United States will be about 15 GW_p, or about 20% of the 70 GWp expected cumulative capacity worldwide.
- Costs—The cost to the end-user (including operation and maintenance costs) will be $3 per watt AC in 2010 and will approach $1.50 per watt AC in 2020. The total manufacturing costs are projected to be 60% of the costs of the system.

Half of U.S. production will be shipped to domestic markets by 2020. Most of this will be in building-integrated distributed resources, one-third in continued expansion of stand-alone applications, and, if the cost goals of $1.50 per watt AC are reached, one-sixth in grid-connected PV generating plants.

Achieving the Vision

The roadmap targets for industry and market expansion are very ambitious. A sustained growth rate of 25% per year will require large capital investments, continuous technology improvements, and rapid growth of profitable PV markets. Achievement of the goals will also require the coordination of many elements of the PV community.

The U.S. Photovoltaics Industry PV Technology Roadmap Workshop, held in June of this year in Chicago, was an important step in generating a full roadmap. The NCPV, on behalf of the PV Industry Roadmap Steering Committee, hosted 44 experts from the PV community—representing PV manufacturers, system integrators, and marketers, and electric utilities, universities, and research organizations—to develop the preliminary outlines for the *PV Industry Roadmap*. The three-day workshop addressed technology and market barriers, and research, marketing, and technology transfer needs of the entire PV industry. The core of the workshop was four facilitated breakout sessions, in which participants explored the primary barriers and needs in four technology development areas: (1) Markets and Applications; (2) PV Components, Systems, and Integration; (3) Manufacturing, Equipment, and Processes; and (4) Fundamental and Applied Research.

These technical and market barriers were divided into near-, mid-, and long-term needs, and the role of various segments of the PV community (e.g., private industry, academia, government support) in addressing these needs was discussed. Some themes and issues discussed in the final session of the workshop involved the need to:

- Identify potential PV end-users and high-value applications—particularly for domestic grid-connected applications.
- Significantly reduce installed system prices.
- Meet customer expectations in terms of performance and reliability.
- Make the value of PV systems readily apparent to potential end-users.
- Develop new building-integrated PV products that are attractive and easily integrated into new and existing buildings.

NREL/PIX08479

Robert Gay of Siemens Solar Industries (SSI) and Harin Ullal of NREL celebrating R&D 100 honors for SSI, the California Energy Commission, NREL, and the Thin Film PV Partnership team. Now and in the near future, as PV captures a larger share of the domestic energy marketplace, the partnership of industry and research laboratories will take on increasing importance. PV products, such as SSI's 12%-efficient thin-film modules, will be crucial to the success of the PV Industry Roadmap goals. The modules are based on copper indium diselenide and are just entering the commercial marketplace.

- Pursue opportunities to enhance the grid-connected market (e.g., tax and regulatory policy, standards, green marketing).
- Make grid-connected PV applications acceptable to the electric utility industry.

Good for Business, Good for Our Nation

As facilitator of the roadmap, the NCPV is fulfilling one of its mandates—"to serve as a forum and information source for the PV community." And the PV industry has responded eagerly, showing that it recognizes the importance of collaborative planning and R&D partnering to its future vitality—especially because no segment of the industry is currently large enough to guide the entire infrastructure and competitive investments on its own. The roadmap addresses the critical needs of PV technology, with a goal of ensuring U.S. industry leadership over foreign competitors and growing investments by their governments. And this is good for the business and economic interests of the United States.

Beyond this, the roadmap is a framework that can serve to develop strategic plans for investments in this technology and business—specifically as a U.S. strategic and national resource. And this is good for the people, environment, and security of the United States.

Contact: Larry Kazmerski at 303-384-6600

Who's Who among the Mappers

The NCPV Advisory Board, which includes representatives of major U.S. PV manufacturers, utilities, and universities, is currently serving as the PV Roadmap Steering Committee. Board members are:

- Allen Barnett, President, AstroPower
- Larry Crowley, President, Idaho Power
- Chester Farris, President and CEO, Siemens Solar Industries
- Harvey Forest, Chief Scientist and Past President, BP Solarex
- Lionel Kimmerling, Thomas Lord Professor of Materials Science and Engineering, and Director, Materials Processing Center, Massachusetts Institute of Technology
- Roger Little, President, Spire Corporation
- William Roppenecker, President, Trace Engineering
- Richard Schwartz, Dean, Schools of Engineering, Purdue University

The NCPV, led by Director Larry Kazmerski, is facilitating the development of the PV Industry Roadmap. Tom Surek, Roland Hulstrom, and John Benner of NREL and Chris Cameron and James Gee of Sandia have all been active in this process. Together, these individuals and organizations are drawing on the expertise of industry, the research community, and other interested parties to develop a strategic plan that will raise the level of financial and technical investment in PV technologies.

*Read the **PV Industry Roadmap** on the NCPV Web site at http://www.nrel.gov/ncpv/roadmap.html*

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

Crafting a Plan—to Guide Five Years o Photovoltaics R&D

But I was thinking of a plan
To dye one's whiskers green,
And always use so large a fan
That they could not be seen.

The white knight in *Through the Looking Glass*
By mathematician, logician, and author Lewis Carroll

The white knight worked in isolation and was nonsensical, as seemingly was everything in that looking-glass world. So he could make private plans with a private logic based on the whim of the moment.

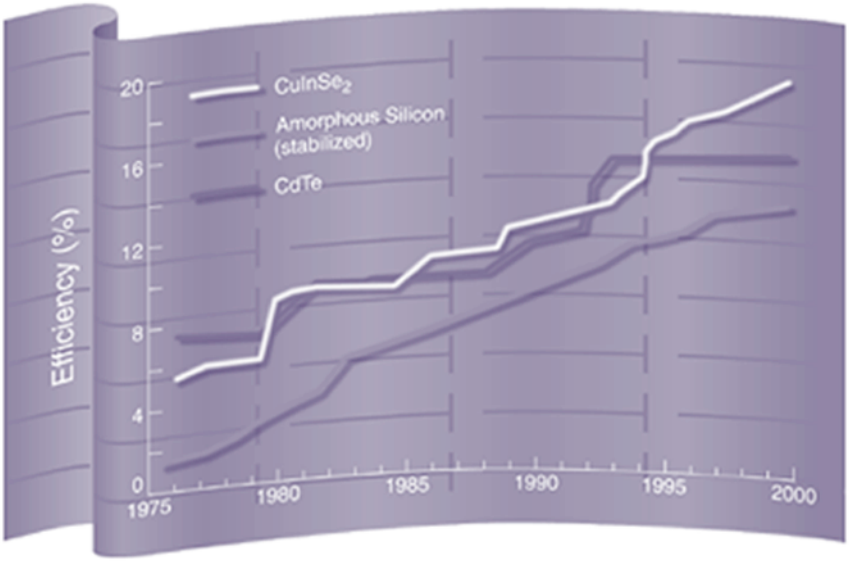
But we do not live in such a world. The *National Photovoltaics Program Plan* we print must reach out to everyone in the PV community and beyond. It must reflect reality as closely as is possible. And the community itself must have been involved with its evolution.

When we started the process of developing the plan, we were not sure that we could gather consensus from the community and still get the plan approved and printed by January 1, 2000. For we knew that the plan would have to be written, designed, and reviewed—and rewritten, redesigned, reviewed again, and approved—by the middle of October. And while this may seem like no big deal, it takes time to build consensus on goals and strategy in a plan that is of critical importance to the PV Program. It represents the strategy of how we're going to perform RD&D over the next five years, and it stipulates the milestones toward which we will strive. These considerations have tended to lengthen the production of PV Program plans to more than a year.

Until *now*, that is. Just eight months after initiating the project, we are ready to print. This is because everybody went the extra mile. Reviewers were quick to respond and project leaders from NREL and Sandia National Laboratories made themselves available for interviews. Jim Rannels of DOE emphasized the importance of making the process work well and work quickly. Richard King, also of DOE, gave the early and clear challenge to have the plan ready on January 1, 2000. The achievement is also due to the smooth efforts of the core NREL group, which first met on February 18th to kick off the effort. This core group consisted of Gary Cook, lead writer; Don Gwinner, key document coordinator; Alfred Hicks, graphic designer; and veteran PV planners, Bob McConnell and Jack Stone. We discussed what we wanted the five-year plan to say, how long it should be, the messages we wanted to include, how to get it done, and the long-term schedule.

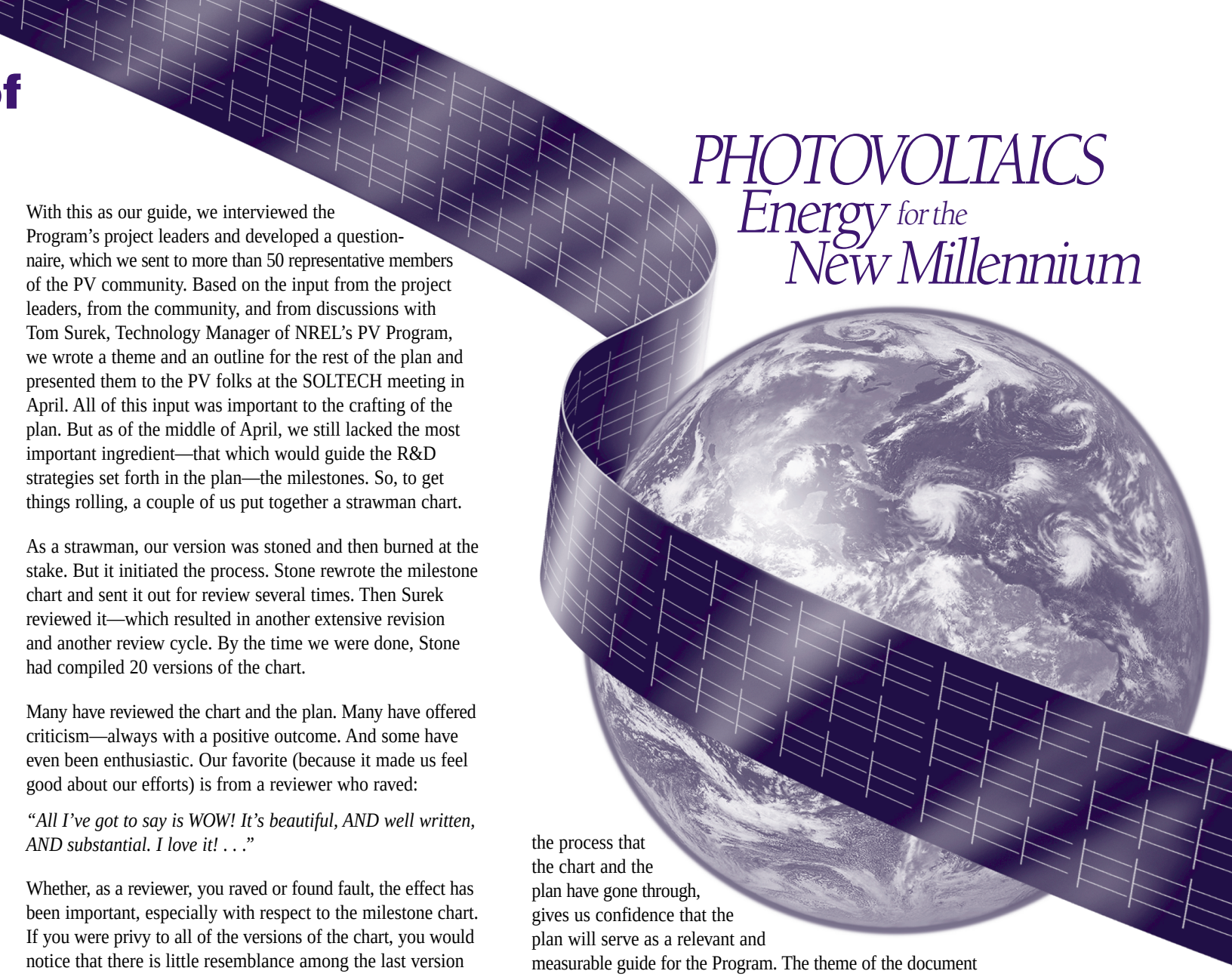
We decided, in light of the process, technology, market, politics, and the history behind the crafting of PV Program plans, that the plan must do several things:

- Have a theme that shows the importance of PV now and well into the next millennium
- Present the Program as a significant factor in the progress of photovoltaics and in America's energy strategy
- Represent the structure of the Program
- Build upon a broad base of input from the PV community
- Mesh well with the PV industry's 20-year roadmap, which was being crafted concurrently
- Be focused and easily readable
- Serve as a strategic document for the PV Program.



Since the inception of the PV Program's R&D on thin films, conversion efficiencies of cells have risen steadily, reaching a high of 18.8% for CIS (copper indium diselenide or $CuInSe_2$) cells, 15.8% for CdTe (cadmium telluride) cells, and greater than 12% for amorphous silicon (a-Si) cells. A milestone for 2001 calls for demonstrating a stable 13% a-Si cell, and one for 2002 addresses demonstrating a 17%-efficient CdTe cell.

PHOTOVOLTAICS *Energy for the New Millennium*



With this as our guide, we interviewed the Program's project leaders and developed a questionnaire, which we sent to more than 50 representative members of the PV community. Based on the input from the project leaders, from the community, and from discussions with Tom Surek, Technology Manager of NREL's PV Program, we wrote a theme and an outline for the rest of the plan and presented them to the PV folks at the SOLTECH meeting in April. All of this input was important to the crafting of the plan. But as of the middle of April, we still lacked the most important ingredient—that which would guide the R&D strategies set forth in the plan—the milestones. So, to get things rolling, a couple of us put together a strawman chart.

As a strawman, our version was stoned and then burned at the stake. But it initiated the process. Stone rewrote the milestone chart and sent it out for review several times. Then Surek reviewed it—which resulted in another extensive revision and another review cycle. By the time we were done, Stone had compiled 20 versions of the chart.

Many have reviewed the chart and the plan. Many have offered criticism—always with a positive outcome. And some have even been enthusiastic. Our favorite (because it made us feel good about our efforts) is from a reviewer who raved:

"All I've got to say is WOW! It's beautiful, AND well written, AND substantial. I love it! . . ."

Whether, as a reviewer, you raved or found fault, the effect has been important, especially with respect to the milestone chart. If you were privy to all of the versions of the chart, you would notice that there is little resemblance among the last version and the early versions. Every milestone has been changed. Even entire project categories have been changed.

When we started, for example, we had project categories such as Domestic Applications, International Applications, and Balance-of-Systems Components. These have been replaced or subsumed under other projects, such as Partnerships for Technology Introduction, and Manufacturing Research and Development.

And those categories that have remained have nonetheless gone through metamorphoses. The 2001 milestones for Thin Films, for example, changed from rather ambiguous milestones that spoke of assessing progress to succinct milestones whose success can be measured. To wit: "Demonstrate stable 13%-efficient a-Si cell" and "Demonstrate 20%-efficient polycrystalline thin-film cell."

In the final version, in fact, every project has a milestone for every year for the next five years—which is something that previous plans had never accomplished. Plus, the great majority of the milestones are specific and measurable. This, along with the process that the chart and the plan have gone through, gives us confidence that the plan will serve as a relevant and measurable guide for the Program. The theme of the document is that photovoltaics is the energy for the new millennium. We open with this theme, saying that we are taking steps toward a new energy frontier; we develop the theme by emphasizing that photovoltaics is good for our economy, our energy supply, our environment, and our future; we reaffirm the theme throughout the document and close with it in the epilogue.

We believe, with this theme and with this consensus on milestones, that the document is not only a planning document but also one that imparts vision and excitement. As such, the *PV Program Plan for 2000–2004* is something we can all live with and use. It is something that will not be hidden behind the white knight's "so large a fan." And it is something that depicts and guides reality and doesn't just reflect the unfounded desires of an isolated community.

For more information, contact Bob McConnell at 303-384-6419

The PV Program Plan will be posted on the NCPV Web site (http://www.nrel.gov/ncpv) on January 3, 2000.

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.

NREL's Outdoor Test Facility (OTF) has a new addition: a 100-watt AC module from **Evergreen Solar**. The AC module consists of two 56-watt modules made from Evergreen Solar's ribbon silicon material and one **Trace Engineering** MicroSine inverter. The AC module and inverter package is listed by Underwriters Laboratories and connects directly to the utility grid. The AC module will be monitored for long-term performance to help both Evergreen Solar and Trace Engineering understand the performance and reliability of their new AC module package. Contact: **Ben Kroposki, 303-384-6170**

Andrey Polisan and **Irina Persits** of **Sovlux** visited **NREL** in August. Sovlux is a joint venture of the Russian State organization **KVANT** and **Energy Conversion Devices** (ECD) of Troy, MI. In Moscow, Sovlux operates a line that produces triple-junction a-Si PV modules. NREL is supporting KVANT with two subcontracts under the Newly Independent States/Initiative for the Prevention of Proliferation Program. The first project is "Development of Next-Generation Building-Integrated Photovoltaic (BIPV) Modules." The second project, "Development of PV Gas Recycling Technology for Solar Cell Production," concerns recovering, repurifying, and recycling the unused gases from the effluent stream of an a-Si PV module manufacturing line. During their visit to NREL, Polisan and Persits delivered 10 small framed PV modules, 4 large BIPV roofing-type modules, and 3 foldable 12-volt power pack, recreational battery chargers for testing to determine their reliability and performance. In the course of developing BIPV modules, Sovlux has also developed a new lightweight encapsulation scheme for modules. The next important step is for Sovlux to demonstrate actual sales of its products. Contact: **Bolko von Roedern, 303-384-6480**

To help **BP Solarex** gain a better understanding of the performance and reliability of its new Millennia modules, **NREL** researchers have installed one of the company's 1.5-kW dual-junction a-Si PV systems on top of the **OTF** building. The array is integrated into the OTF's south-facing facade as a sunshade. It consists of 36 modules rated at 43 watts under Standard Test Conditions and is connected to the OTF's utility grid through a 2-kW Omnion 2400 series inverter. The system's performance is continuously monitored through a data acquisition system. Contact: **Ben Kroposki, 303-384-6170**

In August, **NREL's Bolko von Roedern, David Albin,** and **Ramesh Dhere** visited **First Solar** facilities in Perrysburg and Toledo, OH. First Solar invited the NREL researchers to discuss manufacturing challenges it faces in the new millennium, such as the manufacturing of significant commercial quantities of CdTe thin-film PV modules. Unforeseen problems may arise in the future when the company scales up its current prototype system to commercial size for a new manufacturing line, which would take additional time and resources to resolve. For now, First Solar is minimizing risk by sticking with processing schemes proven in a prototype manufacturing line.

NREL researchers presented material that should help First Solar gain a better understanding of CdTe fundamentals so it can produce better-performing modules under manufacturing conditions. Albin and Dhere gave a formal presentation on studies regarding various aspects of CdS/CdTe intermixing and on back-contact phenomena. The seminar was well attended and much appreciated by First Solar. The NREL team was also given a tour of First Solar's new R&D facility in Perrysburg, OH, which is functional and operating. Contact: **Bolko von Roedern, 303-384-6480**

In July, representatives of **BP Solarex**, Fairfield, CA, visited **NREL** to initiate a collaboration aimed at improving the performance of the company's CdTe module. The first phase will investigate whether vapor $CdCl_2$ processes in current use at NREL can be advantageously incorporated into the BP Solarex process. Both NREL and BP Solarex plan to perform chloride treatments and fabricate devices using their respective back-contact procedures. The study will require the fabrication of a large number of devices, with select chemical, structural, and optical characterization performed at various points in the process. The first phase of the collaboration should take about 2–3 months. **Dave Albin** of NREL's CdTe Team visited the company's Fairfield plant in August to finalize plans for the first phase and present a seminar on aspects of $CdCl_2$ processing of CdTe films at NREL. Contact: **Dave Albin, 303-384-6550**

NREL recently assisted **Energy Conversion Devices** (ECD), **Sovlux**, and **Global Solar Energy, Inc.** (GSE), in testing the performance reliability of their ethylene vinyl acetate (EVA) encapsulants. This included ultraviolet (UV) absorber analysis, cure processing, gel content analysis, and accelerated exposure tests (AET) of two Sovlux EVA formulations, a polymer substrate for an NREL/ECD Cooperative Research and Development Agreement (CRADA) project, and a Japanese-made Bridgestone EVA for GSE. The photo-

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 1998 through September 1999, we awarded 65 new subcontracts (examples listed below) and awarded more than $25 million to new and existing subcontracts. For further information, contact Ann Hansen (303-384-6492).

Pennsylvania State University (8/99–10/02)
Real-Time Optics for the Growth of Textured Silicon Film Solar Cells
$300,000

University of California, San Diego (6/99–8/02)
GaInNAs Structures Grown by MBE for High-Efficiency Solar Cells
$297,039

University of California, Santa Barbara (7/99–9/02)
Growth and Characterization of GaInNAs for High-Efficiency Solar Cells
$260,000

University of Illinois (6/99–8/02)
Medium-Range Order and Stability in Amorphous Silicon
$320,421

University of Oregon (7/99–9/02)
Novel Capacitance Measurements in Copper Indium Gallium Diselenide Alloys
$206,593

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).

Benner, J.; Deb, S.; McConnell, R., eds. *Workshop on Basic Research Opportunities in Photovoltaics: Proceedings of the Workshop Held in Conjunction with the 195th Meeting of the Electrochemical Society, 3 May 1999, Seattle, Washington*. August 1999, 108 pp. NREL/BK-590-26952.

Consumer's Guide to Buying a Solar Electric System. July 1999; 20 pp. NREL/BR-520-26591.

Culik, J.S., et al. *Silicon-Film™ Solar Cells by a Flexible Manufacturing System: Annual Subcontract Report, 16 April 1998–31 January 1999*. September 1999; 40 pp. NREL/SR-520-26834. Work performed by AstroPower, Inc., Newark, DE.

Kapur, V.K., et al., eds. *Photovoltaics for the 21st Century*, Proceedings Vol. PV 99-11, The Electrochemical Society, Inc. Seattle, Washington, Spring 1999.

Kroposki, B.; Hansen, R. "Performance and Modeling of Amorphous Silicon Photovoltaics for Building-Integrated Applications." Prepared for *Solar 99: Growing the Market, 12–17 June 1999, Portland, Maine*. March 1999; 7 pp. NREL/CP-520-25851.

Kurtz, S.R., et al. "Passivation of Interfaces in High-Efficiency Photovoltaic Devices." Prepared for the *MRS Spring Meeting, 5–9 April 1999, San Francisco, CA*. May 1999; 18 pp. NREL/CP-520-26494.

Li, X., et al. "Effect of Nitric-Phosphoric Acid Etches on Material Properties and Back-Contact Formation of CdTe-Based Solar Cells." *Journal of Vacuum Science and Technology A, Vacuum, Surfaces and Films*. May/June 1999; 17(3); pp. 805–809. NREL/JA-520-23550.

Marion, B., et al. *Validation of a Photovoltaic Module Energy Ratings Procedure at NREL*. August 1999; 97 pp. NREL/TP-520-26909.

McMahon, W.E.; Olson, J.M. "Atomic-Resolution Study of Steps and Ridges on Arsine-Exposed Vicinal Ge(100)." *Physical Review B, Condensed Matter*. 15 July 1999; 60(4); pp. 2480–2487. NREL/JA-520-26236.

McNutt, P., et al. *Procedures for Determining the Performance of Stand-Alone Photovoltaic Systems*. September 1999; 37 pp. NREL/TP-520-27031.

Moutinho, H.R., et al. "Investigation of Induced Recrystallization and Stress in Close-Spaced Sublimated and Radio-Frequency Magnetron Sputtered CdTe Thin Films." *Journal of Vacuum Science and Technology A, Vacuum, Surfaces, and Films*. July/August 1999; 17(4); pp. 1793–1798.

Sopori, B.L., Chairman. *Ninth Workshop on Crystalline Silicon Solar Cell Materials and Processes: Extended Abstracts and Papers of the Workshop, 9–11 August 1999, Breckenridge, CO*. August 1999; 236 pp. NREL/BK-520-26941.

Su, D.S.; Wei, S.H. "Transmission Electron Microscopy Investigation and First-Principles Calculation of the Phase Stability in Epitaxial $CuInSe_2$ and $CuGaSe_2$ Films." *Applied Physics Letters*. 26 April 1999; pp. 2483–2485.

von Roedern, B. "Advances in Photovoltaics at NREL." Presented at *SPIE's 44th Annual Meeting and Exhibition, 18–23 July 1999, Denver, CO*. September 1999; 14 pp. NREL/CP-520-26686.

University Corner

The PV industry sponsored the travel of four university graduate students to the *Ninth Workshop on Crystalline Silicon Solar Cell Materials and Processes*, held August 9–11, in Breckenridge, CO. The students are: **Sanjay Rangan, Pennsylvania State University; Ji-Weon Jeong, Georgia Tech; Kirk Babb, University of Arkansas, Little Rock;** and **Ayala Teicher, Carnegie Mellon**. The PV industry considers these travel awards an investment in the future because they provide an excellent opportunity for graduate students, who may someday be working in the industry, an to participate in workshop discussions among senior scientists with many years experience in PV research. Contributors to this award are: **AstroPower, Crystal Systems, EBARA Solar, Evergreen Solar, Siemens Solar Industries,** and **BP Solarex**. The workshop's theme was "R&D Challenges and Opportunities in Si Photovoltaics" and was attended by 102 scientists and engineers (including 18 international participants) working in the PV and microelectronics fields. The theme reflected the growing production challenges Si PV faces in the next century in developing strategies for cost reduction, increase in production, and dealing with new competition from CdTe and CIS technologies. With these challenges come new opportunities for Si PV to wean itself from the microelectronics industry and embark on an aggressive program in thin-film Si solar cells. A summary of the discussion sessions will be published in the near future. Contact: **Bhushan Sopori, 303-384-6683**

The **DOE Center of Excellence for Synthesis and Processing of Advanced Material**s held team meetings on Next Generation Photovoltaics and Thin-Film Silicon in Breckenridge, CO, on August 7–8, prior to the Crystalline Silicon Workshop. Two new members joined the team: **Sergei Ostapenko** from the **University of South Florida** and **Bob Birkmire** from the **University of Delaware Institute of Energy Conversion**. **NREL's Satyen Deb**, who coordinates high-efficiency photovoltaics for the Center of Excellence, presented an overview of the Industry Advisory Committee meeting and the objectives of the Center. This was followed by 19 technical presentations: nine on next-generation PV (described in more detail in the next item) and ten on silicon thin films. A very lively discussion ensued in the afternoon following each topical area, and there was a great deal of interaction among the team members. Contact: **Satyen Deb, 303-384-6405**

Another important meeting was held prior to the Crystalline Silicon Workshop—that of **DOE's Basic Energy Sciences (BES) Next-Generation Team**. Attendees included a range of III-V nitride experts from NREL, NREL-subcontracted universities, BES-funded activities, and **Sandia National Laboratories**. The meeting's presenters searched for explanations as to why III-V nitride material does not have good minority-carrier lifetime properties for use as a third junction in a 40%-efficient, four-junction solar cell. Among the university participants were **Venky Narayanamurti, Harvard University**, who gave a fascinating description of how ballistic electron emission microscopy and spectroscopy would be used to explore the III-V nitrides. **Hongxing Jiang, Kansas State**, presented collaborative work (with NREL and Sandia) on time-resolved photoluminescence studies. **Don Wolford**, **Iowa State**, described his early III-V nitride studies beginning as early as the 1960s. It is expected that beneficial collaborations will continue within this team. The next Next-Generation Team meeting is tentatively scheduled in conjunction with the NCPV Review meeting in the spring of 2000. Contact: **Bob McConnell, 303-384-6419**

Editorial, Continued from p. 2

of legislators than in other industrialized countries, (2) low energy prices, which have created a lax view of the need for a new domestic option (3) lack of environmental parties (as in Europe) or climate change concerns (as in Japan), thus less impetus to change the status quo, and (4) lack of contact with the public on these issues. This last issue is particularly important, because respected national polls have shown that the general public overwhelmingly supports solar development and commercialization more than any other clean energy or conventional energy source.

The public and our industry deserve a level playing field. The public purpose should be directed toward emerging technologies such as photovoltaics that can make a major impact on the quality of life in the United States.

To help fulfill that public purpose, the *PV Industry Roadmap* stresses the importance of making our industry profitable and attractive to investors. This *must* be a cornerstone of our plan. I believe that the way to do that is to trumpet something for which we can justifiably be proud—the sustained and steady progress of PV research, development, and deployment. We're on solid ground here. Investors require the security of solid ground. They get nervous when reading about one PV breakthrough after another because it conveys the impression that our technologies are not quite "ready." The "breakthrough du jour" mentality is bad for business and misleads the public.

Forget the *coulds* and *mights*. We sell reliable products *right now*. These products provide great value to our customers. We've worked hard to get where we are, and we're standing on strong legs. Let's emphasize that.

In this issue, you'll read more about the *PV Industry Roadmap* and the soon-to-be released *PV Program Five-Year Plan*. I ask you to pay close attention to both of these documents. As members of the PV community and people who thrive on the clean air associated with renewable energy, we must recognize that these documents are vital to our business and personal futures.

Industry Update, Continued from p. 8

thermal and thermal stability of these EVA formulations were compared with two commercial EVA formulations (A9918 and 15295) and an NREL-developed EVA-V11 formulation. The NREL/ECD CRADA project, which was funded by the Newly Independent States/Initiative for the Prevention of Proliferation Program, provided support for NREL's use of a part-time temporary technician. This allowed Russian scientists to review the performance reliability of their encapsulants and polymer substrates and improve those materials. The work also helped the PV manufacturer GSE in understanding better the performance reliability of Japanese-made EVA and evaluating whether to use the materials on their PV module encapsulation. Contact: **John Pern, 303-384-6615**

For almost 3 years, **NREL** has been working to get a patent for its EVA formulations for PV module encapsulation. This fall, it finally happened. The NREL EVA formulations, which began in 1992 under the management of **Dick DeBlasio** and were completed in 1996 under the leadership of **Al Czanderna**, show superior photo-thermal stability against UV induced discoloration compared with the two commonly used commercial EVA formulations (A9918 and 15295). The new EVA formulations are expected to improve substantially the performance reliability of PV modules to avoid the so-called "EVA browning crisis" reported in 1990 for modules using commercial EVA formulations. If UV-filtering Ce-glass is used as the superstrate, the long-term performance durability can be enhanced greatly. This patent will add a new item to NCPV's intellectual property portfolio—one that could prove quite valuable to PV and polymer films manufacturers. Contact: **John Pern, 303-384-6615**

About 35 people representing academia, NREL, and the thin-film PV industry attended the 12th National CIS R&D Team Meeting held October 11–12 at the **NREL Visitors Center**. Closed-door meetings were held on the first day by the following industry lead subteams: **Energy Photovoltaics** (EPV), **Global Solar Energy** (GSE), **International Solar Electric Technology** (ISET), **Siemens Solar Industries** (SSI), and **UNISUN**. On the second day, the subteam leaders gave presentations: EPV introduced a new buffer layer to potentially replace the chemical bath deposition (CBD) CdS layer; GSE reported that an average 8% efficiency was achieved across a 50-foot polyimide flexible web, but that stainless-steel substrates appear to be more promising because they can withstand a higher processing temperature; ISET discussed the inclusion of S and Ga into its CIS absorber layers and the effects of composition and stoichiometry; SSI reported that CBD CdS and ZnO deposited at NREL and SSI on SSI CIGSS absorber layers had the same transient effects and thus point toward the CdS CIGSS interface for future research; and UNISUN told the group it had achieved a 11.7% NREL-verified, small-area cell efficiency and 5.0% for a mini-module. The discussions during these sessions were candid, and many ideas were presented for future national team meetings. The next meeting will be held in conjunction with the NCPV Review Meeting at the Adam's Mark Hotel, April 16–19, 2000. Contact: **Harin Ullal, 303-384-6486**

Sixty-six participants from the PV industry and research laboratories, including **NREL** and **Sandia National Laboratories**, attended a 4-day workshop called *Setting a Standard for PV Performance and Reliability*, which focused on testing, test methods, evaluation, and standards. The workshop, held in Vail, CO, October 18–21, covered module performance rating, module qualification testing, power processing, and systems evaluation. Discussion topics included potential new projects and the need to revise published standards or develop new standards for project authorization requests (PARs). The workshop included three additional topical meetings on lead-free solder for PV modules, ASTM solar simulator considerations, and PowerMark Corporation system certification and module performance testing. Several PARs were revised and some new ones were established. Among the participants were **AstroPower, Arizona State University, ASE Americas, BP Solarex, Brookhaven National Laboratory, DayStar Technologies, DOE, EBARA Solar, ENLOG, Florida Atlantic University, Florida Solar Energy Center, Global Solar Energy, NREL, PV Inter-national, PowerMark, Pulse Energy Systems, Sandia, Siemens Solar Industries, Sacramento Municipal Utility District, Spire, STR, Southwest Technology Development Institute, TerraSun, Trace Technologies, Underwriters Laboratories,** and the **Utility PhotoVoltaic Group**. Contact: **Peter McNutt, 303-384-6767**

PV Calendar

February 7–11, 2000, *1st International Conference on Microelectronics and Interfaces*. Sponsor: American Vacuum Society. Location: Santa Clara, CA. Phone: 212-248-0200. Web site: *www.vacuum.org/icmi/cfp.html*

April 10–14, 2000, *The International Conference on Metallurgical Coatings and Thin Films*. Sponsor: American Vacuum Society. Location: San Diego, CA. Phone: 212-248-0200. Web site: *www.vacuum.org*

April 16–19, 2000, *16th NCPV Photovoltaics Program Review*. Sponsors: NREL, SNL. Location: Adams Mark Hotel, Denver, CO. Contact: Camilla Course. Phone: 303-275-4321.

April 19–22, 2000, *SOLTECH 2000: The Annual Solar Energy Conference*. Sponsor: Solar Energy Industries Association. Location: Washington, DC. Web site: *www.seia.org/main.htm*

April 24–28, 2000, *Materials Research Society Spring 2000 Meeting*. Sponsor: MRS. Location: San Francisco, CA. Web site: *www.mrs.org/meetings/spring00*

May 1–5, 2000, *16th European Photovoltaic Solar Energy Conference and Exhibition*. Location: Glasgow, Scotland, UK Contact: Jenniy Gregory, Secretary General, The British PV Association. Phone: +44.118.932.4418. E-mail: PVUK@itpower.co.uk. Web site: *www.wip.tnet.de/pv00.htm*

May 14–19, 2000, *197th Meeting of the Electrochemical Society, Symposium J1–Thin Film Solid State Energy Devices*. Sponsor: ECS. Location: Toronto, Ontario, Canada. Contacts: R.D. McConnell. Phone: 303-384-6419. Or V.K. Kapur. Phone: 310-216-4427. Web site: *www.electrochem.org/meetings/197/meet.html*

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. Web site: *www.wrenuk.co.uk/menu.html*

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*

This quarterly report encourages cooperative R&D by providing the U.S. PV industry with information on activities and capabilities of the laboratories and researchers at NREL.

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