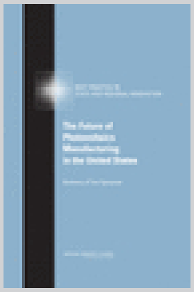

The Future of Photovoltaic Manufacturing in the United States

ISBN
978-0-309-14214-4

288 pages
6 x 9
HARDBACK (2011)

Charles W. Wessner, Rapporteur; Committee on Competing in the 21st Century: Best Practice in State and Regional Innovation Initiatives; National Research Council

The Future of Photovoltaics Manufacturing in the United States

Summary of Two Symposia

Charles W. Wessner, Rapporteur

Committee on Competing in the 21st Century:
Best Practice in State and Regional Innovation Initiatives

Board on Science, Technology, and Economic Policy

Policy and Global Affairs

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

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This study was supported by: Contract/Grant No. DE-AT01-06NA26358, TO #28, between the Department of Energy and the National Academy of Sciences. This report was prepared by the National Academy of Sciences under award number SB134106Z0011, TO #4, from the Technology Innovation Program of the National Institute of Standards and Technology (NIST), U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of NIST or the U.S. Department of Commerce. This report was prepared by the National Academy of Sciences under award number 99-06-07543 from Economic Development Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the Economic Development Administration or the U.S. Department of Commerce. Additional funding was provided by The Heinz Endowments, Acciona Energy, Dow Corning Corporation, IBM, SkyFuel Inc., and the Association of University Research Parks. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number-13: 978-0-309-14214-4
International Standard Book Number-10: 0-309-14214-8

Limited copies are available from Board on Science, Technology, and Economic Policy, National Research Council, 500 Fifth Street, N.W., W547, Washington, DC 20001; 202-334-2200.

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu.

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Contents

Preface

The global economy is characterized by increasing locational competition to attract the resources necessary to develop leading-edge technologies as drivers of regional and national growth. One means of facilitating such growth and improving competitiveness is to foster more robust innovation ecosystems through the development of public-private partnerships, industry consortia, and other regional and national economic development initiatives.

Many U.S. states and regions have developed programs to attract and grow companies as well as attract the talent and resources necessary to develop a knowledge-based economy. These state and regionally based initiatives have a broad range of goals and, increasingly, include significant resources. They often have a sector-based focus and, in many cases, are developed in partnership with universities and private foundations.

However, there has been little or no recent analysis of the role of these innovation partnerships. Despite the growing importance and growth of state and regional programs, relatively little is known about their goals, mechanisms, funding levels, accomplishments, and complementarities with federal programs.

STATEMENT OF TASK

An ad hoc committee, under the auspices of the Board on Science, Technology, and Economic Policy (STEP) is conducting a study of selected state and regional programs in order to identify best practices with regard to their goals, structures, instruments, modes of operation, synergies across private and public programs, funding mechanisms and levels, and evaluation efforts. The committee is reviewing selected state and regional efforts to capitalize on federal and state investments in areas of critical national needs. This review includes both efforts to strengthen existing industries as well as specific new technology focus areas such as nanotechnology, stem cells, and energy in order to gain an improved understanding of program goals, challenges, and accomplishments.

THE CONTEXT OF THIS REPORT

Since 1991, the National Research Council, under the auspices of the Board on Science, Technology, and Economic Policy, has undertaken a program of activities to improve policymakers' understandings of the interconnections of science, technology, and economic policy and their importance for the American economy and its international competitive position. The Board's activities have corresponded with increased policy recognition of the importance of knowledge and technology to economic growth. New Growth Theory in economics also emphasizes the role of technology creation as a driver of local and regional growth.[1]

Recent economic analysis also suggests that high technology is often characterized by increasing rather than decreasing returns, justifying to some the proposition that governments can capture long-term advantage in key industries by providing relatively small, but potentially decisive support to bring regionally based industries up the learning curve and down the cost curve. In part, this is why the literature now recognizes the relationship between technology policy and trade policy.[2] Recognition of these linkages and the corresponding ability of governments to shift comparative advantage in favor of the state, regional, and national economy provide the intellectual underpinning for government support at all levels for high-technology industry.

STEP seeks to bring new insight to bear on issues of national interest though its analyses of specific industries and technologies.[3] The Board's research addresses both demand and supply side realities, the contribution of R&D partnerships, and efforts to enhance U.S. competitiveness. This approach is of particular relevance to current initiatives to create and/or reinforce clusters of firms able to

[1]Developed in the 1990s, New Growth theories highlight the role of innovation as the main driver for economic development, with the implication that policies that embrace openness, competition, change and innovation will promote growth. See Paul M. Romer, "Endogenous technological change," *Journal of Political Economy* October 1990. Also see Gene M. Grossman and Elhanan Helpman, "Endogenous innovation in the theory of growth," *The Journal of Economic Perspectives* 8(1):23–44, 1994.

[2]J. A. Brander and B. J. Spencer, "International R&D rivalry and industrial strategy," *Review of Economic Studies* 50:707–722, 1983, and "Export strategies and international market share rivalry," *Journal of International Economics* 16:83–100, 1985.

[3]National Research Council, *Innovation in Global Industries: U.S. Firms Competing in a New World*, J. Macher and D. Mowery, eds., Washington D.C.: The National Academies Press, 2008. This report follows a previous review of U.S. industrial performance by STEP. See National Research Council, *U.S. Industry in 2000: Studies in Competitive Performance*, D. Mowery, ed., Washington, D.C.: National Academy Press, 1999.

meet new needs and contribute to improved U.S. competitiveness and the creation of high-value employment in the United States.[4]

Public-private partnerships are increasingly recognized as important elements for the support of innovation-led growth because of their contribution to the commercialization of state and national investments in research and development. As documented by recent National Research Council analysis, technology partnerships can be critical to generating an environment supportive of technologies that can have economic benefits with regional and national impact.[5]

One important element of STEP's analysis concerns the growth and impact of foreign technology programs.[6] U.S. competitors have launched substantial programs to support new technologies, small firm development, and consortia among large and small firms to strengthen national and regional positions in strategic sectors. Some governments overseas have chosen to provide public support to innovation to overcome the market imperfections apparent in their national innovation systems.[7] They believe that the rising costs and risks associated with new potentially high-payoff technologies, and the growing global dispersal of technical expertise, underscore the need for national R&D programs to support new and existing high-technology firms within their borders.

Similarly, many state and local governments and regional entities in the United States are undertaking a variety of initiatives to enhance local economic development and employment through investment programs designed to attract and grow knowledge-based industries.[8] These state and regional programs and associated policy measures are of great interest for their potential impact on U.S. competitiveness.

STEP's project on State and Regional Innovation Initiatives is intended to generate a better understanding of the challenges associated with the transition of research into products, the practices associated with successful state and regional programs, and their interaction with federal programs and private initiatives. The project seeks to achieve this goal through a series of complementary assessments

[4]See Charles W. Wessner, *Growing Innovation Clusters for American Prosperity*, Washington, D.C.: The National Academies Press, forthcoming. See also Karen G. Mills, Elisabeth B. Reynolds, and Andrew Reamer, *Clusters and Competitiveness: A New Federal Role for Stimulating Regional Economies,* Washington, D.C.: Brookings, April 2008.

[5]National Research Council, *Government-Industry Partnerships for the Development of New Technologies*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2003.

[6]National Research Council, *Innovation Policies for the 21st Century*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2007.

[7]Most notably, a number of countries are investing significant funds in the development of research parks. For a review of selected national efforts, see National Research Council, *Understanding Research, Science and Technology Parks: Global Best Practices*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2009.

[8]For a scoreboard of state efforts, see Robert Atkinson and Scott Andes, *The 2008 State New Economy Index: Benchmarking Economic Transformation in the States,* Kauffman Foundation and ITIF, November 2008.

of state, regional, and federal initiatives; analyses of specific industries and technologies from the perspective of crafting supportive public policy at all three levels; and outreach to multiple stakeholders. The overall goal is to improve the operation of state and regional programs and, collectively, enhance their impact.

STEP MEETINGS ON PHOTOVOLTAIC MANUFACTURING

Gathering representatives from leading producers of photovoltaics, congressional staff, leading academics and industry analysts, and representatives from relevant government agencies, STEP convened two meetings, held in April and July 2009, to examine the future of the U.S. photovoltaic industry and the practical steps that the federal government and some state and regional governments are taking to develop the capacity to manufacture photovoltaics competitively. Drawing on the experiences of related industries, meeting participants explored the prospects for cooperative R&D efforts, standards, and roadmapping efforts that could accelerate innovation and growth of a U.S. photovoltaics industry.

This report captures the presentations and discussions of these two symposia on the future of photovoltaic manufacturing. It includes a common introduction and summaries of the presentations at both meetings. This workshop summary has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshops. The planning committee's role was limited to planning and convening the workshops. The statements made are those of the rapporteur or individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the National Academies.

ACKNOWLEDGMENTS

On behalf of the National Academies, we express our appreciation and recognition for the insights, experiences, and perspectives made available by the participants of the meetings. We are also grateful to John Lushetsky of the Department of Energy, John Fernandez of the Economic Development Administration, Marc Stanley of the Technology Innovation Program of the National Institute of Standards and Technology, and Christina Gabriel of The Heinz Endowments for their interest and support of this project.[9]

We are indebted to Alan Anderson for his preparation of the meeting summaries. Sujai Shivakumar prepared the draft introduction to this volume and David Dierksheide prepared the report manuscript for publication.

[9] As of July 2009.

NATIONAL RESEARCH COUNCIL REVIEW

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies' Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for quality and objectivity. The review comments and draft manuscript remain confidential to protect the integrity of the process.

I wish to thank the following individuals for their review of this report: Nancy Bacon, United Solar Ovonic and Energy Conversion Devices, Inc.; Robert Collins, University of Toledo; Stephanie Shipp, Institute for Defense Analysis; Richard Swanson, SunPower; and Cyris Wadia, Haas School.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the content of the report, nor did they see the final draft before its release. Responsibility for the final content of this report rests entirely with the author and the institution.

Charles W. Wessner
Rapporteur

I

OVERVIEW

Overview: Partnering for Photovoltaics Manufacturing in the United States

A. ADDRESSING THE RENEWABLE ENERGY CHALLENGE

The United States has entered a time of both urgency and great opportunity with respect to its energy generation. The urgency is driven by substantial national investments in renewable energy in the current economic downturn.[1] The urgency is also driven by a growing consensus that the United States spends too much on energy, uses much of it inefficiently, and must reckon with a "nexus of concerns" related to the impact of carbon-based energy on the environment, on national security, and on economic growth.[2]

In his keynote remarks at the National Academies symposium on the future of photovoltaics manufacturing in the United States, Senator Mark Udall of Colorado listed some of the advantages of more widespread use of solar technologies,

[1]William Branigin, "Obama lays out clean-energy plans," *Washington Post* March 24, 2009, p. A05.

[2]See National Academy of Sciences, *Electricity from Renewable Sources: Status, Prospects, and Impediments*, Washington, D.C.: The National Academies Press, 2010. See also National Research Council, *The National Academies Summit on America's Energy Future: Summary of a Meeting,* Washington, D.C.: The National Academies Press, 2008. Speaking at the National Academies Summit, Dr. Steven Chu noted that reliance on the dominant sources of energy being used today poses grave risks to humans. These "hidden costs" of damages from air pollution associated with electricity generation relying on fossil fuels, motor vehicle transportation, and heat generation alone has been estimated by the National Research Council at $120 billion in the United States in 2005. Not included in this figure are damages from climate change, harm to ecosystems, effects of some air pollutants such as mercury, and risks to national security. See National Research Council, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*, Washington, D.C.: The National Academies Press, 2009.

including new economic opportunities and improved national security.[3] For the economy, he said, solar energy would be able to create "millions" of new jobs and provide a key pillar of the economy for the twenty-first century. Solar energy would spur innovation, he said, and create "a pathway whereby we're producing clean energy in our country." From his perspective as a member of the Senate Armed Services Committee, he said, he saw the advantage of reducing the country's dependence on foreign oil. "We have to keep reminding ourselves," he said, "that this is a critical step."

National Renewable Energy Goals

In 2009, President Obama set a goal of deriving a quarter of energy used in the United States from renewable sources by 2025 (up from seven percent in 2007—see Figure 1) and, to this end, committed $59 billion from the economic stimulus package to clean energy projects and tax incentives and a further $150 billion over ten years to develop and deploy new energy technologies.[4] Elaborating on the President's goals, Under Secretary of Energy Kristina Johnson highlighted, in her symposium remarks, the objective of conserving 3.6 million barrels of oil within 10 years, reducing U.S. greenhouse gas emissions by 83 percent of 2005 levels by 2050, and the building a world-class workforce for a sustainable green economy.[5]

Energy from the Sun: The Photovoltaic Challenge

According to the National Academy of Engineering, fossil fuels are not a sustainable source of energy. Moreover, it has noted, "for a long-term, sustainable energy source, solar power offers an attractive alternative. Its availability far exceeds any conceivable future energy demands. It is environmentally clean, and its energy is transmitted from the sun to the Earth free of charge. But exploiting the sun's power is not without challenges. Overcoming the barriers to widespread solar power generation will require engineering innovations in several arenas—

[3]See the summary of Senator Udall's remarks, delivered in the symposium of July 29, 2009, in the Proceedings section of this volume.

[4]The American Recovery and Reinvestment Act of 2009 includes substantial new national investments in renewable energy, smart grid, transmission, advanced vehicles, energy efficiency, and many other aspects of energy, environment, climate, and sustainability. The $787 billion U.S. economic stimulus bill includes at least $59 billion in new spending and tax credits for the development and expansion of energy technology. The Obama Administration's $3.55 trillion budget proposal for fiscal 2010 calls for spending $150 billion over 10 years to promote clean energy and energy efficiency. It includes nearly $75 billion to make permanent a tax credit aimed at stimulating private-sector investment in research and development.

[5]See the summary of Under Secretary Johnson's remarks, delivered in the symposium of July 29, 2009, in the Proceedings section of this volume.

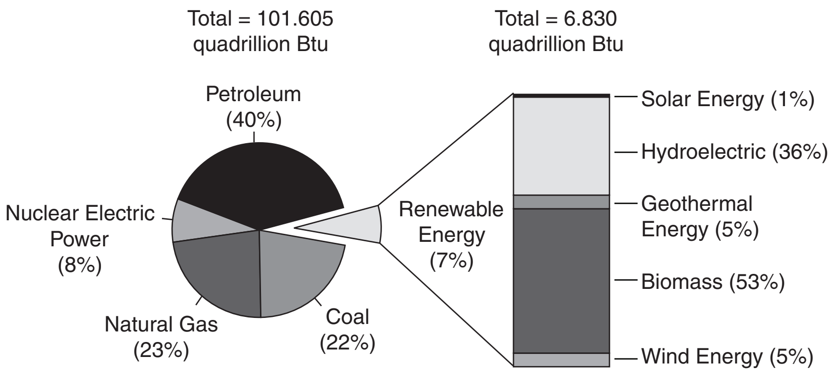

FIGURE 1 Solar energy in the U.S. energy supply (2007).
NOTE: Sum of components may not equal 100 percent due to independent rounding.
SOURCE: Energy Information Administration, *Renewable Energy Consumption and Electricity Preliminary 2007 Statistics*, Washington, D.C.: U.S. Department of Energy, Table 1: U.S. Energy Consumption by Energy Source, 2003-2007, May 2008.

for capturing the sun's energy, converting it to useful forms, and storing it for use when the sun itself is obscured."[6]

Solar power technologies can be divided into two main types: flat plates and concentrators. Flat-plate technologies include crystalline silicon and thin films of various semiconductor materials, usually deposited on a low-cost substrate, such as glass, plastic, or stainless steel, using some type of vapor deposition, or wet chemical process. Concentrator systems use only direct, rather than diffuse or global, solar radiation; therefore, their areas of best application (e.g., in the southwestern United States) are more limited than those for flat plates.[7] This report focuses on the future of photovoltaic cell manufacturing technologies in the United States.[8]

The PV Innovation Challenge

The challenge of exploiting the power of the sun will require innovative mechanisms to facilitate bringing affordable and practical technologies to market. To help address this challenge, the National Academies Board on

[6]National Academy of Engineering, *Grand Challenges for Engineering*, Washington, D.C.: The National Academies Press, 2008.

[7]For an extended description and the trade-offs, benefits, and costs of each type of solar technology, see National Academy of Sciences, *Electricity from Renewable Sources: Status, Prospects, and Impediments*, op. cit., pp. 77–92.

[8]The STEP Board, in 2008, convened a meeting on the challenge of concentrated solar power generation: "Making Big Solar Work: Achievements, Challenges & Opportunities," July 29, 2008.

BOX A
Photovoltaic Cell Technologies

When sunlight strikes the surface of a photovoltaic (PV) cell, some of the photons are absorbed and release electrons from the solar cell that are used to produce an electric current flow, i.e., electricity. A PV cell consists of "two or more layers of material designed for the dual functions of (i) absorbing light to generate free electrons and (ii) driving a current of those electrons through an external circuit. The absorbing materials can be silicon (Si), which is also used in integrated circuits and computer hardware; thin films of light absorbing inorganic materials, such as cadmium telluride (CdTe) or gallium arsenide (GaAs) that have absorptive properties well matched to capture the solar spectrum; or a variety of organic (plastic) materials, nanostructures, or combinations.

A wide range of PV technologies is now at various levels of development. Silicon flat-plate PV technologies are mature and actively deployed today. Reduction in the production cost of the cell and an increase in efficiency and reliability will make the silicon PV even more attractive to consumers. New technologies such as thin film, which has great potential to reduce the module cost, are in a relatively mature development stage, with further research and testing required to bring this technology into commercial production. Other competing technologies, such as dye-sensitized PV and nanoparticle PV are at an early stage of development, and commercialization will require much more technology development.

National Academy of Sciences, *Electricity from Renewable Sources*, 2010.[a]

[a]See National Academy of Sciences, *Electricity from Renewable Sources: Status, Prospects, and Impediments*, Washington, D.C.: The National Academies Press, 2010, pp. 54 and 59.

Science, Technology and Economic Policy (STEP) convened two symposia, held on April and July 2009, that examined the role that a government-industry-academia partnership for PV manufacturing can play in structuring, facilitating, and leveraging the multiple abilities and perspectives needed to increase PV efficiency and reduce costs. These meetings, whose proceedings are summarized in this volume, did not focus on the technical obstacles to the deployment of solar technologies. Instead, they examined how partnerships among government, industry, and academia can accelerate innovation in concentrated solar and photovoltaic (PV) technologies and help develop a robust market and manufacturing base in the United States.

This workshop summary has been prepared by the workshop rapporteur as a factual summary of what occurred at the workshops. The planning committee's role was limited to planning and convening the workshops. The statements made are those of the rapporteur or individual workshop participants and do not necessarily represent the views of all workshop participants, the planning committee, or the National Academies. A key feature of the meetings was to bring experts from national laboratories, representatives of leading firms, officials from the Department of Energy, and members of Congress and their staff. This introduction captures the key themes of both these symposia.

As several participants in the two symposia noted, successful technology partnerships among industry, academia, and government has many elements, including the sharing of experience and information, the joint assumption of risk, and ultimately successful insertion into commercial markets.[9] In particular, the development of roadmaps and agreements on technical standards through partnerships can enhance the PV industry's ability to assess and address technology obstacles, gaps, and opportunities.[10] As several participants at the National Academies symposia also pointed out, a partnership in the PV industry could support research more effectively through the provision of financial support, technical guidance, and performance evaluation. It could also support research directly through partners in government agencies and laboratories, universities, nonprofits, and industry.[11]

Part II of this introduction examines some of the major challenges facing the nation in realizing its goals for generating electricity from renewable sources. Part III reviews some of the challenges facing the PV industry in bringing new products to market. Finally, Part IV reviews how a PV industry research consortium can help accelerate the research and commercialization of PV technologies, drawing key lessons from the experience of the semiconductor industry in advancing collaborative research.

B. REGAINING U.S. LEADERSHIP IN RENEWABLE ENERGY

In her comments at the July 2009 symposium, Congresswoman Gabrielle Giffords emphasized how difficult meeting the nation's renewable energy objectives will be. According the Energy Information Administration of the Department of Energy, summer peak electricity use in the United States is around 780 GW. By the end of 2008, approximately 1 GW of solar PV had been cumulatively installed, including 342 MW installed that year. Assuming that all installed capacity would be available on peak, meeting just 20 percent of peak demand with PV would require a more than 150-fold increase in installed capacity.[12]

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[9]See, for example, remarks by Robert Margolis, summarized in the proceedings of the April 23, 2009, symposium, and Larry Sumney, summarized in the proceedings of the July 29, 2009, symposium.

[10]See, for example, remarks by Subhendu Guha summarized in the proceedings of the July 29, 2009, symposium.

[11]See the summary of remarks by Clark McFadden at the July 29, 2009, symposium in the Proceedings section of this volume.

[12]PV modules are generally most effective during summer peaks, when warm sunny afternoons lead to increased use of air conditioning. However, typical performance of a PV module, even under these near-ideal conditions, is less than 100 percent of its rated capacity.

Political Resistance at Home

One of the most daunting barriers, Representative Giffords said, is political resistance to investments in renewable energy. While oil and coal lobbyists have spent over $76 million during the first quarter of 2009 to advance their causes, the wind power lobby spent some $1.6 million, and SEIA, the solar energy lobbying effort, spent $410,000 over the same period. "This is what we're up against," she said. "I'm not putting this up so we can get discouraged, because obviously with few resources, the solar industry has made tremendous strides. But now we have to figure out how to get this technology out there and installed and making a difference for our country and our world." To do this, she urged that supporters of renewable energy should "organize, advertise, and educate."

Policy Support and Increased Competition from Abroad

The United States enters the twenty-first century renewable energy challenge from behind. It currently trails other nations in the manufacture and installation of PV modules. As Ken Zweibel of George Washington University pointed out, leading European and Asian nations have created incentives for the manufacture and installation of PV systems.[13] While there has not traditionally been a comparable coordinated approach in the United States to stimulate the growth of the PV industry, the 2009 American Recovery and Reinvestment Act has allocated $117 million to expand the development, deployment and use of solar energy throughout the United States.

Political action on a national level has proved crucial for the growth of PV markets in Europe where several national governments have obligated power utilities to buy renewable electricity at above-market rates. Illustrating this point, Subhendu Guha of UniSolar noted in his symposium remarks that Germany offers incentives ranging from 41 cents per kilowatt-hour to 51 cents/kWh. France offers about 40 cents/kWh and, for building integrated photovoltaic structures, they give about 70 cents/kWh.[14] These incentives work, he said, because they allow construction of large manufacturing plants. As these plants bring economies of scale, their costs come down.

Indeed, as Ken Zweibel pointed out, these incentives have, within a short period, led to a rapid growth in the demand for renewable energy technologies.[15] This demand, in turn, is attracting PV manufacturing and research to Europe and

[13] See the summary of Ken Zweibel's remarks, delivered at the April 23, 2009, symposium in the Proceedings section of this volume. See also Vasilis Fthenakis, James E. Mason, and Ken Zweibel, "The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US," *Energy Policy* 37(2):387–399, February 2009.

[14] See the summary of Dr. Guha's remarks, delivered at the July 29, 2009, symposium in the Proceedings section of this volume.

[15] See Mario Ragwitz and Claus Huber, "Feed-in systems in Germany and Spain: A comparison," Fraunhofer Institut für Systemtechnik und Innovationsforschung, 2005.

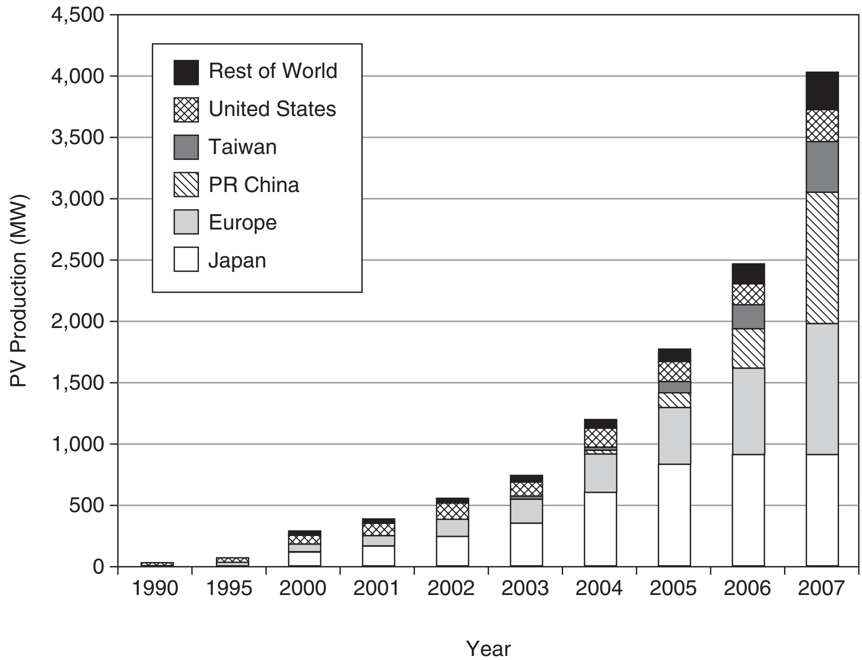

FIGURE 2 United States trails in manufacturing modules.
NOTE: World PV Cell/Module Production 1990-2007.
SOURCE: Arnulf Jäger-Waldau, *PV Status Report 2008*, EUR 23604 EN—2008, Joint Research Center, Luxembourg: Office for Official Publications of the European Communities, 2008, p. 5.

is creating new "green" jobs. According to Dr. Guha, Germany, which has traditionally been the auto capital of Europe, today employs fewer people in the auto industry than the PV industry, which has created 180,000 new jobs.

More recently, several Asian nations have made significant investments in renewable energy industries, funding research and development and setting ambitious targets for renewable energy use, outpacing the programs currently under consideration in the United States. For example, South Korea recently announced plans to invest about two percent of its gross domestic product annually in environment-related and renewable energy industries over the next five years, for a total of $84.5 billion. And India aims to install 20 GW of solar power by 2022, more than three times as much as the photovoltaic solar power installed by the entire world last year, the industry's best year ever. While an admittedly ambitious target, it reflects the Indian government's recognition of the long-term benefits and potential employment contributions of solar power.[16]

[16] See Vikas Bajaj, "India to spend $900 million on solar," *The New York Times* November 20, 2009.

Significantly, China's new stimulus plan raises the nation's 2020 target for solar power from 1.8 GW to 20 GW.[17] Calling renewable energy a strategic industry, China is also shielding its clean energy sector so that it can grow to a point where it has the capacity to export PV around the world. China has already built the world's largest solar panel manufacturing industry. While exporting over 95 percent of its PV output to the United States and Europe, China is also requiring that at least 80 percent of the equipment for its solar power plants be domestically produced.[18]

Declining U.S. Market Share in PV

This growing competition from abroad has led to a decline in the U.S. market share. See Figure 3. As Robert Margolis of the National Renewable Energy Laboratory noted in the symposium, the United States was in a commanding leadership role in the PV industry until the 1980s, with more than half of global PV production. By the 1990s, Japan had begun a program of incentives and quickly became the global market leader while the U.S. share dropped to the 30 to 50 percent range.[19]

According to Michael J. Ahearn of First Solar, Europe is likely to hold two-thirds of the world market by the end of 2009, the United States 10 percent, Japan 7 percent, and the rest of the world 17 percent.[20] On the supply side, he estimated that by year end Europe would have 30 percent of total manufacturing capacity, China 27 percent, Japan 12 percent, the rest of Asia 9 percent, the United States 9 percent, and the rest of the world 13 percent. In absolute terms, the estimated market by 2009 would be 5.6 GW versus existing and announced manufacturing capacity of 12.3 GW. "The numbers can be debated," he said, "but the basic message is right: There's a lot more manufacturing capacity in the world than there is demand. Absent some [policy] change, that's not going to correct itself."

Dick Swanson of SunPower observed that this shift in leadership away from the United States was consistent with the message that manufacturing and the technology need to follow the markets: If we want to have manufacturing in the United States, he observed, the United States has to be a market leader."[21] As

[17]See Steven Mufson, "Asian nations could outpace U.S. in developing clean energy." *Washington Post* July 16, 2009.

[18]See Keith Bradsher, "China builds high wall to guard energy industry," *International Herald Tribune* July 13, 2009.

[19]See remarks by Robert Margolis of the National Renewable Energy Laboratory in the Proceedings section of this volume.

[20]See the summary of Michael Ahearn's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

[21]See the summary of Dick Swanson's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

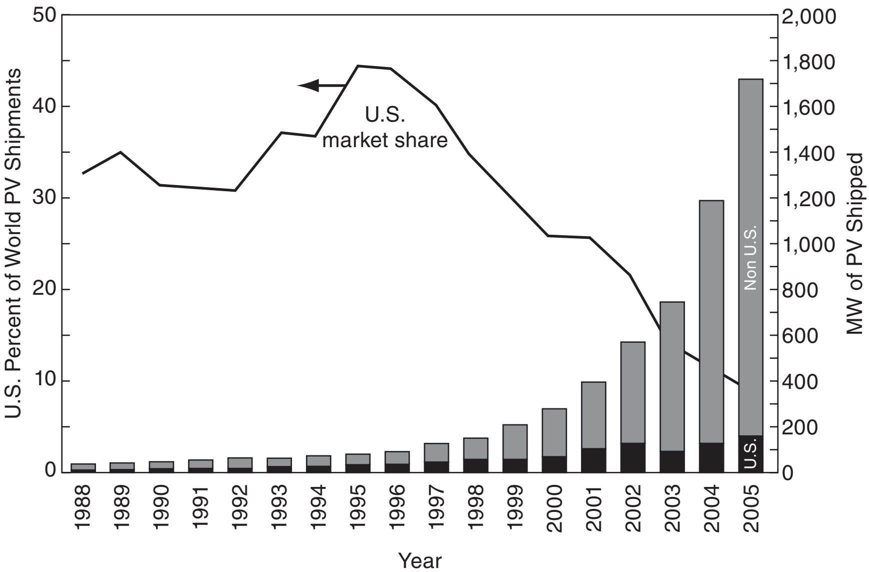

FIGURE 3 U.S. market share & world PV cell/module production (MW).
NOTE: The black curve and left (vertical) axis of the graph illustrate the relative portion the United States has contributed to annual world production. It is useful to note that world shipments increased to a record high of 1727 MW during 2005. The largest annual increase in U.S. production since data collection began—a 35 percent increase—occurred between 2003 and 2004. U.S. production reached a record of more than 153 MW in 2005.
SOURCE: National Renewable Energy Laboratory, 2009.

Ken Zweibel put it, "manufacturing will occur in the United States once we have adequate markets, unless something else drives or attracts it away."

C. CHALLENGES FOR PV MANUFACTURING

The future of PV manufacturing in the United States depends on both the supply of inputs into the manufacturing and installation process as well as the demand for PV technology. Participants at the National Academies symposia examined both sides of the challenge.

Addressing the Supply Side

A solar panel is made up of multiple components. For polycrystalline PV cells, the manufacturing process typically starts with highly refined polysilicon, which is grown into large single crystals, or ingots. Those ingots are sliced into wafers, which are used as solar cells that are laminated behind large glass panels

BOX B
Rising Private Investments in Renewable Energy Technologies

One bright spot for the future of the U.S. renewable energy industry is the surge in private investment over the past few years in solar technologies.[a] Just five or six years ago, private investment in PV was on the order of tens of millions of dollars. This figure has now risen to the scale of billions a year as venture capital and private equity markets have taken on significant new investments in thin-film technologies, multijunction, concentrated PV technologies, and other next-generation technologies (See Figure B-1). According to Robert Margolis of the National Renewable Energy Laboratory, "this has been a dramatic change and [is having] a very big impact on how the industry is organized, how it does R&D, and how it interacts with the government."

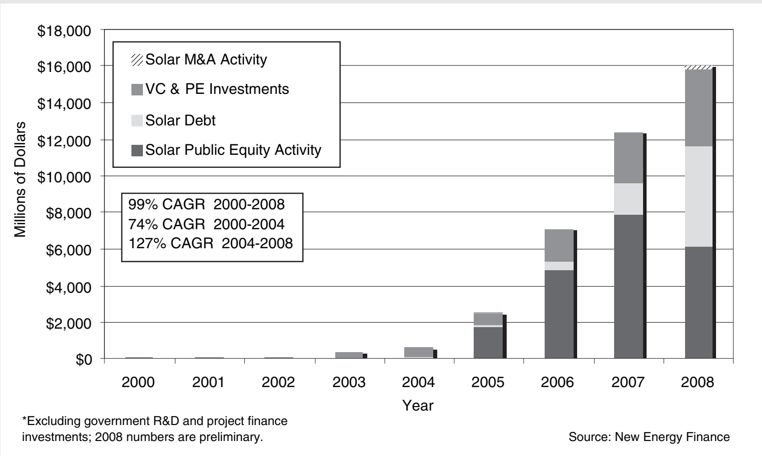

FIGURE B-1 Total historical global investment in solar energy.
SOURCE: Robert Margolis, NREL, presentation at the April 23, 2009, National Academies Symposium on "The Future of Photovoltaics Manufacturing in the United States."

[a]Dr. Margolis noted in his presentation at the April 23, 2009, symposium, that of about 200 companies that received private-sector investment in the past three years, more than 100 are in the United States. Firms in Asia have focused primarily on existing crystalline silicon technologies, with heavy investments in mono- and polycrystalline technologies, both in terms of research and in scale-up of production. See the full summary of his remarks in the Proceedings section of this volume.

and installed in a PV system. Such systems are heavy and somewhat challenging to install, so that the cost of installation is traditionally about 50 percent of the system cost. The weight, fragility, and large size often require that these panels be manufactured locally. The actual ingot is about 20 percent of the cost and the manufacturing and conversion into panels about 30 percent.[22]

Scaling Up to Lower Manufacturing Costs

Making PV panels that are efficient and competitively priced requires lowering manufacturing costs by making the production process more efficient. The PV industry's manufacturing costs have followed a steep downward trajectory, converging, according to NREL estimates, to about a dollar a watt produced by 2011 as manufacturing capacity expands sharply. See Figure 4.

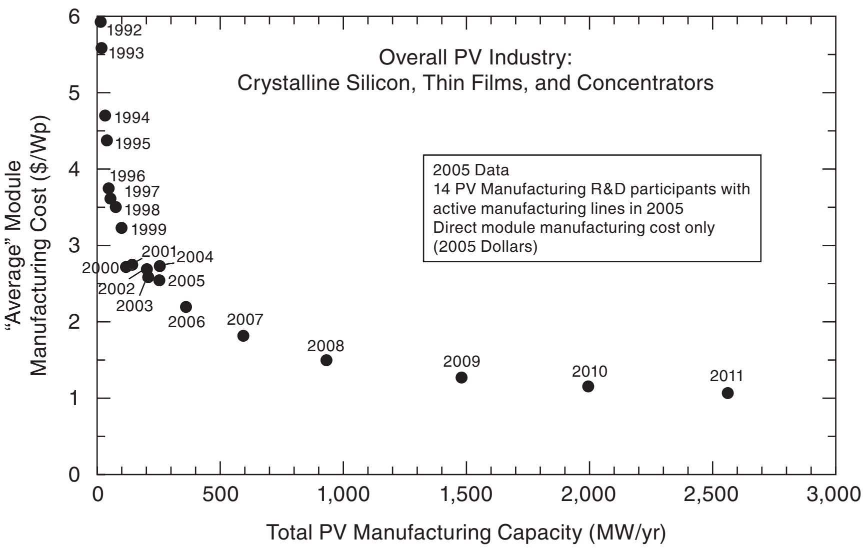

FIGURE 4 PV industry cost/capacity (DoE/U.S. industry partnership).
NOTE: The cost/capacity graph shows the 2005 data of 14 Project participants with active module manufacturing lines in 2005. The graph shows continued progress toward meeting the Project goals of decreasing direct costs of manufacturing and increasing production capacity. From the perspective of technology learning curves, these data reflect an average 17 percent drop in direct costs of manufacturing for every doubling of production capacity.
SOURCE: National Renewable Energy Laboratory.

[22] See the presentation by Dick Swanson at the April 23, 2009, symposium in the Proceedings section of this volume.

Key to realizing lower costs is automation of the production process. Michael Ahearn noted that although the up-front costs of production are high, the incremental or marginal cost of producing a photovoltaic panel is minimized through automation. At first, when production was low, the average cost of production was fairly high, he noted. However, as volume increases, lower incremental cost drives the unit cost down at a rapid rate. Likewise, Eric Peeters of Dow Corning noted that realizing operational excellence and economy of scale requires increased throughput or yield through automation and process innovation.[23]

Mark Pinto of Applied Materials added that factory scale has increased rapidly over the last few years.[24] In 1980, Arco Solar opened the world's first factory with a production line capacity of one megawatt per year and it took 20 years to reach a capacity of 10 megawatts per year. In the next few years there will be factories that can produce gigawatts of capacity, he predicted.

These new factories will be of an enormous scale. Dr. Pinto estimated that a one-gigawatt PV factory would consume 500 tons of glass a day, enough to cover seven and a half football fields. The plant would occupy a site the size of the Magic Kingdom in Disney World. "Making scale drives down the learning curve all by itself."

Also driving down costs is what David Eaglesham of First Solar called "manufacturing learning."[25] "This is boring for academics," he said, "but critical for an industry—just regular old learning, cranking the handle, grinding on continuous improvements. It's a key piece of why you want to stick with things that leverage existing production platforms."

BOX C
Investing in Improvements

"You don't get progress by waiting for a miracle. It's been constant investment. That's one theme we see across multiple industries. Nor do you get a pass if you just stay on the sidelines. This doesn't mean you should not invest in breakthroughs, but constant investment and manufacturing scale can make huge steps."

Mark Pinto, Applied Materials

[23] See the summary of Eric Peeters' remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

[24] See the summary of Mark Pinto's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

[25] See the summary of David Eaglesham's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

The Need for Standards

Along with a high degree of automation, world-class PV manufacturing also calls for improved efficiency and manufacturing standards. Eric Daniels of BP Solar noted that the design and standards for today's solar modules were developed early in the industry's development.[26] A manufacturer can choose to comply with these standards or not, but they are critical in building consumer confidence. In the past, the goal of the PV industry was watts, or "horsepower." Today, he said, the emphasis has to shift to efficiency—from horsepower to miles per gallon; from watts to watt-hours.

Eric Peeters similarly noted the need for improved efficiency and standards across the production process—from the conversion of raw materials to the installation of solar panels on rooftops. He added that because the PV industry is relatively young, industry standards are still evolving, with some standards in use adopted from the electronics, semiconductor, and construction industries. "We have a lot of work to do to ensure that a homeowner installing solar panel on the roof gets the right quality," he said, noting that "some new companies entering the market, especially from overseas, have uneven quality."

The National Institute for Standards and Technology mission is to "promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology." Kent Rochford, Acting Director of NIST's Electronics and Electrical Engineering Lab (EEEL), noted in his remarks at the July 2009 symposium that "to facilitate trade, the companies, vendors, and other participants have to agree on what a product is. Also, if you want to do efficient innovation, you have to be able to measure products throughout the R&D process so you can share results and perform reproducible engineering production and even reproducible research." Eric Lin, Chief of NIST's Polymer Division, said that his organization is working with the relevant parties to provide the infrastructure and scientific foundation for the measurements, and standards needed to support PV and other rising technologies.[27] The support for the PV industry, he said, stretches from the research and prototyping of new technologies and manufacturing concepts to support for later-stage R&D cooperation.

Developing the appropriate standards for an energy transmission system adapted to renewable energy is another major challenge. As Kent Rochford pointed out, a "Smart Grid" must permit the use of intermittent and renewable sources of energy. Elaborating on this point, Eric Daniels noted that a smart grid must develop a means to forecast the impact of weather and resultant change in energy output from the solar- and wind-based energy sources. A smart grid must

[26]See the summary of Eric Daniel's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

[27]See the summary of Eric Lin's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

be able to add solar power to the transmission lines, matching the availability of sunlight with variability in demand. When there is more PV power than needed, the excess can be stored; when there is less sun, a smart grid must be able to tap and deploy this stored energy.

Training Technical Talent

The future of PV manufacturing in the United States also calls for growing and sustaining technical talent in the United States. In her remarks at the July 2009 symposium, Under Secretary Kristina Johnson warned that "60 percent of the science and engineering workforce will retire in the next five years, and these are great-paying jobs. So this is a real national crisis." In his remarks at the April 2009 symposium, Dr. Peeters warned that a skills shortage across the value chain—from research to installation—could prove to be a bottleneck to the development of a robust solar industry in the United States.

Addressing the Demand Side

Fostering a vigorous PV manufacturing industry in the United States requires the interaction of both supply and demand factors. Participants in the National Academies symposia identified some of the conditions and incentives necessary to increase the demand for PV technology in the United States.

BOX D
Manufacturing Follows Demand for PV

"It is going to be impossible to create a U.S.-based domestic industry if there is no domestic demand. This must be stimulated at every level, from residential to utility scale."

Eric Peeters, Dow Corning

Achieving Grid Parity

To be competitive, PV generated power has to achieve grid parity, the point at which photovoltaic electricity is equal to or cheaper than power that can currently be purchased from the power utility. This cost parity has long been a PV industry goal.

PV generated power is already competitive with conventional electricity at peak usage times in some places. In his symposium presentation, Eric Daniels explained that most current PV systems were installed at a cost of about $8 per watt. Before rebates or incentives, he said, this translates into retail costs that are becoming

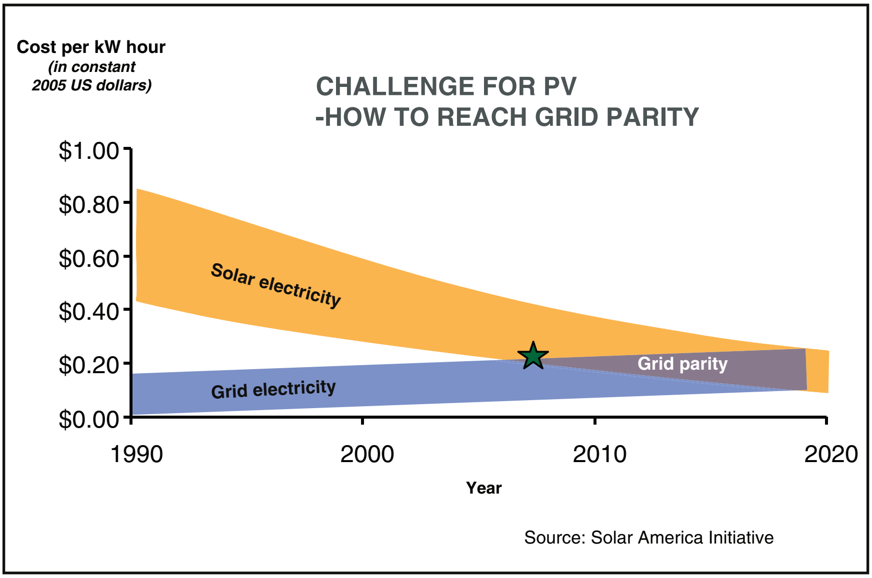

FIGURE 5 A forecast for grid parity.
SOURCE: Subhendu Guha, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

competitive with utilities. For example, for northern California, PG&E charges 35 cents per kWh during peak hours of the day; the retail amortized cost, before rebate, of PV power is about 20 cents. "So," he said, "the math is starting to work."

Subhendu Guha of UniSolar noted that the way to reduce the cost of PV is to work with the entire PV value chain. "You make the solar cell, and then you make the module, which is interconnected solar cells; then the PV array, for which you need inverters and other components to convert the DC solar electricity to AC current. Finally, you sell it to the customer," who wants to know the cost of installing a PV system on his or her roof, and how much electricity will be produced and at what cost over the next 20 years.

Flexible Financing Options for Consumers

Even with true grid parity, the high up-front costs and the long-term return of investing in photovoltaic systems remain a significant challenge in stimulating consumer demand for PV installations. As David Eaglesham of First Solar pointed out, both interest rates and the availability of financing are key determinants of end-user adoption.

To address this challenge, Mark Pinto suggested the creation of a clean energy bank for low-interest loans: He said that solar should be considered a capital good. "Even if you put it on your house, you have to lay out the money ahead of time. So in analyses when you see levelized cost of electricity, there's an assumed interest rate. If the prevailing bank interest rate is used, the economics of solar change dramatically. Using 8.5 percent, the rate of return of a utility, the levelized cost goes up significantly."

Increasing the durability of solar panels can also bring overall costs down. In his remarks at the April 2009 symposium, Eric Peeters noted that although the industry reports its output in peak watts, this is a theoretical measure, more often seen in the laboratory rather than on the rooftop. "What is really important," he said, "is how many kilowatt-hours you can get out of the lifetime of the panel, and how do you improve that. One of the most important things is to ensure that the module lives longer." Today the standard in the industry is that a PV module is guaranteed to maintain 80 percent of its rated power output for 20 or sometimes 25 years. He said that this standard of durability would have to be raised to 90 to 95 percent of the power output for 30 and 40 years through innovation across the PV supply chain.

Feed-in Tariffs

A feed-in tariff is an incentive structure that sets by law a fixed guaranteed price at which power producers can sell renewable power into the electric power network. The tariff obligates regional or national electricity utilities to buy renewable electricity (including electricity generated from solar photovoltaics) at above-market rates. The higher price helps overcome current cost disadvantages of renewable energy sources. By guaranteeing a price, feed-in tariffs encourage the supply of renewable energy and, in turn, the demand for PV equipment.

Given the significant costs of transporting and installing heavy glass PV panels, the manufacture of PV panels is often located close to the source of demand, spurring a domestic manufacturing industry. As David Eaglesham of First Solar noted, market location is driven not only by the decisions of regulatory agencies in each country, but also by the cost of freight, since glass products are heavy and expensive to ship. "For this reason," he said, "glass manufacturing is almost invariably done where it is going to be installed. I already have a barrier in importing [PV] product into Europe from Malaysia." By fostering demand, feed-in tariffs can encourage location of PV manufacturing near the home market.

In his April 2009 symposium presentation, Michael Ahearn noted that the rapid progress in adopting solar technologies in Europe was initially driven by the use of feed-in tariffs. With feed-in tariffs, producers are typically able to count on a market with predictable price points over a known number of years. Company managers and investors who build a factory and staff an organization know they will have time in the market to recoup that investment and perhaps earn a profit.[28]

Mr. Ahearn acknowledged that this approach can be a cost burden that cannot be sustained over a long period by utilities. He argued, however, that the cost-reduction trajectories now present in the industry should allow such tariffs to be reduced quickly and steeply, making feed-in tariffs a viable strategy to increase demand rapidly.

The impact of feed-in tariffs is reflected in current solar market shares. Drawing on a on a consensus of 10 analysts covering solar sector, Mr. Ahearn estimated in his presentation of April 2009 that Europe, where major nations have adopted feed-in tariffs, accounted for two-thirds of the estimated 5.6 GW market for solar technologies in 2009, while the United States, which has not adopted feed-in tariffs, accounted for only ten percent.

Tax Incentives

Steven O'Rourke of Deutsche Bank Securities observed that growing the U.S. solar PV industry requires that up-front costs to the consumer be reduced.[29] This can be achieved via several policy mechanisms, including investment tax credits or grants, accelerated depreciation, and state incentives.

Eric Peeters suggested that a combination of tax incentives for investment at residential level, along with a system of green certificates and electricity meters that can run in both directions, could drive growth in demand. Such incentives, he noted, led to the growth of the PV market in his native Belgium to close to 50 MW in 2008. Extrapolating this scale to the United States, he estimated that this would mean a market of 1.5 to 2 GW in 12 months. When sunlight conditions are taken into account, the United States would actually do much better than that. Every state in the United States, he said, has more sunlight than Belgium.

Mark Pinto noted that his company, Applied Materials, has many potential customers who would be willing to invest in PV factories if there were a sufficient market in the United States. They would not make money at the outset, he predicted, so that tax credits would be less helpful than refundable credits for investing in renewable energy.[30]

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[28] At least 64 countries now have some type of policy to promote renewable power generation. See Michael Ahern's presentation in the Proceedings section of this volume. Feed-in tariffs were adopted at the national level in at least five countries for the first time in 2008/early 2009, including Kenya, the Philippines, Poland, South Africa, and Ukraine. Renewable Energy Policy Network for the 21st Century, *Renewables Global Status Report 2009*, Paris: REN21, 2009, Accessed at <*http://www.ren21.net/globalstatusreport/g2009.asp*>.

[29] See the summary of Steven O'Rourke's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

[30] For an analysis of economic value of PV federal tax credits, see Mark Bolinger, Ryan Wiser, and Edwin Ing, "Exploring the Economic Value of EPAct 2005's PV Tax Credits," Lawrence Berkeley National Laboratory, 2006. Access at <*http://escholarship.org/uc/item/9xn145qf*>.

Broadening Public Awareness

Increasing the public's knowledge about PV and the financing of PV will be essential to grow consumer demand. At her presentation at the April 2009 symposium, Representative Gabrielle Giffords said that interest in solar was certainly spreading in her Arizona district. "We find that people are curious about solar, but they don't understand how it works—how tax credits work, how long they last. We have a 'Solar 101' course we do in conjunction with the Pima County Library, and the interest is tremendous. We need to get the message out to the consumer in our respective communities."[31]

D. ACCELERATING INNOVATION THROUGH COLLABORATIVE RESEARCH

Over the longer run, superior technical achievement is likely to be the key to the success of the U.S. photovoltaic industry. In his remarks at the symposium, John Kelly of IBM argued that energy output of PV panels could not be raised fast enough "through larger slices of glass or more efficient equipment; it has to be closed by leaps in technology. And then once that gap is closed, you cannot assume you can stand still there."[32] He added that the United States cannot compete against companies and countries outside the United States by relying primarily on lower labor costs or larger, more productive equipment. "You fight that through innovation," he said, and "you innovate faster than anyone else."

Some Models for Collaborative Research

Successful innovation is most often the result of highly collaborative processes that often blur the lines between basic and applied research and the development and commercialization of new technologies. Public-private partnerships, involving cooperative research and development activities among industry, universities, and government laboratories can play an instrumental role in accelerating the development of new technologies from idea to the market. A recent major study by the National Research Council found that these partnerships, when properly structured and privately led, contribute to the nation's ability to capitalize on its R&D investments.[33]

Participants at the July 2009 symposium described several models of cooperative research used to advance PV technology.

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[31]Representative Giffords participated in both National Academies symposia on the future of PV manufacturing in the United States.

[32]See the summary of John Kelly's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

[33]See National Research Council, *Government-Industry Partnerships for the Development of New Technologies*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2003.

Industry-University Collaborative Research Centers (I/UCRC)

Thomas Peterson of the NSF Directorate for Engineering noted in his presentation that the NSF places heavy emphasis on research that is both basic and has industrial and commercial potential.[34] Such research, he noted, is almost always interdisciplinary, involving primarily teams of universities, but also of companies and government agencies.

While the majority of NSF funding continues to support basic research, the I/UCRCs represent a means of emphasizing the application and commercialization of knowledge. The basic model for them, he said, was to enable discovery and innovation through collaboration. "The model works almost like a research franchise," he said. "The NSF seed money is small and intended to act as catalyst, while the foundation takes a supportive role throughout the life of the center. The I/UCRCs consist of one or several universities, but they are funded primarily by industry, and its Industry Advisory Committee is the critical component. It is a specific management and structural model with independent evaluation tools." Over the past two decades, the program has supported some 35 to 50 centers each year, with a total of about 100 sites throughout the country.

A specific example of I/UCRC, the Silicon Solar Consortium (SiSoC), consists of four universities (North Carolina State University, Georgia Tech, Lehigh University, and Texas Tech University), several national labs, and 15 industry partners. Its objective is to reduce costs and increase performance of silicon PV material, PV cells, and PV modules while developing novel breakthrough designs and processes.

Providing a university perspective, Jim Sites of Colorado State University noted that universities, after many years of focusing on fundamental contributions, were well positioned to contribute to manufacturing research needs and to the broader development of the PV industry.[35] He noted that while university research, even when directed towards specific problems of industry, must allow for the thorough exploration of fundamental questions that are encountered in the course of a project. Indeed, he noted that a collective approach to PV research problems involving universities, national labs, and industry has the potential to cross-fertilize and synthesize new ideas that may elude individual investigators, thus helping to advance the role of universities to advance foundational knowledge.

The MIT-Franunhofer Center

Another model for commercializing university research is the MIT-Fraunhofer Center for Sustainable Energy Systems. Begun fifteen years ago, the Center is an alliance between the two research institutions based in Cambridge,

[34] See the summary of Thomas Peterson's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

[35] See the summary of Jim Sites' remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

Massachusetts, that seeks to combine the strengths of MIT in basic research with the strengths of German Fraunhofer system in applied research.[36] Describing this new model, Nolan Browne said that the lab has two primary foci: Solar PV modules and building efficiencies. "We find that these are two areas where we can make dramatic differences over a five-year period,"[37]

In operation, the CSE begins with start-up ideas from MIT, national laboratories, or other sources. The group takes these ideas from modeling to design and has a prototyping unit that can build a technology, as well as an incubation unit to begin business development. "Our mission," he said, "is to help grow these ideas to the point where a VC is ready to start funding." Dr. Browne said there was a great need for such industry-university collaboration in the field of PV, as well as for nonprofit applied PV research centers. "In the past," he said, "this lack of collaboration has led to slow or premature commercialization for some technologies. Without a smooth handoff, you can generate unrealistic expectations in the market.

Solar Product Development Center

Participants at the July 2009 symposium also considered the example of a private company that fosters collaboration to advance PV technology. Describing the need to help companies transition from a laboratory-scale prototype to a fully qualified manufacturing process that is ready for funding by the capital markets, Stephen Empedocles of SVTC Solar noted that a solar product development center like SVTC could offer companies the necessary manufacturing tools, infrastructure, and engineering expertise to help client companies advance their technologies. He noted that product development and piloting center like SVTC can "take the output of R&D—research prototypes—and convert them to final products. Eventually we hand them off to the cell and module makers who do the manufacturing."

Industry Research Consortia

Participants at the National Academies symposia on the future of PV manufacturing in the United States extensively discussed the potential role of a public-private partnership as a mechanism for collaborative research. An industry research consortium accelerates the development of technologies by coordinating precompetitive work among firms.[38] Activities, such as those related

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[36]The Fraunhofer Gesellschaft in Germany is a large semigovernmental research facility with 15,000 employees, mostly scientists and engineers, and a research budget of $2 billion. One of world's largest nonprofit contract research organizations, it works in all fields of applied research.

[37]See the summary of Nolan Browne's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

[38]See Kenneth Flamm, "SEMATECH Revisited: Assessing Consortium Impacts on Semiconductor Industry R&D," in National Research Council, *Securing the Future: Regional and National Programs to Support the Semiconductor Industry,* Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2003.

to developing platform technologies and common standards, can be organized cooperatively, even as firms compete privately in their separate R&D efforts. In an R&D consortium a certain portion and type of the R&D—often involving research upstream from the market—is funneled into the organization where it is carried out collectively and is deployed by a variety of other firms. Firms also continue to compete privately through carrying on their own application-related R&D programs. In this way, firms cooperate when it is in their individual and collective interest to cooperate and compete when it is in their individual interest and the interests of consumers to compete.[39]

As we see next, several participants highlighted the experience of the semiconductor industry consortia, and extensively discussed the relevance of the semiconductor industry's experience in fostering collaborative research for the PV industry.

Collaborative Research in the U.S. Semiconductor Industry

Drawing out, first, the similarities between competitive positions of today's PV industry with the semiconductor industry in the mid-1980s, John Kelly noted that "we were seeing a loss of share in the U.S. semiconductor industry, but we were also seeing the entire equipment and materials base leaving the United States." "That was a disaster," he said, "to companies like Intel and IBM, who felt that our supply lines and the security of our own systems could be in jeopardy."

Responding to this challenge, he said, the U.S. semiconductor industry launched cooperative efforts through organizations such as the Semiconductor Research Corporation (launched in 1982) and SEMATECH (launched in 1987). These initiatives in cooperative research, he said, pooled expertise, lowered costs, and encouraged the dissemination of knowledge across the industry, contributing to a significant resurgence in the competitive position of the U.S. semiconductor industry.[40]

[39]For a review of necessary conditions for successful public-private partnerships, including research consortia, see National Research Council, *Government-Industry Partnerships for the Development of New Technologies*, op. cit.

[40]"While many believe that SEMATECH contributed to the resurgence of the U.S. semiconductor industry in the early 1990s, it was by no means the only element in this unprecedented recovery. For example, time for the industry to reposition itself was provided by the 1986 Semiconductor Trade Agreement. The U.S. industry also repositioned itself, profiting from shifts in demand, i.e., away from DRAMS (where Japanese skill in precision clean manufacturing gave significant advantage) towards microprocessor design and production (where U.S. strengths in software systems and logic design aided in their recovery.) Arguments about which of these elements were most decisive probably miss the point. The recovery of the U.S. industry is thus like a three-legged stool. It is unlikely that any one factor would have proved sufficient independently. Trade policy, no matter how innovative, could not have met the requirement to improve U.S. product quality. On the other hand, by their long-term nature, even effective industry-government partnerships can be rendered useless in a market unprotected against dumping by foreign rivals. Most important, neither trade nor technology policy can succeed in the absence of adaptable, adequately capitalized, effectively managed, technologically innovative companies. In the end, it was the American companies that restored U.S. market share." See National Research Council, *Securing the Future: Regional and National Programs to Support the Semiconductor Industry*, op. cit., p. 82.

Semiconductor Research Corporation

Introducing the Semiconductor Research Corporation (SRC), Larry Sumney noted that his organization was founded to address the challenge of improving the reliability and yield of integrated circuits.[41] In the early 1980s, he noted, industry did not have sufficient research capacity and universities were not interested in silicon research, or applied research in general. "It was a challenge to generate a pool of faculty with experience in manufacturing and design," said Dr. Sumney, "or to find educated students who knew something about industry."

The research needs of the industry seemed to be greater than what any single company could muster on its own. Having little alternative, industry decided to organize, and to pool its resources. This was not an easy step, said Dr. Sumney, because the industry was—and still is—extremely competitive. Still, they decided they could collaborate on precompetitive, generic research that would help all of them without jeopardizing their competitive positions.

The activities of SRC are concentrated between "blue-sky" basic research and industry-level product development. In general, industry is more tightly focused on nearer-term research, while universities have more autonomy and time to pursue longer-term research. The collaborations are all governed by research contracts, with milestones jointly worked out with the principal investigator. "Negative progress is fine," he said; "we just need to know about it. In such cases, the partnership has a choice of either changing direction or allowing the work to continue a little longer. The strategy works out well."

Over the years, the SRC has invested over $1.3 billion contributed by members and government; it has supported more than 7,000 graduate students through 3,000 research contracts, 1,700 faculty, and 241 universities. This support has resulted in more than 43,000 technical documents, 326 patents, 579 software tools, and work on 2,315 research tasks or themes. "The task level is really where results come from," he said. "These may be integrated into a center, or they may be a single professor and several grad students."

Dr. Sumney noted that the SRC has evolved as a family of distinct but related programs:

- The Global Research Collaboration ensures the vitality of the current industry, supporting shorter-term research (a 7- to 14-year time frame) with traditional CMOS technology.[42]

[41]See the summary of Larry Sumney's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

[42]The complementary metal-oxide-semiconductor (CMOS) transistor is used to manufacture most of the world's computer chips. While CMOS chips have become steadily smaller, the International Technology Roadmap for Semiconductors (ITRS) predicts that the size limit for CMOS technology is likely to be 5nm to 10 nm, which may reached in 10 to 15 years. Researchers cannot yet predict which new materials or techniques will allow the rising performance and shrinking size of computer chips to continue.

- The Focus Center Research Program, with a 14- to 20-year time frame, is focused on breaking down barriers to extend CMOS as far as it can go.
- The Nanoelectronics Research Initiative seeks to identify the next information element beyond CMOS.
- An Education Alliance provides fellowships and scholarships.
- The Topical Research Collaborations (TRC) is a new SRC research vehicle to apply the collaborative model to new technical areas. One is the Energy Research Corporation, which has a program in photovoltaic technologies. This will begin with an effort at Purdue University to model and simulate different PV structures to assess their viability. A second is the National Institute for Nanoengineering (NINE), a joint program with Sandia National Laboratory.

SEMATECH

In his symposium presentation, SEMATECH's president, Michael Polcari noted that SEMATECH was conceived from separate proposals by the Defense Science Board and the Semiconductor Industry Association to establish a research consortium to respond to the sharp loss of market share in the 1980s to Japanese companies.[43] The key goal of SEMATECH, he said, is to accelerate the commercialization of technology by putting in place the infrastructure that allows the semiconductor industry to accelerate tools and materials development and to help coordinate the elements of the technology necessary to manufacture the next generation of smaller, faster, and cheaper semiconductors.

In hindsight, he said, key factors that led to the success of SEMATECH were

- Commitment from top-level executives, both in government and industry: Without this high-level commitment, he said, nothing would have happened.
- Industry leadership: This was vital because only industry could identify the problems they needed to solve.
- A clear precompetitive mission: The group needed to work together on the U.S. technology infrastructure.
- A broad representation from industry, involvement of the national labs (including NIST), and initially the ability to leverage government funds.

A central factor leading to success, Dr. Polcari said, was that SEMATECH was member driven. Members decided what the problems were, set the research agenda, and apportioned resources. "It is essential that the people whose problems you're trying to solve are the ones who decide what you work on," he said.

[43] See the summary of Michael Polcari's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

The IMEC Model

The perceived success of cooperative research initiatives developed by the U.S. semiconductor industry has since led to the establishment of similar, often substantially better funded cooperative research organizations overseas, of which IMEC in Flanders, Belgium is a key example.[44]

In his symposium presentation, Johan Van Helleputte of the Flanders Inter-University MicroElectronics Centre (IMEC) in Belgium observed that a central challenge for a high-technology manufacturing industry is to deal with both very high cost research and a rapid rate of technological change.[45] He said that this means that no single company can sufficiently tackle these challenges on its own. The answer, he averred, lies in partnering in R&D. Each company had a choice on how to spend the percentage of revenues it devotes to R&D: it can spend all of it on exclusive work, or it can spend part of this budget on a research platform, like SEMATECH or IMEC, and gain a much larger R&D reach.

The IMEC approach, said Dr. Van Helleputte, is to address generic problems somewhat early in a technology's life cycle.[46] It tries to create a program by defining what it intends to do for the next three years and then signs bilateral contracts with companies: partner A, partner B, partner C, and so on. IMEC asks each partner to send one or more industrial residents to do joint research within the team. The rule for intellectual property protection is that any foreground information to which the partner resident has contributed is co-owned with IMEC. If the industrial partner does not contribute to certain elements of the program, it receives a nonexclusive, nontransferable license on foreground results for its own use so there are no "blind spots" in using the technology back home. At the same time, IMEC provides a nonexclusive license for the background information required to exploit the foreground results. In return for these benefits, IMEC charges an entrance fee and a yearly affiliation fee.

Dr. Van Helleputte added that company research labs begin to form their intellectual property from a "research infrastructure" on which they build "technology platforms" of expertise and competence. In other words, a company with multiple technology programs can offer them to multiple partners and harvest greater value from the resulting partnerships, though collaboration within IMEC. "So you're building leverage on leverage on leverage," said Dr. van Helleputte,

[44]In 2008, the government of Flanders invested 44 million Euros in structural funding for IMEC. This investment saw high returns in revenues of 270 million Euros. The investment in IMEC has also positioned Flanders as a global center in semiconductor research, attracting scientists and researchers from around the world. Currently, SEMATECH receives no government support.

[45]See the summary of Dr. Van Helleputte's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

[46]For a review of the IMEC model, and the innovation strategy of the autonomous region of Flanders in Belgium, see National Research Council, *Innovative Flanders: Innovation Policies for the 21st Century*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2008.

"and you reuse the mechanism of co-ownership without any accounting to each other about the foreground research."

Translating the Model: From Semiconductors to PV

The semiconductor and PV industries face many of the same challenges and both can benefit from collaboration by firms at the precompetitive level. According to Dr. Polcari, semiconductor companies need to know, from a strategic perspective, the most productive architecture for a factory of the future. Tactically, they need to continuously reduce costs in today's fabs and manage ever-increasing capital, manufacturing, and R&D costs. There are also sustainability challenges, such as how to reduce the industry's environmental footprint, find safer materials, and conserve consumables. "All of these challenges," he said, "are also relevant to photovoltaic technologies."

Dr. Polcari added that the history and present activities of SEMATECH could yield numerous practical lessons for the PV industry. He said that the SEMATECH model has applications not only in technology development but also manufacturing productivity and collaborative strategies that could benefit all participants at the precompetitive level. "Certainly our experience in organizing and recruiting consortia has helped to bring a lot of cost reduction to the industry."

The Role of Roadmaps

The semiconductor industry's use of technology roadmaps might also have great relevance for the PV industry.[47] Steven Freilich of DuPont noted that an industry roadmap, such as the one developed by the Semiconductor Industry Association, could be a key tool to control a fast-moving technology within fast-moving markets.[48] The International Technology Roadmap for Semiconductors (ITRS) sets out the objectives for each technology, performance goals, milestones, and timing. "Since everybody is working from the same page, everybody understands the same things about where the industry is going, what it needs, when, why, and how much. It gives you a chance to address shortcomings at the R&D phase, or at least before there's been a tremendous investment."[49]

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[47]For a description of the history of the Semiconductor Roadmap, see Robert Doering, "Physical limits of silicon CMOS and semiconductor roadmap predictions," in National Research Council, *Productivity and Cyclicality in Semiconductors*: *Trends, Implications, and Questions,* Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2004, p. 12.

[48]See the summary of Steven Freilich's remarks, delivered at the July 29, 2009, symposium in the Proceedings section of this volume.

[49]The PV industry has established a roadmap that sets the deployment goal f 200GW peak in the United States by 2030. See Sandia National Laboratories, "Photovoltaic Industry Roadmap." Access at <*http://photovoltaics.sandia.gov/docs/PVRMPV_Road_Map.htm*>.

Larry Sumney noted that roadmaps have also accelerated the pace of innovation in the semiconductor industry by setting the pace of competition. In this way, roadmaps have helped to sustain Moore's Law: "You try to get from one node, or minimum feature size, to the next as fast as possible. That has served to excite the industry to beat the roadmap, and they have done that. It wouldn't have happened without that expectation or cadence that Moore's Law provides." Dr. Sumney concluded that "for PV, this kind of expectation could also be used, along with a roadmap developed with the Department of Energy and others."

Challenges and Opportunities for Collaborative Research in PV

While there is much for the PV industry to learn from the successes of the semiconductor roadmaps and research consortium, some participants expressed caution about applying the model directly. Noting that there is no equivalent of a common CMOS technology that can be the basis for a unified technology roadmap for the PV industry as it has been for the semiconductor industry, Mark Pinto stated that any future PV consortium would have to be adapted to the exigencies of that technology.

Doug Rose of SunPower pointed out that a big difference between the PV and semiconductor industries is that processing and chip design in the semiconductor industry has a natural sharing of intellectual property because of shared interest in geometry shrinks and other advances that came on a predictable schedule. "There's no analog to that in PV."[50]

Bettina Weiss of SEMI also added that PV industry presents unique challenges for collaborative research.[51] The industry structure is still not well defined, with a mix of very small to very large companies operating in different technologies and markets and focusing on different manufacturing targets. The PV industry also suffers from deployment bottlenecks and very high logistics costs, especially for transport of modules and panels, she noted.

Setting the difference between the PV industry and the semiconductor industry in perspective, Mr. Lushetsky of the Department of Energy said that "put simply, the IC industry is one materials set with an infinite number of circuits; the PV industry is one circuit with an infinite number of materials."[52] He acknowledged that where the IC industry was able to collaborate on materials, we clearly run into differences in PV. For other technical issues such as metrology, material handling, and deposition tooling at a high level, however, he suggested that there exist opportunities for precompetitive partnerships. Another opportunity for col-

[50]See the summary of Doug Rose's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

[51]See the summary of Bettina Weiss' remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

[52]See the summary of Mr. Lushetsky's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

laboration, he said, lies in developing lower cost installation methods, given that installation is a major element in the cost of PV systems.

Drawing out the opportunities for collaborative research, Mark Pinto noted PV firms could share work on processes such as modeling, simulation, reliability, and characterization. Bettina Weiss added that PV firms could accelerate innovation through the collaborative development of industry standards, industry information that guides investment and planning decisions, and industry advocacy and promotion, among other arenas.

Seizing the Market

In his presentation, Bob Street of the Palo Alto Research Center warned that the United States not only needs to be a leader in materials research but also needs

BOX F
Innovation in PV Manufacturing: The Flexible Film Opportunity

The FlexTech Alliance, formerly the U.S. Display Consortium, was initiated about 15 years ago with support from DARPA. The display consortium was structured much like that of SEMATECH, focusing on the precompetitive aspects of the supply chain of the then-nascent flat-panel display industry. The program brought together companies that could work together and were willing to cost share more than 60 percent of the R&D.

According to Mark Hartney, the FlexTech Alliance has since evolved to focus on innovations in roll-to-roll manufacturing.[a] This process creates electronic devices on a roll of flexible plastic or metal foil that can be up to a few meters wide and 50 km long. Some of the devices can be patterned directly, much like an inkjet printer deposits ink. A key challenge, he said, is to use this high-throughput manufacturing technique to mass fabricate solar cells on large substrates, yielding flexible thin film solar cells at a fraction of the cost of traditional crystalline silicon manufacturing.

In today's PV market, said Dr. Hartney, crystalline silicon predominates, with about 90 percent of PV shipments being silicon wafer-based material. However, thin-film technologies have the highest growth rate, rising from 50 MW in 2007 to a predicted 4.5 GW of power generating capacity by 2012.

Although some technologies representing this new generation of PV products are already in pilot stages, Steven Freilich of du Pont noted that developing thin film PV remains a substantial challenge. In addition to the substrate, thin-film PV also requires a flexible, durable, protective front sheet that is competitive with glass in blocking moisture transmission. "From a polymer perspective," he said, "this is essentially unheard of." He cautioned that progress in this technology will not be incremental and will require substantial investments and cooperative research in "radical new materials and processes."

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[a]See the summary of Mark Hartney's remarks, delivered at the April 23, 2009, symposium in the Proceedings section of this volume.

BOX G
Building a Solar Cluster in Ohio

In her keynote address at the April 2009 symposium, Rep. Marcy Kaptur asked, "How can it be that Toledo, Ohio, ended up leading our nation in such a key area of energy independence?" She then highlighted several key factors that have helped to transform Toledo into a Solar City.

- First, she said, the high power rates charged by investor-owned utilities along Lake Erie's south coast to Cleveland are among the most expensive in the nation. This led to interest in alternative sources of electricity generation and made renewable energy more price competitive with grid power.
- A second reason is that this region of Ohio, once known as the glass capital of the world, had established expertise in a PV related technology.[a] As Norman Johnson of Ohio Advanced Energy also pointed out, Northwestern Ohio was a region of high unemployment of displaced automotive and glass industry employees who had many transferable skills.
- A third reason for Ohio's leadership in solar technology is the presence of a visionary innovator named Harold McMaster.[b] A lifelong resident of the region, Dr. McMaster and a group of colleagues founded Glasstech Solar in 1984 and invested generously in manufacturing and basic research at the University of Toledo and other institutions. These pioneering efforts gave rise to several of the companies and much of the research expertise that characterize the region today.
- A fourth reason is the presence of a stable, long-term funding strategy focused on basic energy research. Ohio, said Rep. Kaptur, had just recognized the fruits of a two-decade-long effort in pursuing innovation and R&D by funding the Wright Center for Photovoltaics Innovation and Commercialization at the University of Toledo.[c]
- Fifth, significant resources have been devoted to commercialization of energy technologies. Rep. Kaptur noted that this is extremely difficult to do from

to move new technologies rapidly from the laboratory to the marketplace.[53] He observed that the science of electronic materials has been advanced over the past ten years by the fast growing display industry, but warned that the large display industry in Asia, and the substantial ecosystem of local equipment manufacturers, materials suppliers, and technology developers that supports this industry, are poised to take over the new flexible PV technology when it is ripe.

We should ask ourselves how easy it will be for these companies to just shift into solar when the time comes and be very competitive with what we can do, he remarked, adding that the focus should be not only on technological break-

[53]See the summary of Bob Street's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

a local or regional base. One way to start was to build a demonstration project now installed at the 180th Fighter Wing in Toledo, where solar cells now produce a 1-MW research base.[d]

- Sixth, establishing standards has played an important role. Ohio's Advanced Energy Portfolio Standard, which mandates that at least 25 percent of Ohio's electricity come from clean and renewable sources by 2025, is expected to advance a portfolio of clean-energy technologies.
- Finally, Rep. Kaptur cited the importance of close partnership among university, industry, and government. "They're all working together," she said. A group of PV enthusiasts, including Norman Johnson, founded the Ohio Advanced Energy business trade association, which has served to promote renewable technology industries statewide over the long term.

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[a]Pioneering Toledo firms included Edward Ford Plate Glass Company (1899-1930), Toledo Glass Company (1895-1931), and Libbey-Owens Glass Company (1916-1933).

[b]Harold McMaster (1916-2003), one of 13 children of a tenant farmer, was once called "The Glass Genius" by Fortune magazine. In 1939, he became the first research physicist ever employed by Libbey Owens Ford Glass in Toledo and went on to found four glass companies. These included Glasstech Solar, in 1984, and Solar Cells, Inc., formed to develop thin-film cadmium telluride technology. Solar Cells was later bought and renamed First Solar, currently a world leader in thin-film PV.

[c]In 2007, the Ohio Department of Development awarded $18.6 million in state funding to establish the Wright Center for Photovoltaics Innovation and Commercialization (PVIC). The PVIC now has three research locations: the University of Toledo, Ohio State University, and Bowling Green State University. Matching contributions from federal agencies, universities, and industrial partners have raised this amount to $50 million.

[d]Rep. Kaptur secured $6.4 million in federal funding for two demonstration projects in Ohio, at the 180th Fighter Wing at Toledo Airport and Camp Perry. The first is a 1-MW field, the largest in Ohio, designed for simplicity and low cost of operation. Installation began in June 2008 and is now being evaluated by the University of Toledo as the prototype of a "solar kit" that produces low-cost electricity.

throughs but on measures to secure the future of photovoltaics manufacturing in the United States.

Initiatives undertaken in states such as Michigan and Ohio show how focused and long-term investments can build a successful manufacturing base for photovoltaic technologies in the United States. At the April 2009 National Academies symposium, Norman Johnson of the Ohio Advanced Energy Association and Rep. March Kaptur of Ohio described the development of a PV technology cluster in Toledo, Ohio (see Box G).

E. WHAT IS THE ROLE FOR GOVERNMENT?

In his remarks at the April 2009 symposium, John Lushetsky said that the strategy for solar programs at the Department of Energy is not to replace anything the private sector would do, but to find a role for government that helps to accelerate what industry can do on its own. He said that the National Academies symposia are helping to develop a better understanding of what private industry needs, and to help guide a government response that is sufficiently "prompt, effective, and strategic."

Several participants at the National Academies symposia offered their views of how the federal government can best support the U.S. photovoltaic industry.

Strengthening the Innovation Framework

Several participants highlighted the role of the federal government in strengthening the innovation base through support for R&D, training the future technical workforce, and setting standards.

Funding R&D: Michael Ahern affirmed the key role for the federal government in funding research and development through universities, national labs, and consortia to maintain a flow of commercially viable technologies. John Lushetsky noted that the budget for the Department's Solar Energy Technology Program (SETP) was under $100 million for six years preceding FY2007, when it rose by more than $50 million under the Solar America Initiative. In FY2009, it rose by approximately $100 million more with the Recovery Act, and $51.5 million of that amount goes to photovoltaic technologies. He added that the request for FY2010 is similar to the 2009 total.[54]

Training and Attracting Technical Talent: Eric Peeters highlighted the importance of providing support for the education of "the people who are going to have those green jobs—a green-collar work force." Steven Freilich noted further that these people are not just U.S. nationals; the government needs to ensure that international students and engineers can easily enter and stay in this country so U.S. industry has access to the best people in the world.

*Setting Standards: T*he federal government can adopt a national renewable electricity standard to accelerate the development of PV. According to David Eaglesham other governments, including those in the European Union, China, India, and Australia, have already taken significant steps in this regard. Both Kent Rochford and Eric Lin of NIST emphasized the key role played by this government agency in developing the standards and measurement tools that set the trajectory of innovation and commercialization of photovoltaic technologies.[55] As Eric Daniels further pointed out, "A manufacturer can choose to comply with standards or not, but they are critical in building consumer confidence."

[54] See the summary of Mr. Lushetsky's remarks, delivered at the July 29, 2009, symposium, in the Proceedings section of this volume.

[55] See the summary of Eric Lin's remarks, delivered at the April 23, 2009, symposium, in the Proceedings section of this volume.

Encouraging Government-Industry-University Collaboration

Securing the future of photovoltaics manufacturing in the United States will also require new ways of collaboration and interaction among governments, firms, and universities. Steven Freilich observed that collaboration of businesses with university or national laboratory partners is essential for successful technological development. He added that it is important for government to understand that funding small companies, universities, and government laboratories is also "critical to the life blood of large companies."

Under Secretary Kristina Johnson noted that federal partnership programs like the Small Business Innovation Research (SBIR) program can play an important role in bringing new renewable energy technologies to the market.[56] She noted that additional funding for renewable energy from the Recovery Act, also enlarges the SBIR budget, which is based on a 2.5 percent set-aside from the Department of Energy's extramural budget. She also highlighted the role of partnership programs within DoE as a part of a portfolio of programs that span from basic to applied research.

Box H describes some of the Department of Energy's key energy partnership programs.

Stimulating Demand: Government as an Early Buyer

According to Subhendu Guha, the federal government has a crucial role in bringing the PV industry to the point of grid parity. That role is to help create a sufficient demand base through incentives and grants. We can have the best technology in the world, he said, but if it does not have a demand base, it will not create manufacturing jobs in the United States.

Eric Peeters stated that the federal government has a leading role in stimulating demand and "making America a 21st-century solar power." Federal policies to promote demand for solar, he said, include federal tax incentives, formulation of national renewable energy standards, federal interconnection and net metering standards, and feed-in tariffs. "We have to get people to connect to the grid," he said, "and make sure the grid works well."

In his presentation, Steven Freilich noted that the government can stimulate a strong PV industry in the United States by acting as an early buyer; "it can set price floors, as it has in other industries." He observed that even a company as large as DuPont constantly has to make decisions about programs at the margins. Often it's the high-risk, potentially high-reward programs that drop off when there is too much uncertainty. "Government incentives that build market size and industry support can help industry make the right decision about those programs on one side or another of that very gray line."

[56] SBIR provides competition-based awards to small companies to develop proof of principle and prototypes of new technologies that address government missions. For a comprehensive review, see National Research Council, *An Assessment of the SBIR Program*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2008.

BOX H
Department of Energy Partnerships
Programs for Solar Energy

Robert Margolis of the Department of Energy's National Renewable Energy Laboratory (NREL) described several of the agency's collaborative programs.

The Solar Program received steady funding of about $80 million from FY2001 to FY2007 and which has been increased substantially under the **Solar America Initiative** to about $160 million per year. Funding for this program is expected to increase again, with new resources to leverage the private sector through a host of collaborative mechanisms.

The goal of the **PV Manufacturing R&D project,** started in 1991, is ". . . to ensure that U.S. industry retain and extend its world leadership role in the manufacture and commercial development of PV components and systems."[a] The project was funded with about $150 million in federal money matched by an equal amount of private-sector money. The project is considered innovative in its use of multiyear contracting and cost sharing with industry.

DoE's **Technology Pathway Partnerships** supports early-stage partnerships between universities and industry. The TPPs started in 1997 with a three-year grant of $168 million in DoE funds, and a total of $357 million including industry matching funds. The partnerships, some of them with over a dozen members, included more than 50 companies, 14 universities, three nonprofits, and two national labs. Margolis suggested that this partnership experiment might be a positive model to accelerate PV technologies to the market.

Most recently, the NREL has sought project proposals as part of the DOE's **Photovoltaic Technology Incubator program** to accelerate commercialization of solar energy technologies. NREL has also announced partnerships with 13 small U.S. solar businesses that have the capability to enter the market by 2012.

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[a]C. E. Witt, R. L. Mitchell, and G. D. Mooney, "Overview of the Photovoltaic Manufacturing Technology (PVMaT) Project." Paper presented at the 1993 National Heath Transfer Conference, August 8-11, 1993, Atlanta, Georgia, August 1993.

The Role of a Carbon Tax

Several participants, including David Eaglesham and Doug Rose raised the issue of a price on carbon emissions that, by raising the price of fossil fuels, can spur demand for solar technologies. In his presentation, Michael Ahearn noted that carbon pricing has been a part of a "whole basket of solutions" in many European countries.[57]

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[57]Denmark and Germany are forerunners in implementing broad-based energy and carbon taxes while also leading producers of wind and solar energy, respectively. For a review of European carbon tax policies, see Stefan Speck, "The design of carbon and broad-based energy taxes in European countries," *Vermont Journal of Environmental Law* 10, 2008.

Providing Subsidies and Direct Incentives

Changing the nation's energy usage by applying new resources of government and innovations of industry will require new financial arrangements to provide incentives to the private sector. Ken Zweibel noted that today's technological landscape, including the locations of manufacturing and installation, is defined by past R&D funding and market incentives. "It isn't much of a leap," he said. "Government policy has defined the landscape of photovoltaics. Photovoltaics isn't a cost-competitive technology. It is a societal contract with manufacturers and technologists and scientists to develop a non-CO_2 source of energy, one that can diversify us away from fossil fuels.

Steve O'Rourke proposed a manufacturing credit to overcome tax disadvantages in the United States. "In China, we deal with companies that have very low cost of capital—three percent on average—and instead of paying taxes, they get tax credits," he noted, adding that "manufacturing migrates to where companies are most profitable, and the single biggest issue in this analysis is taxes." A manufacturing tax credit of 27 cents per watt for equipment manufactured in the United States, and a capital spending subsidy like that provided in Germany, he said, are examples of what can be done with direct incentives to solve a very difficult issue.

Drawing a comparison to the development of the nation's nuclear industry, Rep. Marcy Kaptur noted that substantial federal subsidies helped that industry mature and that the same is needed to grow the solar industry. Nuclear power generates a large proportion of our electricity, she said, but this happened through a concentrated and deliberate approach to broaden our electrical usage. Between 1943 and 1999, she said, the nuclear industry received over $145 billion in federal subsidies, without counting tax subsidies. By contrast, the solar power industry had received some $4.4 billion and the wind power industry $1.3 billion.

F. CONCLUSION

As the nation strives to develop and harness renewable sources of energy, a key challenge will be to retain the industries and high value jobs that these new technologies bring. Participants at the two National Academies symposia summarized in this report identified a number of complementary approaches to respond to this challenge.

Some participants emphasized the need to accelerate innovation through cooperative research and development of PV technologies. They observed that federal policies could create incentives that draw together the tremendous assets of the U.S. research universities of and firms. They held that the U.S. photovoltaic industry may be able to benefit from such collaboration, as has the semiconductor industry in the past.

Several participants also stressed the need to develop incentives for demand. Recognizing that the future of photovoltaics manufacturing in the United States depends on growing domestic demand for PV technologies, several participants at the National Academies symposia emphasized the role that public policies can play to encourage demand through early government procurement, feed-in tariffs, flexible financing options, tax credits for production and use, and expanded consumer education.

The knowledge and views of participants at the National Academies symposia, captured in this volume, can contribute to the development of a better policies and can help identify the practical steps needed to meet the goal of a sustainable energy future.

II

PROCEEDINGS

APRIL 23, 2009, SYMPOSIUM
THE FUTURE OF PHOTOVOLTAICS MANUFACTURING IN THE UNITED STATES

Welcome

Charles Wessner
The National Academies

Dr. Wessner opened the proceedings by welcoming participants and noting the high level of interest in the topic of photovoltaic manufacturing indicated by the full meeting room. He clarified that the program on photovoltaics was not designed to showcase the "latest and keenest in technology," but that its emphasis instead was "how we can deploy those technologies, and how we can set about doing it quickly as possible."

He mentioned that the STEP program, under the guidance of Gordon Moore, Ambassador Alan Wolff, and others, had held numerous symposia on collaborations among industry, government, and academia. He also noted a general "policy hiatus in this area" that invited informed discussion. He welcomed the presence on the program of a representative from the InterUniversity Microelectronics Center in Belgium, which would present a European version of a successful collaboration.

Dr. Wessner noted that an evaluative study of partnerships, chaired by Gordon Moore, had concluded that such partnerships do work, and they work best "when they're properly structured, funded, managed, and led." He added his own personal conviction that industrial partners, rather than academia or government, were best situated to take the lead on multisector consortia. Successful consortia, he said, had the opportunity to contribute to national growth, to the security of the nation "in more profound ways than simple military force," and to job growth as a central force in economic recovery.

He mentioned two programs, the Small Business Innovation Research program, within the Small Business Administration, and the Technology Innovation Program, within NIST, that had made "remarkable progress." He noted that many success stories have come out of both programs, and advocated continued use of these models rather than a search for new ones. "We tend to forget where some of the nurturing of small firms comes from. It comes from proven and existing mechanisms that help us do things quickly, without using exorbitant sums of money. This is easier and more effective when you have mechanisms already in place. You might be able to design a better mechanism, but that would take years, and may not be better after all."

A key question for any country, said Dr. Wessner, is "how to keep the industry we have and generate new industries in the future." Something that is seldom discussed in Washington, he said, is "the fierce locational competition for the industries of today and tomorrow." It should not be solely the concern of lobbyists to support industries and create an attractive environment, he said, because industry is essential for the growth of the country as a whole. One way to do that, he said, is to bring together the tremendous assets of the research universities of the United States, the vibrant industrial structure, and an "informed and activist government with the funds necessary to help us cooperate."

He suggested that the field of photovoltaics—the topic of the symposium—could benefit from such collaboration, as have semiconductors and other fields in the past, and that the symposium attendees were well qualified to contribute to both a stronger policy framework and practical steps needed to forge collaborations at many levels. He thanked, in particular, Clark McFadden, an attorney who had helped lay the groundwork for photovoltaics consortia, and John Lushetsky of the Department of Energy, whose department led the way in support of the symposium.

Introduction

Clark McFadden
Dewey & LeBoeuf LLP

Mr. McFadden welcomed participants on behalf of himself and Dr. Mary Good, the chair of the Committee, who was not able to attend. He said that the country had entered a time "of urgency and great opportunity" with respect to its energy usage. The urgency comes partly from the current steep economic downturn, he said, and the government's efforts to reverse it, partly through quick and substantial spending. There is urgency in the energy sector as well, he said—not only that the country spends too much on energy, but that "we do it with inefficiency and high collateral costs." This urgency also brings opportunity, he said, in "the willingness, indeed the necessity, of changing behavior in a crisis, and from the government's commitment to change our energy future." He cited President Obama's decision to make energy, along with health care and education, a central priority in strengthening prosperity, competitiveness, and national security. This has been accompanied by a commitment of major government funding and the establishment of the ambitious goals of deriving 10 percent of energy in the United States from renewable sources by 2012 and 25 percent by 2025.

Photovoltaic (PV) technology, or solar-cell technology, can play a major part in addressing this urgency and opportunity, he said. To succeed, however, solar energy, like most other forms of energy, needs to be converted more efficiently to electricity. This is a goal of photovoltaic manufacturing. Manufacturing in general provides significant benefits to a nation, through high-value jobs, stimulation of infrastructure, and research. Photovoltaic manufacturing has another promise, Mr. McFadden said: It can greatly enhance the energy output of solar energy.[1]

One analogy is the manufacturing of integrated circuits in the semiconductor industry. At their infancy, integrated circuits were too expensive for all but the most cost-insensitive applications, such as military rockets. But manufacturing improvements helped lower the cost of integrated circuits dramatically and persistently, bringing new capabilities, in accordance with "Moore's law."[2] There are many differences between the photovoltaic and semiconductor industries, but the history of semiconductors may provide useful models, including the experience of semiconductor consortia.

At such a moment of opportunity, Mr. McFadden asked, can we change the nation's energy usage by applying new resources of government and innovations of industry? For photovoltaic manufacturing, this will require improvements in process technology, such as the application of flexible electronics, new materials, and manufacturing tools. It will require new financial arrangements to provide incentives to the private sector. And it will require new ways of collaboration and interaction, new relationships between government and firms that go beyond those of standard government procurement.

Mr. McFadden said that the symposium would focus on the best forms of this cooperation between government and industry. "To do this in the very best tradition of the STEP board," he said, "we plan to ask industry what is needed." The first two panels would focus on industry's experience, he said, and the third panel would look at current lessons and best practices, both from U.S. models. These would include SEMATECH and IMEC, the Interuniversity Microelectronics Consortium in Belgium. Panel IV would look at the economics of photovoltaics in the United States, and Panel V would examine the opportunities presented by flexible electronic materials to meet the needs of solar panel manufacturing and generation. Panel VI would be a roundtable discussion of "what had been learned and what we need to learn."

He again thanked the Department of Energy for its support, especially John Lushetsky, who had had extensive experience in the solar industry and now led DoE efforts in energy efficiency.

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[1]The photovoltaic effect was observed as early as 1890 by Henri Becquerel, and was the subject of scientific inquiry through the early twentieth century. In 1954, Bell Labs in the United States introduced the first solar PV device that produced a useable amount of electricity, and by 1958, solar cells were being used in a variety of small-scale scientific and commercial applications. Source: Solar Energy Industries Association.

[2]Moore's law, named after Intel co-founder Gordon Moore, grew out of his observation that the number of transistors that can be placed on an integrated circuit (like other electronic capacities) has roughly doubled every two years since the invention of the IC in 1958. In photovoltaics, no such "law" has been proposed, although the industry has consistently increased the electrical efficiency of solar cells and has reduced the cost per watt.

Opening Remarks

John Lushetsky
U.S. Department of Energy

Mr. Lushetsky began by referring to discussions about renewable energy at DoE over the past six to nine months—topics that at first seemed somewhat unfocused: How to reduce costs, industry standards, workforce needs, corporate partners, finance models. "At a certain point, he said, "we realized that we were really trying to look at the future of photovoltaic manufacturing in the United States. How do you bring together all these issues to provide some comprehensive response that is helpful to this industry?"

He said that the strategy for solar programs at DoE is not to replace anything the private sector would do, but to find a role for government that helps to accelerate what industry can do on its own. Mr. Lushetsky said that the purpose of the symposium was to understand in finer detail what industry needs, and to help guide a government response that is sufficiently "prompt, effective, and strategic." He noted that some of the models that might be helpful in this effort, such as SEMATECH, had already been studied extensively by the National Academies. This is one factor that had convinced him that much could be gained by collaborating with the Academies on the design and execution of this symposium.

Panel I

Opportunities and Challenges Facing PV Manufacturing in the United States

Moderator:
Kevin Hurst
Office of Science and Technology Policy
Executive Office of the President

Mr. Hurst expressed his appreciation for the participation of three leaders from several leading PV manufacturers in the world—First Solar, SunPower, and Dow Corning—and his approval of solar power as a central element in the country's renewable energy portfolio. He then described new policy directions of President Obama to try to advance PV and other forms of renewable energy. The FY2010 budget, he said, contained several energy policy priorities, beginning with a comprehensive approach to reduce the country's dependence on petroleum and its contributions to climate change, and to simultaneously increase the numbers of "green jobs" in the country. Second, the Administration proposed a greenhouse gas emissions cap-and-trade program that aimed to reduce emissions 80 percent by 2050. Third, the Administration planned to invest $150 billion over 10 years to develop and deploy clean energy technologies, starting in FY2012, making use of a portion of the revenues from the cap-and-trade auction.

Mr. Hurst also said that the President had announced a goal to double the non-hydro contributions of renewable power generation by 2012. This goal, he said, was backed up by elements of the American Recovery and Reinvestment Act of 2009:

- A grant program, in lieu of the tax credits, where beneficial;
- Expansion of the DoE's loan guarantee program;
- Improvements to the investment tax credit and establishment of a new manufacturing product credit for solar, PV, and other renewable manufacturing.

Noting the "incredible progress that's been made in the solar PV industry," including an increase in domestic PV production capacity by over 50 percent in the past year, he stressed the importance of learning "how we can continue this pace of improvement." Mr. Hurst cited several other provisions of the loan guarantee program of the Recovery Act, including an appropriation of $6 billion, which now covers credit subsidy costs. In addition, it provides a new aspect of loan guarantees specifically for renewable energy and electric power transmission. Finally, DoE had announced the offer of a $535 million loan guarantee to Solyndra, Inc. to construct an industrial-scale PV plant in California.

The DoE's solar R&D program, he said, was a broad-based program embracing the full spectrum of opportunities, including long-range R&D, pilot production and supply chain issues, manufacturing issues, and mechanisms to move PV systems into the field.

Mr. Hurst concluded with a quote from a speech given by President Obama, given a day earlier at a wind turbine manufacturing site. He said, "America pioneered solar technology but we've fallen behind countries like Germany and Japan in generating, even though we have more sun than either country. I don't accept that this is the way it has to be. When it comes to renewable energy, I don't think we should be followers. I think it's time for us to lead."

He concluded by noting that he looked forward to hearing from the speakers this morning to learn how we can work together to achieve the President's vision.

FIRST SOLAR, INC.

Michael J. Ahearn
First Solar

Mr. Ahearn opened with the observation that "this is part of the awakening to the Obama administration's change in attitude and momentum, and it's most welcome by the industry." He then offered a brief history of First Solar, which had grown rapidly since its founding in 1999. Eschewing standard crystalline silicon modules, First Solar adopted a lower-cost thin-film technique using cadmium-telluride solar cells. This proved to be a difficult process to master, and the company needed six years to reach steady-state production with its first manufacturing line. Since then, progress has accelerated. In 2005, the first year of production, the company manufactured 20 megawatts of solar panels. In 2008, it made just over 500 megawatts of solar panels, a 2500 percent increase in four years. This year production is expected to double to about a gigawatt.

Mr. Ahearn noted that an important part of the First Solar story has been the lowering of manufacturing costs. At the beginning of this period, manufacturing costs were about even with the rest of the industry at $3 a watt produced. Over the next four years, however, the cost dropped by two-thirds, falling below a dollar a watt at the end of 2008. "That trajectory," he said, "is continuing at a fairly steep rate."

He also stressed the economic development value of the industry. In the course of the manufacturing scale-up, First Solar invested over a billion dollars and created more than 4,000 direct jobs. In terms of the broader value chain, he said, this figure represented tens of thousands of jobs. "So this is an example of a fairly significant success story," he said. "I would also say that this is not unique in the solar industry. It is going on in a number of solar companies, some of whom are represented here. And it's being driven by a confluence of technology, good execution, and good policy, emanating for the most part out of Europe." He noted that work previously done in Europe and elsewhere had allowed his company to "skip a few steps" that would otherwise have slowed development and made it more expensive.

Mr. Ahearn summarized his firm's technological activities, which began with building a conveyor system that moves two-by-four-foot sheets of glass robotically through a continuous process that takes about 2.5 hours. The initial step is the deposition of a film of semiconductor material about the thickness of a human hair. "It's difficult to get into commercial production with any kind of thin-film technology," he said, "but once you're in production at a steady state, there are dramatic cost and scale improvements because of the inherent nature of the materials."

One improvement lever is the potential for greater conversion efficiency—the efficiency at which sunlight is converted into useful electricity. Since First Solar began commercial production, its average conversion efficiency has grown from about 6 percent to about 11 percent. This was due to significant process and device improvements that are inherent to the materials. As more power is added to a panel, for example, there is no incremental cost in making the panel, so that the cost per watt drops significantly. To project future cost per watt by today's situation, he said, is to ignore a very real technology trajectory.

A second source of improvements is economies of scale. Although First Solar's up-front cost is high, its incremental or marginal cost of producing a photovoltaic panel is minimal, because the automated process requires little labor or material. At first, when production was low, the average cost of production was fairly high. As volume increased, the low incremental cost drove the unit cost down at a rapid rate.

A third lever, Mr. Ahearn said, is that of productivity. Higher productivity results from the "so-called learning curve effect—cycles of learning that begin once you're in a rhythm, once you're doing the same things over and over. With learning, a factory is able to produce higher yields, more equipment up-time, and reduced bottlenecking, all of which lower the cost per watt.

With increasing productivity extended into the supply chain and factory replication, the company has been able to accelerate the construction time and ramp-up time for a new factory from 12 months and 18 months respectively to beginning construction of a new factory every three months and a ramping-up cycle much shorter than 18 months. To do this, he said, required bringing along the whole supply chain: equipment suppliers, raw materials suppliers, engineering procurement, and construction. "What our experience demonstrates," he said, "and what others have demonstrated in Europe, is that the private sector is capable of driving such capacity improvements over time."

First Solar had also entered into energy savings performance contracts[3] to build big utility plants in the United States. "We felt that this is the only way to hit the cost point," said Mr. Ahearn. "It's a much more difficult environment here. And what we've seen from relatively little experience to date is a rapid improvement in installation time, cycle time to build these plants, and very fast cost reduction."

The Key to Improving Efficiency

Mr. Ahearn said that the key to real improvements in photovoltaic efficiency is the presence of a market of sufficient size. Despite a modest market opportunity in the United States so far, First Solar, and the industry generally, have been fortunate in being able to take advantage of significant markets in Europe, led by Germany. In 2004, when First Solar was achieving steady-state production, Germany adopted a set of programs that have allowed companies to scale[4] and demonstrate these kinds of results. The markets in the rest of the world, he said, are still small, such as markets for off-grid sites, remote villages, and other special needs. Japan, while pursuing solar power, is virtually closed to companies from other countries. The United States has less than 10 percent of global demand and "has not been a factor," he said.[5]

The rapid progress in solar technologies in Europe was initially spurred by governments' use of the feed-in tariff.[6] This guarantees that anyone who generates solar power can sell that power at favorable rates to the national electrical grid without special permissions or relationships to the local utilities. Thus producers are typically able to count on a market with predictable price points over a known number of years. Company managers and investors who build a factory and staff an organization know they will have time in the market to recoup that

[3]An energy savings performance contract is a contract under which a contractor designs and constructs an energy savings project and a federal agency pays the contractor over time from savings in utility bills.

[4]Scalability, as a property of systems, is defined according to the specific requirements of the system that are deemed important. A system whose performance improves after adding hardware, proportionally to the capacity added, is said to be scalable. An algorithm, design, networking protocol, program, or other system is said to scale if it is suitably efficient and practical when applied to large situations. (Wikipedia, "Scalability," accessed May 26, 2009.)

[5]According to the industry report Solarbuzz, the United States was third in PV market demand in 2008 at 0.36 GW; demand in Spain was 2.46 GW and in Germany 1.86 GW. Total global demand was 5.95 GW. At the same time, U.S. polysilicon production accounted for 43 percent of the world's supplies. <*http://www.solarbuzz.com/Marketbuzz2009-intro.htm*>.

[6]A feed-in tariff is, in essence, a requirement by the government for a utility to pay above-market rates for green electricity.

investment and perhaps earn a profit. In addition, the markets in Europe tend to be fairly uniform, so a firm can make a standardized product and focus its efforts on scale and cost reduction.[7]

The main criticism of this approach is that feed-in tariffs are expensive and cannot be part of a sustainable model. However, Mr. Ahearn argued that the cost reduction trajectories he has experienced should allow such tariffs to be reduced quickly and steeply as productivity increases. He demonstrated from the First Solar internal roadmap how this might happen, noting that other solar companies had similar roadmaps. For the past four years, the company roadmap has projected by 2012 a pricing capacity of 8 to 10 cents per kilowatt-hour. That assumes a turn-key installed system cost of between $2 and $2.75 per watt, depending on the irradiance and financing cost assumptions.

"This is a real plan," Mr. Ahearn said. "We're two years into this and we're more than 50 percent through the milestones. I know a number of solar companies that can tell you the same thing. These are detailed, bottom-up plans that are being executed in the European market to real metrics." He expressed confidence that if the market opportunity continued to exist, these trajectories toward productivity and efficiency would continue.

Mr. Ahearn then turned to the situation in the United States. He said that the symposium presented a good opportunity to be "realistic and fairly candid about where we are." Referring to the comment by the preceding speaker about a 50 percent increase in solar capacity, he reminded his audience that that increase had come "off a miniscule base." The United States, he said, still had a "minimal" amount of solar manufacturing. Even those manufacturers who were based in the United States, including First Solar and SunPower, put the bulk of their manufacturing abroad. This was not by choice, he said, but the realities of a home market that was "fragmented and sporadic"—not the kind of market where a firm can scale the technology or run an efficient business. "There hasn't been a lot of choice," he said. He also noted that almost every state in the United States offers solar incentives of some type—such as a 30 percent income tax incentive—which appear to constitute significant support. And yet a tax incentive may not be sufficient in the absence of strong local and global demand.

Lessons Learned from Europe

Mr. Ahearn did express optimism that a stronger U.S. industry could emerge, despite the current lead held by Spanish and German manufacturers. The United States was still in an early stage, and he foresaw abundant opportunity for it to

[7]At least 64 countries now have some type of policy to promote renewable power generation. Feed-in tariffs were adopted at the national level in at least five countries for the first time in 2008/early 2009, including Kenya, the Philippines, Poland, South Africa, and Ukraine. *Renewables Global Status Report 2009*, <*http://www.ren21.net/globalstatusreport/g2009.asp*>.

move to a leadership position. He added that the timing would also help, because U.S. firms could benefit from the cost reductions and other lessons learned in Europe.

On the demand side, the estimate he had developed based on the consensus of ten industry analysts suggested that Europe would hold 66 percent of the world market by the end of 2009, the United States 10 percent, Japan 7 percent, and the rest of the world 17 percent (he noted that the 10 percent figure for the United States seemed too high). On the supply side, the same analysts estimated that by year end Europe would have 30 percent of total manufacturing capacity, China 27 percent, Japan 12 percent, the rest of Asia 9 percent, the United States 9 percent, and the ROW 13 percent. In absolute terms, the estimated market by 2009 would be 5.6 gigawatts vs. existing and announced manufacturing capacity of 12.3 gigawatts. "The numbers can be debated," he said, "but the basic message is right: There's a lot more manufacturing capacity in the world than there is demand. Absent some change, that's not going to correct itself."

Mr. Ahearn said that policies aimed at increasing manufacturing capacity would not drive a sustainable industry unless they strengthened market demand. "Market demand doesn't increase by itself," he said. "This takes subsidies. And existing markets in Europe cannot grow at an exponential rate or even a meaningful compound annual rate because the burden on ratepayers and taxpayers won't sustain it. So you can't ignore this capacity problem without thinking about demand."

He also pointed to China's large global share of manufacturing capacity. "Polycrystalline silicon production has become commoditized," he said. "Barriers to entry are low or nonexistent. Anybody in this room who wants to get into manufacturing of polycrystalline silicon can do that today. What that means is if you want to be competitive in this, you have to be in China or another low-cost country." He pointed also to technology-driven solutions, such as high-efficiency monocrystalline silicon.

Where to Site a Manufacturing Plant

Mr. Ahearn noted that organic photovoltaic materials, such as flexible substrate, are "a different story. That's where manufacturers like us have a choice in where we put the manufacturing." There are two categories of sites for a manufacturing facility, he said. One is in the country where markets already exist. This is done when a company wants to signal to local politicians that their substantial investment to create a market is recognized and that the host country will now get its payback in the form of investment and value added. A firm might also be drawn to such a country when it has a core set of human skills, technology, and resources, as is the case in Germany.

The second kind of site is one with low labor costs and sufficient intellectual property protection. Such a low-cost environment is less important for a company like First Solar, because manufacturing for its product is largely automated and labor costs are already low. The best opportunity for the United States, Mr. Ahearn said, is the first kind of site, with high technology and a market capable of attracting world-leading firms. He further suggested taking a page from the European experience, which had benefited from a "whole basket of solutions," ranging from renewable energy to energy efficiency to carbon pricing.

Mr. Ahearn turned to a broader view of the low-carbon energy market. In this new market, each candidate technology must move along a timeline of development. This timeline moves through a series of approximate states, as follows: (1) R&D, (2) commercialization, (3) scale-up, (4) sustainable market infrastructure, and (5) mass market penetration. He pointed to onshore wind and hydropower as technologies that have reached the scale-up stage after three decades of development, mostly under feed-in tariff programs, that have brought costs down by 80 percent.

Drawbacks of a Least-Cost Solution

Mr. Ahearn noted that Europe had made the significant decision to promote the sector of renewable energy as a whole. "What Europe does is essential," he said, "European countries review the position of each technology along the development scale, and decide what needs to be done to move it to commercial scale." If countries tried to do this through market forces alone, he said, the market would lead to the least-cost solution. If the policy goal is to scale up a number of alternative technologies that might be needed for the best overall solution, least-cost is clearly not the best. "We're going to have to get our hands a little dirtier here to get the right result."

Solar, he said, is on the early part of the development timeline, moving from R&D toward commercialization. It awaits a set of commercially viable technologies, driven by fundamental R&D that manifests itself in existence proofs, Alpha products, and concept lines—outcomes that characterize technology with commercial potential. "Now we have to put together a cause-and-effect scenario, showing how this technology moves from lab scale to something that will be compelling in the marketplace."

Mr. Ahearn noted that the United States had done a pretty good job in developing its solar technologies. He called the technologies that have come out of U.S. universities and labs "pretty impressive." He said that NREL, the National Renewable Energy Laboratory in Colorado, had been instrumental in First Solar's technology development through the thin-film partnership. He affirmed the key role for the federal government in funding basic science and development through universities, national labs, and consortia to maintain a flow of commercially viable technologies.

Eventually, however, this flow needs more. "When those [technologies] become interesting and ready to put into operation," he said, "you need to move to the next stage of commercialization where you have entrepreneurial activity and risk capital. Those are the traditional strong suits of the United States. We're really good at raising and putting venture capital to work, and we've got a great entrepreneurial base of talent. What's needed to galvanize all that is a compelling market opportunity."

Mr. Ahearn added that during the last few years, several billion dollars in venture capital had flowed into hundreds of photovoltaic start-ups. Most of these new firms, he said, once in production, were planning to move their facilities to Europe to take advantage of incentives. This would constitute a signal to U.S. politicians about the need for local incentives. "This commercialization piece is where it becomes very important to create a U.S. market in a transparent way," he said. "People need to see what's possible if they risk capital."

He also urged that any incentives designed by governments should be non-selective. Trying to pick winning companies, or groups of companies, carries risks. The choice may be wrong and the money might be wasted. And in a new, high-technology field, it is likely that *most* efforts will not be successful. Instead, he suggested, support should be more generic to the point when the private sector can engage. Selection of individual companies can skew the market and signal that government sponsorship is available only for certain technologies. This would provide selective benefits to the exclusion of real market opportunity, and it would leave many companies on the sidelines that could otherwise participate with private sector money.

Once the first manufacturing line is working and the product can be vetted, the need for capital grows quickly and the company needs access to the billions of dollars available only from the capital markets. The United States has well-formed capital markets, he said, with many companies with experience in commercializing technology products.

Mr. Ahearn closed with a plea to let the markets do their work at this commercialization stage and to avoid selective subsidies. "This is an issue for the loan guarantee program," he said. "We're going to see a big logjam now because we have to work through a selective process of the DoE with no visibility. I think we'd be much better off if the government simply enabled all banks to make loans that the market would direct to the right place."

THE GLOBAL PV VALUE CHAIN

Dick Swanson
SunPower

After thanking the Academies and organizers, Mr. Swanson said he would give a short overview of SunPower and review the value chain and its various costs. The company was formed in 1985 to develop technology developed at Stanford University. That early program was funded largely by the Electric Power Research Institute (EPRI) and the U.S. Department of Energy. The initial concept was to produce concentrating systems: large reflecting dishes that focused light on high-performance solar cells, all situated in the desert.

The market for concentrators did not form, however, and SunPower "sort of wandered in the woods a long time building specialty products, such as high-performance solar cells." These culminated in a solar-powered airplane for NASA, which set an altitude record, but did not have broad commercial importance. The company's development was hampered by high product costs.

The fortunes of SunPower turned in 2000, however, when it merged with Cypress Semiconductor. Cypress agreed with SunPower's vision of a large-scale enterprise, and injected much-needed manufacturing expertise into the company. Indeed, photovoltaics is today primarily a manufacturing-oriented business, where successful companies are distinguished by operational excellence.

SunPower opened its first manufacturing line in the Philippines. There the company decided to start moving downstream. In 2007 it merged with PowerLight, which was the world's largest system integrator, and began installing power plants on the roofs of commercial buildings and in large fields. Today the company is global, with offices in the United States, Europe, Asia, and Australia, many of them with manufacturing plants. Revenues for 2008 were about $1.4 billion, placing the company ninth worldwide in photovoltaics in terms of megawatts produced. The company is now in all the main PV market sectors: the retrofit market, allowing people to put panels on existing roofs; new production homes, where PV are designed as part of the roof and are accepted more willingly by customers; commercial and public installations; and power plants, which had driven the original vision behind PV in the 1970s.

Photovoltaic History in the United States

Mr. Swanson reviewed photovoltaics history with respect to the United States. The United States was in a commanding leadership role until the 1980s when the "killer app" of direct residential rooftop installation was developed in Japan. This was followed in the 1990s by the European use of the feed-in tariffs, which drove the second great wave of expansion, leaving the United States behind. Mr. Swanson said that this shift in leadership was consistent with the message that manufacturing and the technology need to follow the markets. "The basic message of my presentation," he said, "is that if we want to have manufacturing in the United States, the United States has to be a market leader."

Mr. Swanson then showed photos of several kinds of SunPower installations: the Sunset Home, in Silicon Valley, CA, a 4-kW SunPower Solar Electric System; the 904 kW roof on the FedEx Express Oakland, CA hub; the U.S. DoE headquarters SunPower Solar System in Washington, D.C.; and the 14MW system at Nellis Air Force Base, Las Vegas.

He turned to the topic of the polysilicon value chain, which he noted is more complex than that of thin-film PV. The SunPower manufacturing process starts with highly refined polysilicon, which is grown into large single crystals, or ingots. Those ingots are sliced into wafers, which are used as solar cells that are laminated behind panels and installed in a PV system. The systems are heavy and somewhat challenging to install, so that the cost of installation is traditionally about 50 percent of the system cost, requiring local manufacturing and labor. The actual ingot is about 20 percent of the cost and the manufacturing and conversion into panels about 30 percent.

Mr. Swanson said that in preparing for this talk, he met with the company's operations leaders to calculate the U.S. content in the current value chain. "We meticulously calculated it," he said, "and the answer knocked my socks off." Basically, he said, the U.S. content for a SunPower module, even though it is manufactured in the Philippines, is 70 percent. "It shows us that you really don't want to focus on where the cell is made, because that is not where all the value is." Part of the reason is that essentially all of the installation—at half the cost—is done in the United States. He did say that the U.S. number would have been 100 percent 20 years ago, and that stemming the shift toward non-U.S. sources will be challenging in the future.

Beginning on the left-hand side of the value chain, SunPower buys its polysilicon from Hemlock Semiconductor Corp. in Michigan. "This is hugely capital intensive," he said. "And despite numerous startups in China and elsewhere trying to get into production, most of the polysilicon is still produced in the United States. Other major suppliers include REC, a Norwegian-owned plant located in Montana, and MEMC, a U.S.-owned plant in Pasadena, Texas. The only non-U.S. suppliers to SunPower are Wacker, in Germany; DCC, in Korea; and a new firm, M-Setek, in Japan.

The next step is growing ingots, and SunPower buys its ingots from a joint venture with Woongjin Energy of Korea. This step is capital intensive, requiring only 25 to 50 people per MW of capacity. A single operator can look after 12 ingot-growing machines.

Producing the wafer, on the other hand, is fairly labor intensive, requiring 75 to 100 people per MW of capacity. The plant locations for this step are in the Philippines and Japan. Much of the equipment, however, is produced by Applied Materials in the United States.

Making solar cells is considerably more labor intensive, employing 300 to 600 people per MW. The manufacturing plant is in the Philippines (SunPower Manila) and a second plant is being built in Malaysia. Again, much of the equipment is built in the United States.

Regional MODCOs

SunPower hopes to reduce the labor cost of the solar panel stage by further automation, which is now being developed. This is an exciting development for SunPower, Mr. Swanson said, because it will allow construction where local markets exist and reduce the need to ship components from low-labor-cost countries to large-market countries. Today, for example, SunPower buys glass in the United States, ships it to China for module construction, then returns the modules—which account for 95 percent of the weight of the finished product—to Germany for installation. In the future SunPower will use "regional MODCOs," or module companies, located near the market that can respond quickly to customer changes in demand, avoid months of inventory tied up on ships, and use standardization to bring the costs down.

System integration, the final link in the value chain, is also by its nature a local activity, he said, which uses steel and concrete and depends on a lot of labor—currently about 250 people per hundred MW. This number, like the others, can scale up or down depending on the kind of market expected. In any case, it takes traditional construction, electrical, engineering, management, and other skills to build PV power plants.

In conclusion, Mr. Swanson described a straightforward advance that promises to raise the efficiency of system installation. This is the use of local assembly sites that are standardized and predesigned. Panels are arrayed on a tracking structure, factory-like, and installed by the same technique at every site. This innovation will be accompanied by another that uses simple concrete foundation pads to replace the higher-cost tradition of drilling through the ground for concrete piers. Without the challenge of rock and other features of local geology, a crew can install a PV plant far more quickly. At end of last year the company was assembling 2 MW of capacity per day per crew, or three-quarters of a GW per year per crew. They were essentially building a large power plant in one year.

UNLEASHING THE POWER OF THE SUN

Eric Peeters
Dow Corning Solar Solutions

Dow Corning plays a very different role than First Solar or SunPower in PV activities, Mr. Peeters began. Dow Corning is one of the first joint ventures created in the United States, founded by Dow Chemical and Corning in 1943 to explore the potential of the silicon atom, which it still does today. And the silicon atom plays an essential role in the solar PV industry, either as a semiconductor material or a material used in other parts of the value chain. Dow Corning is a $5.5 billion company which employs about 10,000 people, divided almost equally among the United States, Europe, and Asia.

The organization is heavily R&D-oriented, he said, which is rare in the chemical industry. It sees itself as becoming the "material house" to the PV solar industry, in three general ways:

- In 2006, Dow Corning launched the first commercially viable metallurgical grade silicon feedstock produced using large-scale manufacturing.
- In 2008 the company announced an investment in a facility to produce monosilane gas as a feedstock material for amorphous silicon thin-film panels.
- There is a good fit between the silicons and the kinds of materials used in construction, electronics, and other industries that raise efficiency in the solar PV market.

Mr. Peeters added that Dow Corning materials help lower cost and improve efficiency, two of the primary manufacturing challenges.

In 2007, the company invested $1 billion in Hemlock Semiconductor Corp., in Michigan, a joint venture for which it is majority owner and a leading provider of polycrystalline silicon and other silicon-based products. In 2008, it announced additional investments of up to $3 billion to expand production, which is very capital-intensive. One reason Dow Corning chose to make that investment in the United States is that the level of technology is high, trade secrecy must be preserved, and it allows huge integration benefits with Dow Corning silicon plants. "That is helping us have a world-class cost structure here," Peeters said. "It is very automated, almost like a chemical plant, so that labor cost is fairly low. Integrating and recycling all the byproducts is important in polysilicon manufacturing. The company is also making investments in R&D application centers."

The Challenge of Reducing Costs

The fundamental challenge for solar PV or any other alternative energy technology is to reduce the cost of the energy per kWh, Peeters said. While the industry needs some form of subsidy and government assistance to grow, he continued, "clearly in the future it has to be self-sustaining. This means the ability to provide energy at an affordable cost without subsidy." What SunPower and First Solar and Dow Corning are really working on, Mr. Peeters said, is the technology roadmaps to reduce costs sufficiently so they can be competitive with anyone, anywhere. He noted that First Solar was hoping to achieve a cost of 10 cents per kWh or less. "I really believe that's where this industry has to get to," he said.

Actually reducing the cost per kWh, he said, rested on four pillars: technology innovation, operational improvements, better raw material conversion, and improved durability.

The first step of innovation refers not just to incremental improvements to the mainstream crystalline PV industry, but true technological change. While Dow Corning does have an important position in the polysilicon operation of Hemlock, he said, there is room for other technologies as well. "This is a big market that's going to segment into different needs," he said, "so innovation is needed. I expect a virtually unlimited diversification of different technologies that will co-exist for quite a long period."

The second factor of central importance, Mr. Peeters said, is operational excellence and economy of scale. This is not limited to the chemical and electronics levels in producing solar cells or modules, but requires

- Increased throughput or yield through automation and process innovation;
- Lowering of capital investment by means of process optimization and innovation; and
- Reduced labor with better management.

The third pillar, he said, is raw material conversion efficiency. "The reality is that the solar industry is young. In practical terms, this means that we have some fundamental inefficiencies. For example, when an ingot is sliced into wafers, the saw is as thick as the wafer, so about 50 percent of the material is lost. That is true throughout the value chain. The industry is improving, however: Half a decade ago, most manufacturers used about 10 to12 grams of polysilicon for 1 watt peak. Today, raw material usage has dropped to 7 or 8 grams for some firms, and a few are below 6.

Finally, increasing the durability of solar panels brings the cost down. Although the industry reports its output in peak watts, this is basically a theoretical measure that is seen in the laboratory rather than on the rooftop. "What's really important," Mr. Peeters said, "is how many kilowatt-hours you can get out of the lifetime of the panel, and how do you improve that. One of the most important things is to ensure that the module lives longer." Today the standard in the industry is that a module is guaranteed to maintain 80 percent of its rated power output for 20 or sometimes 25 years. He said that this would have to be raised to 90 to 95 percent of the power output for 30 and 40 years—again through innovation across the value chain.

Partnering with the Academic World

In addition to reducing costs, a successful PV industry will depend on basic improvements in manufacturing. This must begin by backing up manufacturing with ongoing R&D and innovation. Some of this will happen in industry, he said, but success will come primarily from the academic world, and from strong collaborations between academia and industry. Mr. Peeters noted the presence of a representative from the Interuniversity Microelectronics Centre (IMEC) at the symposium—"not just because I'm a Belgian, but IMEC is a really good example of how to do this successfully." He said that while feed-in tariffs and other policy measures have helped make the solar market successful, the research institutes, such as IMEC, Fraunhofer, and a few others, have also fueled innovation and industry growth.

Improved manufacturing also benefits from firms working together. “I think we are doing that through natural market mechanisms,” he said, “but there is room for government to provide more infrastructure to promote that.” A solar panel essentially is a system, he said, with different components, so that improving the system means improving every element of the system. He praised efforts at cross-industry collaboration along the whole value chain as well. “If someone comes up with a great new glass technology, and then someone else comes up with a great new way to assemble that glass into a panel, the whole industry benefits.” Mr. Peeters said that the United States Department of Energy, as long as it remained “technology-agnostic,” could help stimulate some of that research so it goes in the right direction. “It’s important not to try to pick the winners when it’s too early,” he said, “but to stimulate all the different players. This industry will for a long time need some pretty creative solutions.”

Investment is also needed to achieve world-class manufacturing standards with a high degree of automation. This is true especially for the United States, where labor costs are high. This must be accompanied by stringent quality standards for fabrication and installation of the modules. Because the PV industry is so young, there are no real industry standards, and those standards in use are adopted from the electronics, semiconductor, or sometimes the construction industry. “We have a lot of work to do to ensure that a homeowner installing solar panel on the roof gets the right quality,” he said, noting that some new companies entering the market, especially from overseas, have uneven quality.

A fourth success factor for PV manufacturing is technical talent, which must be educated and developed to work throughout the value chain as well as in installation. He warned that this could prove to be a bottleneck to solar development. In a new industry such as this one, installation is done by many different people, especially in residential settings, so achieving a consistent quality of work will require extensive work force development.

The last, and most important factor, Mr. Peeters said, is demand. “It is going to be impossible to create a U.S.-based domestic industry if there is no domestic demand. This must be stimulated at every level, from residential to utility scale.” He said that there are no barriers to doing this, and pointed to Europe as an example. Belgium used a combination of tax incentives for investment at residential level with a system of green certificates and electricity meters that can run in both directions. The market there in 2008 was close to 50 MW. At the scale of the United States, this would mean a market of 1.5 to 2 GW in 12 months. When sunlight conditions are taken into account, the United States would actually do much better than that. Every state in the United States, he said, has more sunlight than Belgium.

What can the government do? asked Mr. Peeters. Clearly, he said, the federal government has a leading role in stimulating demand and “making America a 21st–century solar power.” Obvious federal policies to promote demand for solar include federal tax incentives, formulation of national renewable energy standards, federal interconnection and net metering standards, and feed-in tariffs. "We have to get people to connect to the grid," he said, "and make sure the grid works well." In addition, increased federal funding for solar R&D is essential, he said, as is support for the education of "the people who are going to have those green jobs—a green-collar work force." In short, he concluded, the task is to "establish the federal government as a green energy leader."

DISCUSSION

Roger Little, founder of Spire Corporation, commented that "the United States is on the brink of becoming the fastest-growing producer of PV in the world," with the help of the stimulus bill and state initiatives. He cited market projections that estimate about 5 GW of capacity in 3 years, which equals today's global market. That market, he said, will be filled principally by today's technology of crystalline silicon, which today has a manufacturing capacity of a few hundred MW. A likely consequence of an expanded U.S. market, he said, is the creation of "10,000 Chinese jobs," noting that Spain's recent market surge led to some 8,000 jobs in China. "Now is the time to have a buy-American clause in contracts," he said, "so we get a chance to develop our domestic industry. We don't mind if people come from Europe or from China to establish factories, but if we import the modules that are going to be required in 2012, we're going to obliterate domestic manufacturing."

A participant from NIST addressed a remark to Mr. Ahearn, questioning the wisdom of having the government step back at the point of commercialization and letting the private sector take over. "From my own personal experience that doesn't work very well," said the participant from NIST. "My experience with VCs, as an entrepreneur who has started two companies, is that the VCs take technology they don't understand and run it into the sand bar because of their need for quick turnaround. A lot of innovative technologies die on the vine because the VCs get involved. So I think there's room for both VCs and public in commercialization."

Mr. Ahearn said he disagreed. He said he had not had a successful result with a public investment, and that "if the market opportunity is clear, we ought to be thinking about what does it take for GE, or Dow, or SunPower, or First Solar—the big companies that are going to make a difference—to come in and build that capacity rapidly and invest in the value chain."

Mr. Ahearn said he did not favor government selection of specific companies for support; this takes too much time and effort, compared with the marketplace's ability to move faster. Noting how rapidly China had moved to create capacity, he said that "we're going to need something that can move quickly and smartly. And usually getting that to the market force level works best."

Panel II

Opportunities and Challenges Facing PV Manufacturing in the United States: Large Companies' Perspective

Moderator:
Pete Engardio
BusinessWeek

Mr. Engardio commented that his magazine was extremely interested in the issue of U.S. global competitiveness in green technologies, especially as the country emerges from the current financial crisis. What kinds of industries will create the jobs of the future? Will the immense investment in R&D translate into jobs and industries that employ more than engineers and people who install equipment? The broader issue before this panel, he said, is of critical importance: How sustainable is our lead in not just solar technology but in a whole range of industries for the long term. He encouraged panel members to address this question.

PV MANUFACTURING IN THE UNITED STATES

Eric Daniels
BP Solar

Mr. Daniels began by saying he had been in the solar energy industry for nearly 30 years, and believed there is a strong future for solar technology in the United States. Of the companies in the business, BP is one of the most senior, he said, and has reached a "watershed moment" in its expansion plans. Its factories in the United States at one time led the industry in capacity, and it was now planning to restructure its manufacturing in preparation for the next stage of growth, with an effort to site competitively priced manufacturing closer to key markets.

He said that BP Solar was the first to commercialize multicrystalline technology, which grew to about 50 percent of the substrate market. The company had worked with the Department of Energy and universities for most of those years in "successful relationships," and had produced in particular one product through those relationships that is critical to the company's future—"new students, architects, engineers and marketers for this industry."

Mr. Daniels described three kinds of forces that were necessary to moving the business ahead. The first was R&D, he said, describing a dozen or more essential partnerships of great value, including one with Dow Corning, one with IMEC, and a new one with Applied Materials. The other two forces, he said, were market incentives and manufacturing incentives. He singled out the manufacturing incentives offered in China as "pretty spectacular," saying that for one project his team had been offered "more or less free facilities, with infrastructure supplied, in an environment where growth is essentially unlimited. Those are hard incentives to turn down."

Mr. Daniels pointed to some events (market incentives) of the past as "a good indication of things to be concerned about." Most of the industry, he said, had grown up in an off-grid market. Japan launched several incentive programs in the 1980s and early 1990s[8] that stimulated growth for the industry as a whole and gave birth to the idea of solar-powered homes. As the solar home market was penetrated and market incentives declined, a lot of the Japanese local market opportunity began to diminish, and Japan itself tried to shift to export markets. More recent German incentives,[9] he said, had been critical to the growth of the early part of this decade, when many companies had found profits in utility projects. Today, incentives in Germany are being restructured to favor the residential market.

"My reading of the tea leaves," he said, "is that more of the German community can participate in the growth of the industry by looking at the residential market than they could from a focus on utilities." At the same time, he said, utility scale projects "are critical in bringing the scale we need for our cost curve." The Spanish government began its incentives in 2008, and consumed *at least 70 percent of the industry's output*—over 2 GW—in that year. However, in 2009 this consumption is expected to shrink sharply to about 300 MW. "In the space of a year," he said, "because of how fast they brought enormous supply to market, in 2009 Spain is likely to now be a smaller part of the overall pie." As a result, he foresaw a year, 2009, when growth will be capped, capacity stranded, and prices decline as much as 15 percent. "As a manufacturer thinking about bringing on new capacity and new technologies," he said, "it's hard to plan around that (e.g., changes in market incentives)."

Mr. Daniels said that he was not pessimistic, however, because the industry had been through this kind of "jolt" three or four times already. He said he had learned that "we always end up with the massive amounts of growth after such market corrections, primarily because of changes of price points in the market. We're already seeing substantial change in pricing going into '09."

[8]See, for example, the New Sunshine Program of 1993, whose short-term (2000) target was to develop PV technology that could produce electricity at a cost competitive with conventional electrical rates.

[9]See Michael Ahearn's discussion of trade-in tariffs, above.

Strong Job Creation

Mr. Daniels noted that the solar industry also has a bright future in job creation. At the current time, the Photovoltaic Association in Europe calculates that three of every four jobs related to the industry are in "downstream" installation activities, with one of four in manufacturing itself. The ratio is even larger if one includes making existing home conversions, procurement, and other ancillary activities.

He turned to the topic of grid parity,[10] which has long been an industry goal. Most current PV systems were installed at a cost of about $8 per watt. Before rebates or incentives, he said, this translates into retail costs that are becoming competitive with utilities. For example, for northern California, PG&E during peak hours of the day charges 35 cents per kWh; the retail amortized cost, before rebate, of PV power is about 20 cents. "So," he said, "the math is starting to work."

Further optimism for pricing is caused by 2009 installation costs approaching $4 per watt for crystalline and thin-film products, which is about half the costs for existing installations. "We're starting to get into rates that are competitive with off-the-peak utility rates."

Turning to manufacturing challenges, Mr. Daniels said that BP Solar had "a long history in the silicon part of the value chain." A particular challenge was to "extend the art beyond multicrystalline technology." The company in 2006 discovered a new technique it is now bringing to market—in effect a new way to grow monocrystalline silicon, leading to the production of high efficiency cells and allowing for lower costs. The company is working with IMEC and others who had already achieved over 17 percent efficiency with traditional technologies and are now looking at over 18-19 percent with some specialized cell processing. This technique, however, requires a high capital outlay. "It's a wonderful thing if you can plan on the future being there to use that capacity and new technology," he said. "It's a disaster if we go into this with 50 percent capacity utilization." This technique, Mono^{2}™, also requires access to metallurgical silicon with low energy costs of production, and market access to be successfully deployed.

The Need for Improved Standards

Mr. Daniels emphasized the need for improved standards and quality as the industry grows. The design and standards for today's solar modules, he said, came from the United States early in the industry's development. A manufacturer can choose to comply with these standards or not, but they are critical in building consumer confidence. In the past, the goal of the industry was watts, or

[10]A state of grid parity is achieved when the cost of photovoltaic electricity is equal to or cheaper than grid power. President George W. Bush set a goal of 2015 for solar power to achieve grid parity in the United States.

"horsepower." Today, he said, the emphasis has to shift to energy—from horsepower to miles per gallon; from watts to watt-hours. In most markets today the customer pays for watts. "We would like to begin being paid for kilowatt-hours. There will be a natural migration of jobs back to the United States as we move to bring on market scale. A lot of programs today are making the solar modules more efficient." He mentioned the company's ThermoCool™ technique that will change the thermal characteristics of the module toward higher energy output. He also said that circuit optimization in solar arrays can raise energy production by more than 28 percent due to being more shade and soiling tolerant, "which is good for utilities and consumers. However, if the customer is only paying for watts, or power, it's of less interest. Here's an opportunity to think about industry incentives in a new way, energy focused instead of on watts."

A strong point for solar power systems is their reliability over time. "We have regularly delivered solar power systems that have 99.998 percent availability," he said, "which is a phenomenal statistic if you're in the power business. Solar power can be deployed on either side of distribution (wholesale or retail), so in the smart-grid sense, solar can be sold on the retail side of distribution without adding more current or carrying capacity." A disadvantage of solar is that it is not "dispatchable," so that a major area of current BP research is power storage.

Utilities also worry about the effect of clouds and weather moving from one part of a grid to another and the effect of weather on power generation.

The "SmartGrid/EnergyNet" concept seeks to develop a means to forecast the impact of weather and resultant change in energy output from the renewable energy device. Within the SmartGrid/EnergyNet concept, solar can be thought of as a wireless power supply that can be deployed off grid or on grid, and its value increased beyond being a clean energy source for residential, commercial, and utility markets. He mentioned companies that use solar modules on the retail side of distribution to generate power for wastewater treatment, irrigation, and other daytime uses, reducing the peak load on the grid. During the day, the energy is provided at the point of consumption by the solar power system without having to travel over grid lines. At night, energy is provided over traditional utility distribution grids. In doing so, loading on our grid infrastructure is reduced. How is this valued economically?

Finally, Mr. Daniels made the point that PV electricity has a natural role in DC lighting systems, some of which already have storage. Solar can be added as a source of power when the sun is available; when there is more PV power than needed, the rest can go to the grid or to storage; when there is less, stored sources are tapped or energy is taken from the grid. Such newer lighting systems take advantage of efficient LED bulbs that can operate on DC electricity and in doing so avoid the need to have solar DC power converted in to AC. Wireless communications are another application in the EnergyNet that can be similarly powered. Each such application is small, he said, but collectively they consume a substantial amount of energy. Such applications offer the means to take electrical loads off our capacity-strapped distribution infrastructure. "Pursuing such applications for solar is also a great way to engage more industries in the clean-tech journey and create more green jobs than currently envisioned in smart grid discussions," he said. Support for applications development may also provide means for sustainability via broader uses for solar.

In summary, Mr. Daniels, like other speakers, made the point that "good market growth leads to jobs." Not all jobs need to be solar device-oriented, he said, but could grow further through incentives for applications development and energy modeling support. Nor is there any reason to limit clean tech to the SmartGrid as currently conceived: It can bring broader industry engagement and support, and lead to an improved grid. There are many ways to leverage the technology's natural attributes, he concluded. By simultaneously leveraging utility, commercial, and residential markets, the United States can drive scale while creating incentives for broader industry participation.

APPLIED MATERIALS' PERSPECTIVE

Mark Pinto
Applied Materials

Mr. Pinto reviewed the history of his company, which was founded 40 years ago and became a world leader in semiconductor equipment manufacturing. In the early 1990s it entered the flat-panel display market and is now the largest maker of equipment for the LCD, TV, and monitor industry. Five years ago it moved into equipment and manufacturing solutions for energy, and today manufactures equipment for wafers, thin-film-based PV modules, and flexible substrates. In the past 12 months, revenue in the energy area was almost $1 billion, out of total revenues of $7.4 billion, indicating rapid growth. He showed a slide indicating that Applied Materials is the world's leading supplier of equipment for the production of PV cells and modules,[11] producing nearly twice the dollar value of its nearest competitors (almost all of which are European).

He showed the company's progress against a background of the Moore's law learning curve, which he said was useful in understanding where the industry might go. Since 1968, the cost of a transistor has shrunk from about a dollar to about a nanodollar. By the same scaling, an iPod manufactured in 1976 would have cost $1 billion, vs. a hundred or so dollars today. "So that's the power of the learning curve," he said.

What underlies the drop in cost, he said, is the drivers of the cost per function, and many lessons learned in the semiconductor field can be applied to PV. An overarching lesson is that cost is extremely important in consumer products. Cost per function can be divided into two things: a process cost (consisting of

[11] Source: VLSI Research, February 2009.

such components as substrate cost, tool productivity, consumables costs, and utility costs) and the function being improved (such as materials innovation, process innovation, and process uniformity); in other words, how much value you get per unit area. In integrated circuits (ICs), the value per unit area is measured in transistors—how many transistors can fit (Moore's law). In PV technology, the value is watts: How many watts do you produce.

Mr. Pinto listed several factors that drive cost per function:

- Nanomanufacturing technologies have driven down integrated circuit and flat panel display costs and encouraged adoption.
- Demand drivers have been critical. IC applications were first driven by government—for use in missiles, for example. Then came information technology and mobile technology. In displays they were used first in laptops, moved to the monitor, and are now in television. Those developments have driven investment and progress, with different cost points making each investment worthwhile.
- Some level of standardization is important to create critical mass. In semiconductors, the standard use of CMOS[12] underpinned the entire technology, but in solar, there will be diverse technologies. He predicted that other factors would bring standardization and help the industry gain critical mass.
- Large-area tooling can be a major factor when process cost is significant. This differs from ICs, where the primary goal has been transistor density. Costs of architectural glass and flat-panel displays are driven by the process cost per unit area. Reducing that cost requires large-area equipment to increase throughput and reduce unit costs.
- Factory site location does not necessarily signify ownership. Applied Materials supplies equipment to sites around the world.

Steady Progress on Costs

Mr. Pinto described the learning curve of solar in terms of module per cost per watt. There has been steady progress since 1980, when the cost was $1 per kWh in equivalent electricity cost. Today the cost is almost 10 times lower. There was a "little bump" in that curve caused by polysilicon shortage in 2007, which is now being resolved. In addition, the advent of thin-film technologies around 2007 is bringing even lower production costs, even though they have to compensate for lower efficiency.

Factory scale has changed even more rapidly in the past few years, he said. In 1980, Arco Solar opened the world's first factory with a production line size of 1 MW per year; it took 20 years to reach a capacity of 10 MW. In the next few years there will be factories that can produce gigawatts of capacity. This steady

[12]The complementary metal-oxide-semiconductor (CMOS; pronounced "sea moss") is a major class of integrated circuits used widely in both digital and analogy circuits and transceivers.

progress he attributed to demand initiatives in Japan and Europe, continuous innovation, and manufacturing scale. "You don't get progress by waiting for a miracle. It's been constant investment. That's one theme we see across multiple industries. Nor do you get a pass if you just stay on the sidelines. This doesn't mean you should not invest in breakthroughs, but constant investment and manufacturing scale can make huge steps."

Mr. Pinto turned to data he had assembled in October about his customers' plans to add capacity in various areas of the world, both in wafering technology and in cells. China accounted for almost 50 percent of planned new wafering capacity; the United States planned virtually none. For cell capacity, China's plans accounted for 35 percent, the United States for about 5 percent. "I did this by headquartered companies," he added, "not by where they planned to site the plant. That would look even more dramatic." He noted also that 66 percent of solar equipment suppliers are headquartered in Europe, 22 percent in the United States, and 12 percent in Japan (not including wafering).

The keys to crystalline silicon manufacturing, he said, begin with extremely thin wafers that are sliced with minimal materials loss. This requires advances in materials science, he said, where "interfaces at the nanoscale really matter." Another essential step is development of high-throughput tools. He illustrated a system in silicon that has raised the throughput from tens of wafers an hour to 3,000 wafers an hour. Finally, he stressed the importance of manufacturability and factory control. "If you're not careful," Mr. Pinto said, "you can go to higher efficiency but get a much wider spread in your factory output, which makes the whole factory investment less efficient in the number of watts per year. The only way it can work is to keep distribution tight, and that's been a challenge for the industry."

As an example of manufacturing improvements, he said that the firm had begun in 2007 to build garage-door-size panels to lower production and installation costs. There are now 14 such projects worldwide, with five in production: Three are in China, one in Taiwan, one in India, one Abu Dhabi, and the rest in Europe. None are in California. "One message," he said, "is that eventually these factories will be sited where the building material will be consumed. So they will come to the United States; it's a question of when."

The new factories are enormous. A one-gigawatt thin-film factory would consume 500 tons of glass a day, enough to cover 7.5 football fields. The plant would occupy a site the size of the Magic Kingdom in Disney World. The point of this kind of scale is that it brings the equivalent of a 20 percent cost reduction, which is equivalent to reaching grid parity one year earlier, or raising module efficiency by 1 percent. "Making scale drives down the learning curve all by itself."

Importance of the Demand Side

In discussing what could stimulate growth in U.S. PV manufacturing, Mr. Pinto, like others, emphasized the demand side. Here he stressed the importance of accounting for true future costs. "One of the things I find frustrating in talking with utilities," he said, "is that they think about their current model, not about where the utility may go. We need to broaden the discussion to the future—to smart grids, the value of time of day and year, and fossil fuel cost uncertainties. One thing Europe did in their feed-in tariffs was to include the hedged value of the fluctuation of the oil prices. That is typically not done here, and is something we should have learned in the last 12 to 24 months."

He described other aspects of the demand side that should be considered in stimulating growth:

- Appropriate cost mechanism for carbon: The cost of burning carbon must be included, he said, because "it is coming."
- The value of distributed power: PV has the unique advantage that it can be built to any scale at any location on or off the grid: a house, a field, or a desert. This flexibility should lower the total utility cost.
- Multiyear generation contracts: When a technology has as steep a learning curve as PV, the costs are coming down rapidly. If they are averaged over the next five years, for example, the cost of panels would be lower than today's cost.
- Progressive and enforceable renewable energy efficiency standards: "We shouldn't wait until 2019 to all of a sudden catch up."
- Refundability of renewable credits: He said that Applied Materials has many potential customers who would be willing to invest in factories if there were a market in the United States. They would not make money at the outset, so that tax credits would be less helpful than renewable credits.
- A clean energy bank for low-interest loans: He said that solar should be considered a capital good. "Even if you put it on your house, you have to lay out the money ahead of time. So in analyses when you see levelized cost of electricity, there's an assumed interest rate. If the prevailing bank interest rate is used, the economics of solar change dramatically. Using 8.5 percent, the rate of return of a utility, the levelized cost goes up significantly."

Mr. Pinto concluded by noting the advantage of incentives for both manufacturing and for R&D, as practiced by Germany. He said that one of the company's first customers for a thin-film factory was an Indian national investor based in the United States. The factory, however, was sited in Germany—because of the incentives.

In summary, he closed with a quotation from J. Robert Maxwell, Westinghouse's Director of Solar Programs in 1981: "If a guy took out a piece of glass, poured some fluid on it, held it up to the sun and got some voltage off it, he made a headline and got funds. Those days are over. It's time for big money commitments." That statement, he said, is even more accurate today.

DUPONT REFLECTIONS ON PHOTOVOLTAICS

Steven C. Freilich
E. I. du Pont de Nemours and Co.

Dr. Freilich summarized DuPont's solar activities as "upstream in the supply chain and value chain as a materials supplier." He displayed the corporate vision "to be the world's most dynamic science company," and said that "one way to keep that vision fresh is by focusing on—and in some cases, creating—the global megatrends." These global trends, notably driven by the unprecedented growth in developing countries, he said, lead to increased need for efficiency in food production and new kinds of renewable energy, such as photovoltaics.

DuPont, he said, had been in the photovoltaics industry "since its beginning." The first solar battery, produced at Bell Labs in 1955, used DuPont ultrapure silicon. He said that DuPont, since those early years, has specialized in nonsilicon materials for the conductors, back sheets, front sheets, encapsulants, engineering resins, and processing chemicals of PV modules. The company believes, he said, that thin-film PV is "a tremendous opportunity," not just for DuPont but also for the industry.

Thin Film on Flex

Dr. Freilich turned to the specific topic of thin-film PV on flexible substrates. "My feeling is that PV on flex creates an opportunity for thin films in opening up new applications and potentially whole new markets," he said. At the same time, he emphasized that thin film represents substantial materials challenges. It requires a flexible, durable, protective front sheet that is competitive with glass in blocking moisture transmission. "From a polymer perspective," he said, "this is essentially unheard of." Yet his laboratory in Central Research and Development is now developing just such a polymer system as a protective front sheet for thin-film modules. The coating is only 20 nm thick, and in 85 percent relative humidity 85°C on a CIGS (copper indium gallium diselenide) thin-film cell, its durability and protective ability can indeed compete with glass. So far, he said, these are laboratory results, and they are "asking an awful lot out of a polymer system."

He said that another exciting potential of "thin film on flex" is low-cost roll-to-roll processing with monolithic integration.[13] A number of labs have found that using CIGS brings large (4-5 percent) increases in efficiency as the temperature of deposition rises. What is required is a flexible, insulating substrate, such as a polymer that can survive at 500 to 600° C and match the coefficient of thermal

[13]A joint project with the NREL. Monolithic integration aims to provide cost-effective and reliable integration of all components of an optoelectronic device on a single substrate for a wide range of applications.

expansion in the film system, he said, which is "virtually unheard of." Moving to such materials will not be possible by incremental improvements from existing materials, but will require substantial investment in "radical new materials and processes."

A common thread for this and other efforts, he said, is that they are done in collaboration with university or national laboratory partners. This concept of "open innovation" has been a feature of DuPont research for the last century. "We recognize that while we have a strong and vital research facility ourselves," he said, "we cannot possibly have all of the best people in the field. So we have to reach out to our industrial partners as well as the national laboratories and universities." Dr. Freilich added that it is critically important for government to understand that funding small companies, universities, and government labs is "critical to the life blood of large companies."

The Advantage of "Open Innovation"

Open innovation is most important in a rapidly moving industry such as photovoltaics, he said. When both technology and markets are moving quickly, the rate of change is very high, and this in turn means that investment becomes obsolete quickly. Dr. Freilich offered a cautionary tale from the display industry. In 2005, four major technologies were jostling for market share as the size of display panels grew ever larger: the traditional cathode ray tube (CRT); plasma displays, which was pushing the CRT for dominance in the mid-sized displays; liquid crystal displays (LCDs), which dominated the high-definition hand-held market and had suddenly solved problems in larger dimensions; and rear projection, which had dominated the largest sizes. Plasma was quickly pushed by LCDs, out of the mid-size market, which then pressured the rear projection displays, leaving the market to just two technologies instead of four. The investment of every one of these technologies amounts to billions of dollars per fabrication unit, and yet companies must be prepared to shift quickly to keep up with evolving technologies, consumer tastes, and price changes. "You may think that [the display competition] is over now," he said, "but up in the corner [of this chart] you find organic light emitting diodes, and in a couple years we're going to start seeing this shift happening all over."

The same cautionary tale must be applied to PV, he said, with all its different technology options. "From a materials supplier's standpoint, there can be a disincentive to do truly revolutionary work when you see this rapid change in markets and technologies. We can do it, but the investment is so great, and rate of return so dependent on the longevity of the technologies, that you're not going to see the kind of innovation you need." Instead, Dr. Freilich said, companies had to confine themselves to the incremental change of existing materials and technologies.

One solution for this state of affairs, he said, is government support to "de-risk" R&D in these areas. "The materials industry is wonderful at managing situations of large market uncertainty, a good rate of market change, and a moderate

rate of technological change. Government labs, universities, and industrial basic research organizations are good when the technology is new, technological rate of change is high, and the market is embryonic."

One organization that manages this balance well, he said, is DARPA, which is experienced at driving consortia and development support. As an example, Dr. Freilich mentioned a high-efficiency solar program initiated by DARPA several of years ago. DuPont is now the prime contractor and works with up to 13 organizations—industries small and large; academia; and government labs—toward a clear target. There is financial support not only through the invention stage but all the way through development, prototyping, and the early stage of manufacturing.

Controlling a Fast-Moving Technology

Another way of controlling a fast-moving technology and fast-moving markets, Dr. Freilich said, is through roadmapping. He gave the example of the International Technology Roadmap for Semiconductors (ITRS), in which DuPont has participated. The roadmap for lithography explored five technologies of note from 2000-2003: 157-nm lithography (which was dropped in 2004); 193-nm lithography with water immersion and double imaging; 193-nm lithography with high-index fluid immersion; EUV; and nanoimprinting. The ITRS was able to lay out the objectives for each technology, performance goals, milestones, and timing. This is important to a materials supplier, he said, because it clearly shows when a research program is not performing well. "You may think you're doing fine," he said, "but the roadmap makes it clear that there is some other component to success that isn't happening at the right time scale. Since everybody is working from the same page, everybody understands the same things about where the industry is going, what it needs, when, why, and how much. It gives you a chance to address shortcomings at the R&D phase, or at least before there's been a tremendous investment."

Dr. Freilich noted that the federal government plays an important role in technology development. In addition to helping close the "valley of death" between federally funded R&D and major private investment, federal support for universities and government labs is also needed to train the people who make up the industry. Since these people are not just U.S. nationals, the government needs to ensure that international students and engineers can easily enter and stay in this country so U.S. industry has access to the best people in the world.

Dr. Freilich closed with some thoughts about the issue of incentives. Although the right policies and incentives are "kinetically" important in jump-starting the industry and keeping it moving at the embryonic stages, they cannot be "thermodynamically" important. That is, the industry itself has to be self-sustaining. "We want to be sure we create incentives that if pulled out will not sink the industry. PV has to stand on its own. One of the things that can help is that the government is an early buyer; it can set price floors, as it has in other industries. Even a company as large as DuPont constantly has to make decisions about programs at the margins. Often it's the high-risk, potentially high-reward programs that drop off when there is too much uncertainty. Government incentives that build market size and industry support can help industry make the right decision about those programs on one side or another of that very gray line."

DISCUSSION

Dr. Wessner asked Dr. Freilich what level of R&D support is needed for the industry, and to what extent has recent progress in Asia been driven by lower costs of capital. Dr. Freilich said that the level of R&D support would vary with the particular technology being pursued. "The question really should be about when you bring in support," he said. "If you bring it in at the early stage of R&D, it's not clear to me that it will be as effective as when you need to get it out of the lab into prototyping. That tends to be much more expensive, and is when companies perk up and pay attention."

An attendee from the Rochester Institute of Technology asked how we can ensure the cost-effective availability of the scarce nonsilicon materials now being used, notably indium. Dr. Freilich agreed that this is a concern. Indium is currently more important to displays than to PV, he said, but companies are actively seeking alternatives for thin film. He added that nonrenewable fossil fuels are currently needed for the thin-film polymers, and they are alert to opportunities to develop polymers from other sources.

Michael Heben of the University of Toledo asked how the level of investment in the United States compares with levels overseas. He expressed concern about many jobs going to China, for example, where subsidized or free energy and land may be offered as incentives. He asked whether the cap-and-trade mechanism is one way to level the playing field, or whether would give an advantage to countries that do not include carbon emissions in the cost of manufacturing. A panelist said that the carbon content in PV is relatively small, so that it is not central to the cap-and-trade debate. Another panelist doubted the value of a protectionist trade policy, placing more value on the design and innovation leadership of U.S. products.

A questioner asked about China's foundry businesses, which had not done well, and whether its entry into the PV business would also be hampered by technologies that are not quite state of the art. Mr. Pinto noted that China could raise demand for solar and create its own large market, which could be an advantage for an economy that needed more electricity. In terms of the technology, he said, China might also do well, as it has shown by its aggressive support of Chinese PV manufacturer Suntech. "Manufacturing efficiency and scale can get you there," he said, "and Suntech[14] is proving that it can do both."

[14]Suntech, founded in 2001, is already one of the largest manufacturers of solar modules in the world, and now plans a manufacturing presence in the United States.

Panel III

National and International Consortia: Lessons and Best Practices

Moderator:
Clark McFadden
Dewey & LeBoeuf LLP

COLLABORATION FOR SUCCESS IN SEMICONDUCTORS

John E. Kelly
IBM

Dr. Kelly began by referring to earlier discussions about market incentives and enhancement of manufacturing productivity. Like Dr. Freilich, he emphasized that the industry's success will depend primarily on technical achievement. "I would argue that this industry has no future if it does not understand that it has to tackle this through technology," he said. "It has to be driven by R&D." He said that efficiency cannot be raised fast enough "through larger slices of glass or more efficient equipment; it has to be closed by technology. And then once that gap is closed, you cannot assume you can stand still there." He added the second point that the United States cannot compete against companies and countries outside the United States by relying primarily on lower labor costs or larger, more productive equipment. "You fight that through innovation," he said. "You innovate faster than anyone else."

Dr. Kelly said he would "draw a few analogies and some lessons learned from the semiconductor industry." The semiconductor industry had experienced many of the same challenges as the PV industry over the past three to four decades. He listed four fundamental pressures felt by the industry on a continuing basis, "all of which have caused the industry to remake itself several times":

- Foreign competition: "We are under constant competition from low-cost entities for governments and government subsidiaries."

- The equipment and materials ecosystem.
- Highly skilled workforce: "As soon as you decide to compete based on innovation, you need the best work force, and that is a pipeline statement beginning with K-12 education."
- Research and development: Creating a leading node of logic technology now, he said, costs approximately $1 billion. "And you need to be doing three or four nodes at any given time—a big, big investment." This ongoing expense, coupled with the slowing of semiconductor revenue increases from the high teens to the mid-single-digits, has "put industry under extreme pressure," he said. "This has caused the industry to do things we might otherwise not have done."

Strength in Collaboration

The solution, Dr. Kelly said, is collaborations of many kinds between industry, government, and academia. Among examples in the semiconductor industry, he began with the Semiconductor Research Corporation (SRC), which is at the intersection of industry and academia. The second example is SEMATECH, which is at the intersection of industry and government. The third and fourth examples, he said, are new: the Nanotechnology Research Initiative and the Focus Center Research Programs. These are successful partnerships of all three sectors, he said. "Most recently, we have aligned those efforts with those of NIST and NSF, which are represented here today. We want to leverage this further into pure government-university research that is aligned with where industry needs to go. There is also extraordinary collaboration between industry players who you might think are severe competitors, but have managed to pull together to a degree which I think is probably unique in the world."

SEMATECH, he said, originated in the mid-1980s and gained momentum with government funding in 1988 during what was judged to be a national crisis. "We were seeing loss of share in the U.S. semiconductor industry," observed Mr. Kelly, "but we were also seeing the entire equipment and materials base leaving the United States. That was a disaster to companies like Intel and IBM, who felt that our supply lines and the security of our own systems could be in jeopardy." SEMATECH received $100 million from both industry and government, he said, "which I think at that time was unique." Based on that experience, he gave his personal opinion that it would cost hundreds of millions of dollars per year to advance solar R&D and close the competitiveness gap "if we want to get off the subsidies and keep the United States in a leadership position."

SEMATECH itself broadened its focus from R&D to address industry standards for equipment, wafer size, packaging, "and other things we often take for granted, but which make the whole industry more efficient." It changed further in becoming International SEMATECH, reaching out to collaborate with global members on precompetitive projects of mutual interest. In addition to increasing the number of members, it has updated its research capacity. Its original facility in

Austin, Texas, capable of producing eight-inch wafers, had been for two decades the core R&D facility, where the equipment industry, material suppliers, and small semiconductor companies went to do research. A new facility designed for 300mm wafers has now been opened in Albany, New York, for the most advanced current work.

The Value of SEMATECH to Members and Partners

Such facilities are thought to yield high value to members and partners. The average member-reported ROI is greater than five times, and the reported leverage on their yearly R&D investment is about 20 to 1. "This is what happens," Dr. Kelly said, "when seeming competitors pool their resources. This has brought more than $2 billion in research value to members over five years."

The Semiconductor Research Corporation, he said, was instrumental in sustaining the essential "pipeline of skills." "If you decide you're going to compete on innovation, versus lowest cost only, you have to have the skills to innovate." The SRC was formed in 1982 to help recover U.S. semiconductor market share lost to Japan. Begun as a consortium of companies to support relevant university-based research in semiconductors, it is now the largest and most successful organization of its type. In 1982, fewer than 100 students and faculty conducted silicon research. Today, the SRC has built an academic force of 500 faculty and 1,500 students. This academic community is credited with some 20 percent of the world's research on silicon. The number of publications credited to SRC universities grew from 180 in 1981 to 2,226 in 2008. This research output, he said, is larger in some dimensions than that of some of the largest corporations in the industry. "We have put thousands of highly qualified students into the industry," he said, "most of them hired by the member companies."

The SRC has also become international, collaborating on research with foreign companies. It has a focused research initiative in nanotechnology, an educational component, and Topical Research Collaborations, in which topics are chosen by participants. Such initiatives, he said, are also suitable for solar projects.

The new Focus Center Research Program (FCRP) supports collaborations between government, industry, and universities. This program was created in response to roadblocks indicated by the roadmap five to 10 years away. The five FCRP centers were established at 41 universities in 19 states to address these roadblocks "before we hit the wall." They are funded jointly by about $20 million from both the Semiconductor Industry Association (SIA) and DARPA, which "makes a big difference in the economics of the universities." The five centers are divided by topics in design, materials, and interconnect wiring, "and it really does represent the who's who in the best universities in the United States. My comment here, said Dr. Kelly, is that if you want to do collaborative work between industry, universities, and government, there is a model here, with mechanisms that cover issues all the way through intellectual property, which is non-trivial."

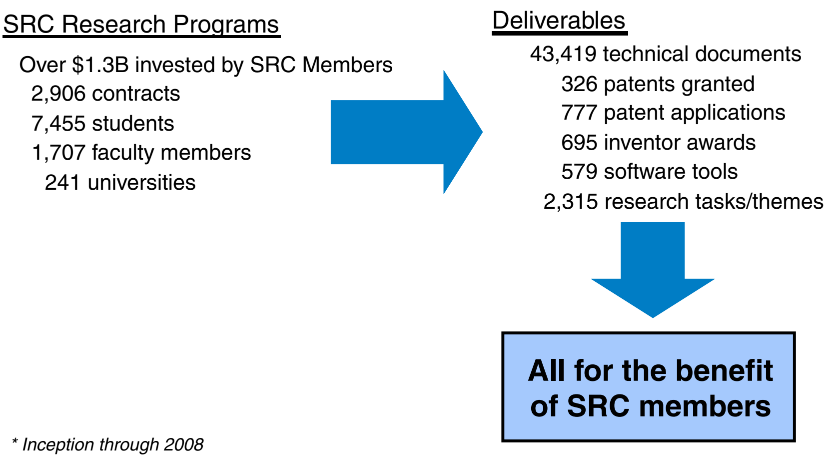

FIGURE 1 SRC numbers.
SOURCE: John Kelly, Presentation at April 23, 2009, National Academies Symposium on "The Future of Photovoltaics Manufacturing in the United States."

A Nanoelectronics Initiative

The Nanoelectronics Research Initiative takes an even longer view of research—beyond 10 years, when the shrinking of transistor size is projected to reach its end. "We have a few more turns of the crank left with the wonderful transistor that was invented at Bell Labs back in 1957," Dr. Kelly said, "but beyond that we're going to need a new switch—something far beyond the transistor as we know it today. This effort looks beyond the current silicon switch into alternate structures, such as nanotubes and quantum devices, so that new technologies are developed when we need them." Here, too, companies have reached out to form collaborations with universities to establish large industry-funded centers with some government collaboration and considerable state funding. Four centers are set in different regions of the country, addressing five primary research vectors:

- New devices (device with alternative state vector).
- New ways to connect devices (noncharge data transfer).
- New methods for computation (nonequilibrium systems).
- New methods to manage heat (nanoscale phonon engineering).
- New methods of fabrication (directed self-assembly devices).

Dr. Kelly closed by describing an industry-only collaboration, a result of the enormous ongoing rise in research costs. IBM, he said, realized that even a company of its size could afford only three or four research nodes, so they decided a decade ago to change their model by bringing in two industrial partners. That number has grown to eight, representing countries around the world, all collaborating in IBM labs and sharing the research risks. This "IBM Semiconductor Ecosystem" has now expanded to include other levels of collaboration, including manufacturing, design tools, design services, design IP, and more recently even the equipment suppliers. "So even within industry," he said, "you can form these very radical collaborative efforts to tackle very large multibillion-dollar investment problems. And I think there are many lessons here that [the solar] industry needs to draw upon and move very quickly."

CONSORTIA IN EUROPE: IMEC

Johan Van Helleputte
IMEC

Mr. Johan Van Helleputte began with a brief review of the creation of IMEC in 1984. Recognizing that the investments required for a microelectronics research laboratory surpassed the ability of any single university, IMEC's founder, the late Prof. Roger van Overstraeten, persuaded the government of Flanders to create and support IMEC as an independent R&D center for microelectronics. Recognizing also the need for IMEC to be effective and sustainable, Prof. Overstraeten stressed the importance of operating at a global level in order to reach a critical mass and, importantly, to work out a new business model that would maintain popular support by not using taxpayers' money to fund research contracts with foreign firms.

This "taxpayers paradox" was resolved by organizing research around more generic problems of interest to Belgian as well as foreign companies within a larger research program, ensuring a return to the Flanders economy. This business model has proven successful. Macroeconomic impact studies have demonstrated that, IMEC's revenues have always exceeded the government's investment. In 2008, the government invested 44 million Euros in structural funding, while revenues were 270 million Euros. In addition, about 76 percent contract revenue for research in IMEC's facilities in Flanders came from international companies through international collaborations, and 13 percent came from local companies, which he termed "amazingly high for such a small region" taking into account the size of IMEC.

IMEC began with a staff of about 70 people and a founding budget of 62 million Euros. By 2008, IMEC had a staff of 1,750 (about 1,650 in Leuven and 100 in Eindhoven) of whom about 1,000 are Belgians and a budget of 280 million Euros (including 45 million Euros from the Government of Flanders and 10 million Euros from the Dutch Government). Mr. Van Helleputte showed a graph depicting the evolution of staff at IMEC, whose members represent more than 60 nationalities. The international nature of the effort at IMEC is reflected both in IMEC's payroll staff as well as in a substantial and fast-growing cadre of employees of international companies residing at IMEC and research fellows and 185 doctoral students conducting research at IMEC. These international staff members join mixed teams with IMEC researchers, enriching the intellectual environment and technical perspectives.

A Larger R&D Reach Through Partnerships

Referring to the high complexity and cost of microelectronics research, Mr. Van Helleputte noted that "No single company could tackle all the challenges on its own." The answer for firms lies in collaborating in R&D. Each company has a choice on how to spend the percentage of revenues it devotes to R&D: they could spend all of it on exclusive work, or they could spend part of it on a research platform, like SEMATECH or IMEC, and gain a much larger R&D reach. They could further multiply the benefits by doing it in a number of places, each time expanding their R&D reach. A central challenge for IMEC, as for similar research institutions, remains one of dealing with the combination of the huge cost of research and the rapid rate of technological change.

At the heart of research activities on the IMEC campus are two large clean rooms, one with a 200mm pilot line and one with a 300mm pilot line. Both lines are in continuous operation to maximize the return on investment in expensive equipment. The IMEC approach is to address generic problems somewhat early in a technology's life cycle. IMEC tries to create a program based upon a forward-looking vision and by defining which research they intend to do for the next three years and then sign bilateral contracts with different companies, joining a same research program: partner A, partner B, partner C, and so on. They ask each partner to send one or more industrial residents to do joint research within the program team. The rule for intellectual property protection (IP) is that any foreground information to which the partner resident has contributed is co-owned with IMEC. If the industrial partner does not contribute to certain elements of the program, it receives a nonexclusive, nontransferable license on foreground results for its own use. This approach ensures that there are no "blind spots" in using the technology back home. At the same time, IMEC provides a nonexclusive license for the background information required to exploit the foreground results. In return for these benefits, IMEC charges an entrance fee and a yearly affiliation fee.

IMEC tries to achieve an IP policy that has something for everyone through the IMEC Industry Affiliation Program (IIAP). This program offers such variations as co-owned (shared) IP with individual companies, exclusive IP and shared (licensed) IP. "What is very important for us and for each company," Mr. Van Helleputte said, "is not to have exclusive ownership of each subset of IP, but to have a unique IP 'fingerprint.' This is a combination of exclusive IP and shared IP, and these elements vary with each bilateral partnership. So, the total portfolio for each partner is unique, while at the same time the partner shares with IMEC the costs, early insight, access to IMEC results, better time to market, talent, and risks."

Building Technology Platforms

"An important organizational point," Mr. Van Helleputte said, "is that IMEC begins to form its IP from a 'research infrastructure' on which they build 'technology platforms' of expertise and competence." Building from this idea, IMEC provides a complex, five-level "leveraging strategic approach" to increase value for the institute and its partners. As stated in its overarching theme, "an R&D institute's growth path depends on its capability to maximize its leveraging effects at different levels." In other words, a research institute with multiple technology programs can offer them to multiple partners and harvest greater value from the resulting partnerships. "So, you're building leverage on leverage on leverage," said Mr. Van Helleputte "and you reuse the mechanism of co-ownership without any accounting to each other about the foreground research."

He turned to IMEC's strategic orientation in view of industry trends. He said that industry is now making a distinction between "More Moore"—continued CMOS scaling and maximization of chip performance—and "More than Moore" or maximizing the functionality of single chips. The first approach focuses predominantly on device performance where materials are paramount, with lithography being an instrumental path of research. The second approach focuses on heterogeneous integration of different functionalities into a single chip (SOC) or into a single package (System-in-a-package). In More Moore, IMEC is now working on 22nm, 16nm, and even smaller devices, where new materials and device research are central. "IMEC tries to explore multiple options," he said, "so companies can see at an early stage which one has a chance to become a market winner." He added that with a "core partner system," each core partner can subscribe to a total menu of programs or choose a subset of those. These partners include "the whole ecosystem" of firms: leading integrated device manufacturers, memory suppliers, logic suppliers, equipment and material suppliers, pure foundries and designers.

Help with Custom Applications

Mr. Van Helleputte described a new initiative called CMORE that builds on the existing infrastructure and technology platforms to aim at custom application solutions.[15] "For example," he said, IMEC can work with companies that may have a brilliant new idea but have difficulty implementing it in a commercial setting. This involves first testing the technical feasibility," which "may involve joint R&D, development-on-demand, prototyping, and low-volume production." He mentioned the case of a partner who asked for help putting 10 million mirrors on a chip that could be steered individually. The chip had to be

[15] IMEC's CMORE initiative is a platform designed to allow companies to turn their innovative concepts into packaged microsystems products, based on IMEC's expertise in the field.

no larger than 10 square centimeters and achieve 10^{12} cycles without fatigue or creep. "That," he said," was a typical example of Development-on-Demand CMORE activity."

IMEC has several major application programs under the "More than Moore" umbrella that build on its expertise in semiconductors. These include

- Communications technologies: Cognitive reconfigurable radio and >60GHz communication, and ULP-Radio;
- Biomedical electronics: wearable health and comfort monitoring; brain-IC interfaces/neuro-electronics; smart implants and biosensor technology based on nanotechnologies;
- A new Center for Neuro-Electronics Research/Flanders (NERF), part of a new interdisciplinary research center for the integration of neuroscience and neuro-electronics & clinical experimental neurosurgery. NERF is hosted at IMEC; and
- Energy: PV, GaN/Si for power switching and solid-state lighting.

IMEC's Solar Research

"Indeed, IMEC has a substantial PV program as well, and the workhorse of the program is silicon PV for the reason that we have a lot of expertise in silicon and that there is still a lot of room for improvement," noted Mr. Van Helleputte. "And we do believe that there is room for both thin-film and crystalline silicon in the future. Companies like First Solar, will push toward a further acceleration of the PV roadmap and IMEC will gladly respond to such a challenge." IMEC also has an activity with organic PV and with highly efficient PV stacks for solar concentration. The IMEC program on crystalline silicon PV research has a number of research modules, with two major themes: One is a wafer-based approach, and the second explores epitaxial thin film on silicon. They are experimenting as well with new ways to produce ultrathin wafers without the kerf losses incurred in cutting ingots. These are called stress-induced lift-off methods (SLIM) where the active wafer is lifted off a substrate rather than cut.

Finally, IMEC is experimenting with a stacked approach for concentrator solar cells (CPV) as an alternative to monolithic approaches. In this design, each layered cell absorbs a part of the light spectrum, not all of it, combining its contribution with those of the other cells. "It is more complex," he said, "but it avoids some technical drawbacks of the monolithic approach (such as tunnel junctions and current matching), and may increase conversion efficiency and energy yield, although this has not yet been proved in a total system approach."

Mr. Van Helleputte concluded by mentioning the Solar Europe Industrial Initiative, which has included on its roadmap the goal of meeting 12 percent of electricity demand from PV sources by 2020. "To accomplish this," he said, "Europe would have to develop about 350 gigawatts of PV capacity." "And it also assumes that by 2020 the lifetime of the solar modules will be 30 years," he said, "this is quite ambitious."

PUBLIC-PRIVATE R&D COLLABORATION: LESSONS FROM PV PARTNERSHIPS

Robert M. Margolis
National Renewable Energy Laboratory

Dr. Margolis said he would speak about trends in PV development, the DoE's Solar program, and lessons from several public-private partnerships. He began with some background on the global PV industry and investment trends highlighting the fact that global PV production has been growing very rapidly over the past couple of decades and that both public and private sector investment in PV technology has grown dramatically during the past four to five years. In 1980, the United States was responsible for more than 75 percent of global PV production in what was then a nascent market. By the 1990s, Japan had begun a federal program of incentives and quickly became the global market leader; the U.S. share of production dropped to the 30 percent to 50 percent range. In the past decade, leadership has shifted to European countries and, more recently, China and Taiwan have expanded production rapidly. Cumulative installed photovoltaic (PV) capacity worldwide as of the end of 2008 was estimated to be 13.7 GW. Germany was the leader at 5.4 GW of cumulative installed capacity, followed by Spain, Japan, the United States, South Korea, Italy, and France. U.S. cumulative installed PV capacity through 2008 was 1.1 GW. California continued to dominate the market with 530 MW in cumulative installed capacity, a 67 percent market share, with New Jersey second at 70 MW or 9 percent market share. U.S. cumulative installed capacity of 1.1 GW was a 43 percent increase over 0.77 GW in 2007.[16] While the growth in PV production and installations has been very rapid, PV still accounts for only a small fraction of U.S. generating capacity.

In addition to rapid growth in production, the growth in investments in solar technologies has been dramatic during the past couple of years. Just five or six years ago, according to data from New Energy Finance, only a few tens of millions of dollars were going into PV from the private sector; this figure had risen to tens of billions of dollars a year. "This has been a dramatic change," said Dr. Margolis, "and has had a very big impact on how the industry is organized, how it does R&D, and how it interacts with the government."

Venture capital and private equity, he said, have taken on a larger role beginning in the mid-2000s, and especially in the last three years. This investment varies enormously by region and technology. For example, the EU has invested primarily in crystalline silicon technologies and project development. In contrast,

[16]Data drawn from numerous sources as presented in Price and Margolis (2009).

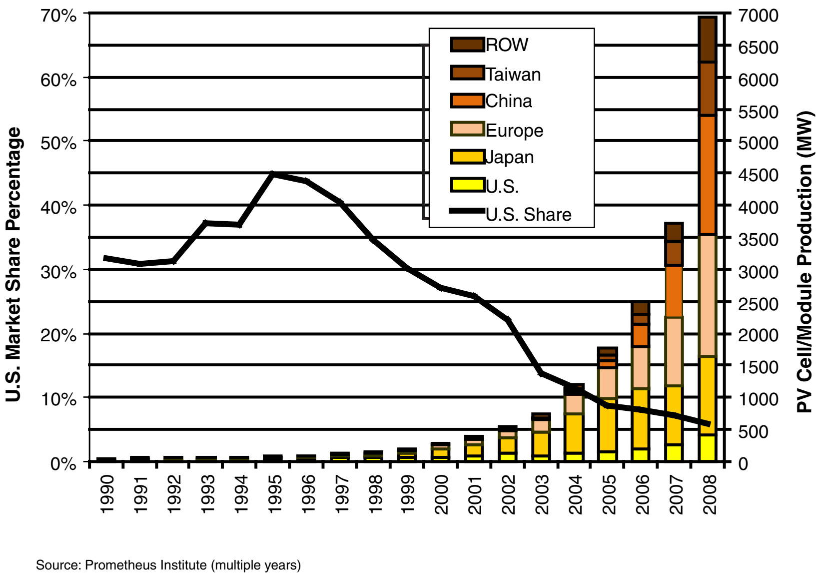

FIGURE 2 Historical global PV production and U.S. market share.
SOURCE: Robert Margolis, Presentation at April 23, 2009, National Academies Symposium on "The Future of Photovoltaics Manufacturing in the United States."

U.S. investors have been pursuing a much more diverse set of technologies than investors in other regions. Significant investments in the United States are going into thin-film technologies, multijunction concentrating PV technologies, and next-generation PV technologies. Of about 200 companies that received private-sector investment in the past three years, more than 100 are in the United States Asia has focused primarily on existing crystalline silicon technologies, with a small shift toward thin-film technologies during 2008. Asia also has been making significant investments in polysilicion production.

A Five-Year Projection

Dr. Margolis presented a meta-analysis of near-term projections from about a dozen analysts. According to this set of projections, a five-fold increase in PV production is expected to occur between 2008 and 2012. Crystalline silicon is expected to remain dominant, with thin-film technologies growing more rapidly than they have in the past. "But we've also learned that things can change really fast," he said. "For example, the global economic crisis may bring about lots of changes going forward, and already many analysts have lowered their projected 10-25 percent."

Global PV industry revenues are also projected to continue rising. The current level of revenues across the PV supply chain was about $30 billion in 2008. He said this level of revenues places the PV industry where the semiconductor industry was in the early 1980s. "So maybe this is the perfect time to discuss whether SEMATECH is the right model. The industry is getting to a similar scale of production to where the semiconductor industry was in the early 1980s, and going forward we're talking about billions of dollars of investment in new PV 'fab' facilities."

Next, Dr. Margolis turned to the Department of Energy's Solar Program, which received steady funding of about $80 million from FY2001 to FY2006. Then, in FY2007, the Solar Program's budget increased substantially, under the Solar America Initiative, to about $160 million per year. This is expected to increase again under the new Obama administration, with new resources to leverage private sector investments through a host of collaborative mechanisms.

The DoE solar R&D pipeline, he went on, is not really a linear process, but one with feedbacks and interactions. He focused on one piece, the Technology Pathway Partnerships (TPPs). The whole pipeline supports many early-stage partnerships between universities and other parts of the supply chain. The TPPs started in 1997 with a three-year grant of $168 million in DoE funds, and a total of $357 million including industry matching funds. This represented a shift from the prior focus on the device and module level to an emphasis on total system costs, including installation, inverters, and balance of system components. The partnerships, some of them with over a dozen members, included more than 50 companies, 14 universities, three nonprofits, and two national labs. Dr. Margolis suggested that this experiment might be a model for how to foster collaboration across different actors in the PV industry.

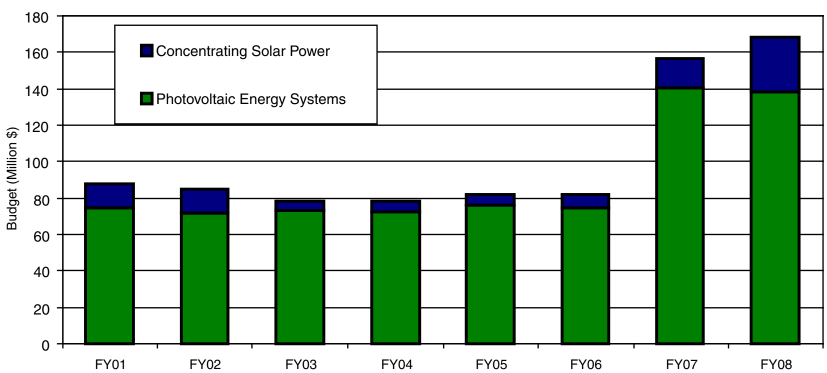

FIGURE 3 DoE solar program funding FY2001-FY2008.
SOURCE: Robert Margolis, Presentation at April 23, 2009, National Academies Symposium on "The Future of Photovoltaics Manufacturing in the United States."

A precursor to the TPPs was the PV Manufacturing/PV Manufacturing R&D (PVMaT/PVMR&D) project that was started in 1991. Its original goal was "… to ensure that U.S. industry retain and extend its world leadership role in the manufacture and commercial development of PV components and systems."[17] This was the period when the U.S. market share was declining from 75 percent to 30-50 percent. The PVMaT/PVMR&D Project was a collaborative effort focused on helping the PV industry improve its manufacturing processes and equipment, accelerate cost reductions, raise commercial product performance and reliability, and lay the groundwork for scale-up of U.S.-based PV manufacturing capacity. The project was carried out over a 15-year period and was funded with about $150 million in federal money matched by a roughly equal amount of private-sector money. The project was considered innovative in its use of multiyear contracting and cost sharing. About three-quarters of the completed projects achieved cost reductions, increased output, and improved efficiencies. For 14 manufacturing R&D participants, the cost of manufacturing came down 54 percent and manufacturing capacity increased by a factor of 17.

Tools for Partnerships

Dr. Margolis reviewed the tools used for the partnerships funded through the PVMaT/PVMR&D, beginning with cost sharing. The approach to cost sharing ensures both the sharing of R&D risk and enabled firms to own any resulting IP. Also built into the proposal was an evaluation process, as well as key collaborative aspects, beginning with problem identification. In 1991, 22 firms were selected through a competitive bidding process. They each received $50,000 for phase 1, a three-month study, which was required to qualify for phase 2. This stimulated the involvement of many people, he said, and was effective in educating DoE and NREL on critical manufacturing problems. The evaluation process was carried out by independent panels of representatives from industry, government, and universities who helped establish the credibility of the project. It was a challenge for government to give up some control, find good people for the panels, and keep panels together. One constructive response was to hold annual review meetings, which provided a venue for participants to interact and share results.

An approach that did not succeed was a plan to form teams for generic research on problems of common interest to companies. A key roadblock was concern over IP. This is still an issue in precompetitive research, he said, though it is better understood.

Dr. Margolis closed with several conclusions. First, the PVMaT/PVMR&D

[17] C. E. Witt, R. L. Mitchell, and G. D. Mooney, "Overview of the Photovoltaic Manufacturing Technology (PVMaT) Project." Paper presented at the 1993 National Heath Transfer Conference, August 8-11, 1993, Atlanta, Georgia, August 1993.

project used innovative forms of cost sharing and collaboration to strengthen information flows between partners. Second, under the TPPs, DoE encourages vertical collaboration—across the value chain—which has helped move the industry from a component focus to a systems-level focus. And finally, the DoE's approach to engaging the private sector in collaborative R&D will need to evolve as the PV industry grows and matures.

DISCUSSION

A questioner asked about forming industry consortia in such a diverse industry. With so many technologies, he asked, what kind of critical mass do you need? Won't some players decide to go it alone? Dr. Margolis answered that on the basis of the semiconductor experience, the majority of the large players must participate, and there must be some mechanism for the involvement of the industry as a whole. In the case of the SIA, he said, consortia needed the top dozen or so semiconductor CEOs, as well as mechanisms to bring in other participants. For the PV industry, it would include the module manufacturers and significant suppliers of that value chain. He added that the government can help bring the right people together. Eventually, in the case of the semiconductor industry, "people were suddenly afraid of being left out rather than concerned about how to jump in. Even fierce, fierce competitors came to the table and worked together."

Panel IV

Economics of Photovoltaics in the United States

Moderator:
Richard Bendis
Innovation America

GLOBAL MANUFACTURING OF PHOTOVOLTAICS: WHERE DOES THE UNITED STATES STAND?

Ken Zweibel
George Washington University

Professor Zweibel said that he would begin with the current position of the United States in manufacturing PV modules and then examine its competitive position. "And they are quite different," he noted, "because we are much more competitive than our production volume would indicate." He said he would also make the "somewhat controversial" point that government policy in each region has been the most important determinant of the state of photovoltaics worldwide.

He summarized this country's position by saying that "the United States trails in manufacturing modules and in installing modules." Of world market PV demand of 5.95 gigawatts in 2008, Spain has installed 2.46 GW of capacity, Germany 1.86 GW, and the U.S. only 0.36 GW. But it is no surprise that the United States trails, he said, because the U.S. has not created incentives for the installation of systems, as others have, or for manufacturing. In the few places where there is manufacturing activity, such as Michigan, he said, the states have provided the incentives.[18] "The biggest barriers are the absence of a major U.S. market and whether there are incentives or not," he said. "When the U.S. market becomes available, there will be U.S. manufacturing." He added that both the

[18]UniSolar, which makes photovoltaic laminates for commercial and residential roofing applications, receives major incentives from the state of Michigan.

mainstream U.S. industry and most of the U.S. government have taken PV less seriously than the rest of the world "because it hasn't been a top energy or environmental priority. Manufacturing will occur in the United States once we have adequate markets, unless something else drives or attracts it away."

Technological Competence in the United States

Professor Zweibel reviewed the technological competitiveness of the United States. "There are a number of technologies in PV," he said, "and the United States has someone in a leadership role in each: crystalline silicon, SunPower; cadmium telluride, First Solar; thin-film or amorphous silicon, Unisolar and Applied Materials; and copper indium diselenide alloys (CIS), Solyndra, and many start-ups. No other place has that." He added that China has little technological expertise beyond crystalline silicon.

He noted a great deal of progress in U.S. manufacturing. "Thin films have come from pretty much nowhere to start taking a bigger role," he said. "First Solar has come from no production in 2004 to be the second largest PV company in the world in 2008, an innovative thin-film company in cadmium telluride. This is an example of how disruptive leadership technologies in the United States, which benefited from the DoE's support for applied PV research, have a major role in today's photovoltaics." He also praised SunPower for its technological leadership.

He said that these leading companies are in the United States for several reasons. First, their technologies were developed at home. Second, in using an innovative technology, a company needs to keep its researchers and engineers close to the manufacturer the first time its scales up manufacturing. The first factories were built here, he said, because it was too risky to send them abroad.[19] However, future factories will go where the markets and incentives exist.

Professor Zweibel then listed the U.S. position vis-à-vis the leading technologies. The United States and First Solar dominate thin-film cadmium telluride, which is the lowest-cost PV technology for any system above residential size. No company yet dominates the copper indium diselenide (CIS) process because the technology is new and has not yet reached economies of scale. However, he said, it is expected to be competitive with cadmium telluride. The first company to announce a major plant is Showa Shell, a Japanese company, which has announced plans to open a 1-GW manufacturing facility in 2011. "We'll know then a great deal more," he said, "about whether the CIS technology can bring together its great efficiency with its difficulty of manufacturing to reach a product that is competitive." In crystalline silicon, he called the U.S. position "thin," with only SunPower, Advent, and Evergreen as representatives, "but the United States is definitely in the hunt in every major technology." Since this report, Evergreen

[19] An example is First Solar, which built its first manufacturing plant in Perrysburg, Ohio. Subsequent factories have been sited abroad.

closed its Massachusetts factory and moved it to China, and Advent was forced to sell its assets to Applied Material. Both events were a result of the recent downturn in PV module prices, which caused them competitive disadvantage.

How Government Shapes the PV Landscape

Professor Zweibel said that today's technological landscape, including the locations of manufacturing and installation, is defined by past R&D funding and market incentives. "It isn't much of a leap," he said. "Government policy has defined the landscape of photovoltaics worldwide. Photovoltaics isn't a cost-competitive technology. It is a societal contract with manufacturers and technologists and scientists to develop a non-CO_2 source of energy, one that can diversify us away from fossil fuels. When we reach cost competitiveness, that might change, but that's not the case yet. DoE emphasized thin films from 1979 to 2005. Among its emphases was cad-tel [cadmium telluride], and that's why the United States is a leader in thin-film cad-tel. Most other nations emphasized crystalline silicon and thin-film silicon, where the United States is competitive but not a leader. So every region can be clearly defined by what its government technology program emphasized or left out."

He noted that the original thin-film R&D partnerships (e.g., the Thin Film PV Partnership at NREL) pursued product development through every step: materials research, solar cells, module development, process area scale-up, pilot production, reliability testing, and first-time manufacturing. This brought the necessary confidence that the entire process of module manufacturing was understood. He called this process "applied research and manufacturing," and said that it was necessary to understand what these "almost infinitely complex semiconductors are like, especially in manufacturing, but also in solar cell design." He emphasized that "solar cells are really strange. Very similar techniques may produce cells that are terrible or cells that are great. You have to have some subtle sense in how those cells are made to make them successfully. That's why a solar cell scientist these days can walk out the door at NREL and earn a million dollars in stock by starting a new PV company. You can't start a manufacturing company except for that expertise. Very few people can make these new manufacturing companies work, and there is a dearth of them."[20]

The Great Risks of First-Time Manufacturing

Professor Zweibel recalled that in the early days of PV research, companies could afford very little R&D, compared to funding now available. "We didn't get a chance to tame the complexity of those semiconductors, because we could only afford one-of-a-kind experiments. We'd make a small area cell, or three of them, then

[20]Dr. Margolis is credited with directing the early success of PrimeStar Solar.

turn the machine off. We'd come back to it a week later and try it again, assuming the machine still worked. Sometimes minor, unmeasured calibration changes would occur. These were irreproducible results where you followed your intuition toward a better and better result. We never had a robust R&D program in this field. We simply couldn't afford it on the $10 million-$15 million dollar budget we had for applied research in thin films. First-time manufacturing is still a time of very great risk. In fact, some of the new technologies like CIS are still fighting the first-time manufacturing problem. It doesn't mean they're not worthy technologies, it just means it's harder, and needs more time, money, and patience."

Professor Zweibel emphasized the importance of the module manufacturing feedback loop. "Yes," he said, "you're trying to increase efficiency, but you're also trying to reduce area cost, raise throughput, and make device refinements while you're manufacturing. You're simplifying a process to bring down the cost while you're still trying to get high efficiency. You're increasing the area of your machine because machine costs go up as the log of the width. You're checking the stability of the semiconductor layers. PV semiconductor research is excruciatingly hard, which is rarely appreciated by those who lack experience in doing it."

Technologies vary in their difficulty, he said. Silicon technology requires less new fundamental knowledge (because it is widely understood from other uses, e.g., in computers) than CIGS, for example, where manufacturing consistency is still elusive. Cadmium telluride has advanced further, but still awaits understanding on a foundational level. Much research can still be done, he said, to accelerate these new technologies down their learning curve. This is often not appreciated, because to most outside the field, technology development appears to be a "black box."

He concluded with as summary of other lessons he had learned working in at NREL and the industry:

- Cells and modules are the drivers of photovoltaics, because they drive both module cost and balance of system cost. They are also the overwhelmingly most challenging aspect of PV development.
- The continuity of research matters. Avoid jumping from one challenge to another. Define a worthy success (e.g., stabilizing CdTe contacts) and do it. Avoid unimportant issues.
- Complementary competencies matter. Problems are easier to solve if different talents are brought to bear on the same question. But people must be committed to applied research and not simply acting out their academic discipline's interest.
- Investors and strategic partners are wise to fund smaller, dynamic companies. Such one-product companies are likely to work harder, he said, because their survival depends on it. Solar units that started within larger companies must compete for the attention of upper management. He said that all of the leading

firms in the United States—SunPower, Unisolar, and First Solar—are one-product companies.

• The government should fund research challenges that are "one step ahead of companies' comfort zones." Research directors generally respond with enthusiasm if asked to tackle a challenge that is not just their next fire drill. But make these practical research activities, not diversions or red herrings. This also advances the technologies generally. Avoid funding "far out" ideas if you think you are funding technology development.

• Include a process for differences of opinion. Reduce hierarchical barriers, especially in government, to speed knowledge sharing. Organized debate that includes decision makers creates new opportunities.

FINANCING PHOTOVOLTAICS IN THE UNITED STATES

Steve O'Rourke
Deutsche Bank Securities

Mr. O'Rourke said he would discuss the photovoltaic industry from a financial perspective. "I like to think that if we can distill an issue to a math problem," he began, "we can define a solution. The solution might be unpalatable, and if that is the case, we can begin to define boundary conditions that we can use."

He offered a snapshot of the industry, first at the manufacturing level. For solar PV, he said, the cost of producing electricity is declining more rapidly than anticipated, "to the credit of the companies driving this technology." At the same time, the cost of grid-supplied electricity is going up. The next stage of development, he said, will be determined by forces of supply and demand. The PV industry is in a state of oversupply, which will last for several years.

Financing Challenges

Mr. O'Rourke foresaw three challenges from a financing perspective. First, the overcapacity situation in the industry needs to be reduced—the industry needs to be rationalized. This, he said, would likely "happen more slowly than we would like." Second, the industry needs to finance a capacity base for future growth. Third, financing must be found for the installations that will drive the market overall. Meeting all of these challenges, he said, requires better positioning the industry within the energy market. "This is being done in other countries," he said, "and it can be done here."

He said he would suggest three steps to begin to address what will be needed over the next few years: (1) define the investment required, (2) define the competitiveness gap, and (3) suggest some ways to close the gap. Addressing these steps would have "a lasting impact for the long term," he said. "And if we're right about what happens in this industry, demand will be enormous 5, 10, and 15 years in the future. But this requires preparation now."

He turned to the PV value chain for both crystalline and thin-film approaches. Upstream is manufacturing, he said, and downstream are installations. "If we parse this," he said, "far upstream we have polysilicon and precursors of polysilicon. This is a manufacturing industry long-since established in this country, which has done a remarkable job of keeping it here. It's not going away. The percentage of the industry in the United States declines because of growth by incumbents elsewhere, with some contribution from start-ups in Asia. I'm not too worried about this part of the industry."

The Biggest Issue: Taxes

Next, Mr. O'Rourke looked at manufacturing in the United States. This upstream portion of the value chain extends from raw materials all the way to modules, the energy generating assets. The United States has very little domestic manufacturing between polysilicon and the module "Manufacturing migrates to where companies are most profitable," he said, "and the single biggest issue in this analysis is taxes."

Continuing downstream to solar PV energy generation, he said, one sees a small market in the United States. "If we define the efficacy of incentive programs based on the size of the market," he said, "we have a problem. It's not enough." The solution requires overcoming several issues in project design and management, he said. To install a project and move it forward requires several conditions. Project returns need to be adequate, cash flows need to be acceptable, and risks need to be accommodated. Without all three, he said, a project does not move forward.

He looked ahead to the next two decades in manufacturing as it expands globally. Within that period, he said, global capacity could increase by 22 GW in the single biggest year of growth. The total installed capacity in 20 years could exceed 200 GW. PV would then produce about 4-4.5 percent of total electricity generated. "What we would need to spend to put this in place is upwards of $100 billion."

A Manufacturing Site Abroad Versus a Site in the United States

Next, Mr. O'Rourke quantified the gap between what companies can earn if they site their manufacturing abroad and what they can earn when they locate in the United States. Currently, most manufacturing is done in Asia, with some in Germany, some in the United States, and some elsewhere. What would happen, he asked, if a company with a majority of assets located in Asia moved approximately 20 percent of its future manufacturing capacity to the United States? Such a move, he answered, would bring down net margins by a meaningful amount because of taxes, reducing profitability by as much as 14 percent for the best companies. "That's the biggest issue to resolve from a financial perspective when we think about where to site a manufacturing plant," he said.

He proposed another example, for a company that did no manufacturing in the United States. He repeated the exercise of moving a modest amount of capacity from Asia to the United States. Net margins are affected, with taxes as the primary input, and profits reduced by 4 percent. "That's meaningful," he said—"almost insurmountable. In order to accommodate this with taxes alone, you would need to lower taxes in the United States to below 10 percent from what is now a corporate tax rate of 35 percent."

He looked at the situation in other countries. "In instances in China we deal with companies that have very low cost of capital—3.5 percent on average—and instead of paying taxes, they get tax credits. That is difficult to overcome here." He went through the same exercise for Germany, finding declines in net margins, with taxes as the primary impact. "You often need a negative tax rate to make manufacturing work in the United States," he said. "All other things being equal, that's the problem. That's the quantified issue and now we have to surmount it."

Suggestions on Incentives

Mr. O'Rourke experimented with some steps to improve this disadvantage, beginning with the worst-case scenario, in which a company moves operations from a high-incentive country to the United States. The impact on profits is understood—but what can be done about it? He began with installing some incentives for the U.S. operation, such as a modestly lower tax rate that could stay in place for a reasonable period. This, he said, could account for about a third of the impact. Then he proposed a manufacturing credit of 27 cents per watt for equipment manufactured in the United States. Finally, he included a capital spending subsidy, like that provided in Germany. "This," he said, "is an example of what can be done with direct incentives to resolve a very difficult issue that is caused predominantly by taxes that reduce the profitability of companies."

Another factor that must be considered in manufacturing, he said, are indirect impacts. "I cannot emphasize this enough, even though it's been said over and over today: If we had a rapidly growing end market in this country, it would draw manufacturing. It would not be 70 percent of the manufacturing base—that's unrealistic—but rather than the current 5 percent, we could have 20 percent."

He turned to the solar PV energy market and the issue of what must be financed over the next one to two decades. If the solar PV industry in the United States grows as it could as much as $150 billion per year, he said, it will require forms of financing that don't yet exist for this industry. For a simple crystalline silicon system that costs $5.50 per watt installed, the levelized cost of electricity today ranges from ~$0.20/kWh to ~$0.40/kWh depending on location. This can be reduced via several mechanisms, including an investment tax credit or grant, accelerated depreciation, and state incentives. The final cost has to compete with other sources of electricity: wind, combined cycle natural gas peaking power plants. In order to get explosive growth in the industry the levelized cost of energy should be close to $0.10/kWh, which would equate to an installed system cost of ~$2.00 per watt, he said.

Closing the Gap in ROI

Among various ways to discuss the closing of this gap, Mr. O'Rourke said he would first look at financing. When a project is evaluated in terms of return on investment, several assumptions are needed. He said he would begin with a 1-MW system in the Midwest and if he also assumed no incentives, a long-term power purchase agreement return would bring a return on investment of about minus 20 percent. With today's existing incentives, both federal and those offered by some states, the ROI for the project would climb to about 6 percent; this constituted a base case scenario. He assumed a desirable ROI target of 10 percent. The ROI for plants in Germany is about 8 percent today, he said, with some growth in the industry. He then looked at the two most important variables, which he said are system price and the cost of capital. To meet the 10 percent ROI target without subsidies, either the system price would have to be cut in half, or the financing would have to be essentially free. "This would be a difficult challenge to overcome in the near term," he said.

He suggested some single-point solutions to overcome this challenge. Feed-in tariffs, he said, had been shown to promote industry growth. They are simple, and easily built into financing arrangements. If the base case were supplemented with a very modest feed-in tariff, on top of what would be paid for the power under a power purchase agreement, the ROI begins to resemble the figures seen under feed-in tariffs in Germany and Spain today.

Mr. O'Rourke then looked at a different approach from the perspective of cash flows over 20 years, and added an up-front grant at a certain percentage of those cash flows. This would require a significant up-front investment to generate a reasonable ROI. Then he raised the issue of the how sensitive the ROI is to any changes in system prices or costs of capital. For this reason, analysis would have to be done on a case-by-case basis. This sensitivity, he said, must be kept in mind when looking at alternative solutions that are supplemental to the base case. These might include additional grants, a lower cost of capital, additional feed-in tariffs, or an up-front profit match. He said these were potential incremental solutions to solve the project return issue, which is "the first issue to resolve." "If the return does not meet a threshold, investors walk away and the project doesn't happen."

The Next Concern: Cash Flow

The next concern that must be resolved, Mr. O'Rourke said, is cash flows. "The other issue that can make investors walk away," he said, "is an out-of-pocket amount up front that is too high." To solve this, he considered the typical case of a 30 percent grant to fund the system, which leaves a need for 70 percent financing. "Is there a way to eliminate an up-front cash outflow for the project owner, maintain the project ROI, and maintain this same net outflow of cash from the government over a 20-year term?" he asked. "The answer is yes, but it's difficult to do." His suggestion: Keep the 30 percent up-front grant, provide 70 percent in additional funding that flows from the government to a government-sponsored entity—an energy infrastructure bank of sorts. This could then be allocated as a below market rate loan to fund the project. The owner would then pay back the loan with interest on the entire system price. This would provide a means to repay the government-sponsored entity and the government over 20 years. This would lower the near-term return on the project from 6 percent to 2 percent, but still provide an 8.5 percent return on a 30-year term, the useful life of the system. This is not perfect, he said, but it solves the issues of project return and cash-flow mismatch.

Addressing Primary Risks

Two more primary risk issues can derail projects early, Mr. O'Rourke said. The first is stranded assets. For example, an investor places a 1-MW PV installation on a building. The tenant of the building, who pays for PV electricity and building rental under an agreement, disappears. This leaves the asset but no one to pay for it. However, the PV asset (and free sunlight) continues to generate electricity, which has a value that can be monetized in an ongoing fashion; it must be sold. This differs from a house with a traditional mortgage; if the owner defaults, it no longer has value that can be monetized. One kind of arrangement to address this risk, he suggested, would specify an account that could be funded initially by a government-sponsored entity, and administered by the utility. This could evolve into an account that would be funded on a rate-adjusted basis. In the event of customer default, it would allow the owner to sell the energy back to the utility through the grid at the PPA rate, allowing up to two years to repurpose the asset.

A second primary risk is the risk of new technology. If very high financing premiums are attached to cover this risk, they can prevent new projects from moving forward. One solution is to guarantee warranties, he said, which is costly. A second is to create an insurance product that compensates the owner of the project with a higher return in the event of technology failure. He said that this, too, may initially be expensive, but must be examined in more detail. Although he cited some uncertainties in this overall analysis, he suggested that the major issues surrounding PV energy could be solved, including expanding the market and using structured finance to solve the ROI, cash flow, and primary risk issues.

Mr. O'Rourke also advocated a structure that allows the public sector to shift these functions to the private sector over time. The natural intermediaries, he said, would be banks. Funds would move from the DoE to the banks at low cost, allowing the banks to make a profit by lending at a higher rate, creating liquidity for the industry and providing a reasonable return. Gradually this would be accompanied by the mandated sale of those assets to private investors, who would purchase them on leverage and earn reasonable returns. This, he said, would be the first step of a securitization process, engaging the private sector to finance the PV industry. Over time, banks would assume the responsibility for loan origination, stewardship of the industry would shift from government to the private sector, and the industry could become self-sustaining.

A Possible Solution in Structured Finance

Although this process would take years, Mr. O'Rourke concluded, it can be initiated now and take effect within the next several years by properly structuring the financing. Structured finance requires more subsidy money up front, but that money can be recouped over a 20-year term. Most importantly, it can allow the industry to develop projects and the market to grow. He noted that the financial structuring would need to be accompanied by improved manufacturing subsidies to overcome the tax issue and directly bring more manufacturing to the United States. However, he also stated that the best way to build a manufacturing industry in the United States would be to incentivize a large end market. Manufacturing could also be driven by expanding the U.S. market, he said, which could be accomplished by greater up-front priming of the pump by government.

Mr. O'Rourke ended on an optimistic note about renewable energy in general. He noted that he had talked about photovoltaics in isolation, but said that he did not believe that this was the right perspective. "My inclination is to believe that over the next few years solar PV should not be viewed as a point solution," he said. "We have to look at overall renewable energy solutions, of which solar PV is a part. To end on a qualitative note, I would be willing to bet that when we really start to do the math, the returns on renewable energy solutions are going to be better than most people think. But that's a whole different discussion."

THE TOLEDO, OHIO, SOLAR CLUSTER

Norman Johnston
Solar Fields LLC, Calyxo GmbH, and Ohio Advanced Energy (OAE)

Dr. Johnston reviewed the efforts of a determined group of people to develop a photovoltaic industry in the state of Ohio. They began in coordinated fashion in 2003, said Dr. Johnston, when it was "all but certain" that the economic strength of the automobile industry in Ohio would diminish. That was also the year of the

Northeast Blackout of 2003, which began in Ohio and advanced the debate about alternative sources of electricity.[21]

There were both specific and general arguments for supporting a PV industry in the region. First, the Toledo area had been a center of expertise in glass technologies for more than a century.[22] "It used to be known as the glass city," said Dr. Johnston. "We're working on making it the solar city." More generally, northwestern Ohio, like many other regions, had high electricity costs that were rising at about 7 percent a year. At that rate, the current cost, now about 12.8 cents per kilowatt-hour, will be 51.2 cents in 2026. Northwestern Ohio was also a region of high unemployment of displaced automotive and glass industry employees who had many transferable skills.

PV Pioneers from Toledo

The plan to initiate a PV industry in Ohio was not without precedent. In fact, it was a direct outgrowth of decades of work by a determined inventor and entrepreneur named Harold McMaster.[23] A lifelong resident of the region, Dr. McMaster and a group of colleagues founded Glasstech Solar in 1984 and invested generously in manufacturing and basic research at the University of Toledo and other institutions. These pioneering efforts gave rise to several of the companies and much of the research expertise that characterize the region today.

Dr. Johnston, an engineer and heir to Dr. McMaster's enthusiasm for solar energy, was in 2003 founding his own firm, Solar Fields LLC, in a business incubator at the University of Toledo. He points to substantial achievements for northwestern Ohio in the field of PV development over the last few years:

- Organizational support: The group of PV enthusiasts that included Dr. Johnston formalized its identity and mission as the Northwest Ohio Alternative Energy, or NOAE. This title has now broadened into Ohio Advanced Energy, or OAE, a business trade association promoting the interests of advanced and renewable technology industries statewide.
- Extramural funding: After slow initial progress, the state recognized the

[21]The Northeast Blackout of 2003, according to the U.S.-Canada power System Outage Task Force, began with the entry of inaccurate input data by an Ohio utility and continued in a series of cascading human and system errors that illustrated numerous weaknesses in grid management <*http://www.nerc.com/docs/docs/blackout/ch5.pdf*>. One appeal of PV is its flexibility—it can power a self-contained system immune to grid system failures or feed power directly to a grid.

[22]Pioneering Toledo firms included Edward Ford Plate Glass Company (1899-1930), Toledo Glass Company (1895-1931), and Libbey-Owens Glass Company (1916-1933).

[23]Harold McMaster (1916-2003), one of 13 children of a tenant farmer, was once called "The Glass Genius" by Fortune magazine. In 1939 he became the first research physicist ever employed by Libbey Owens Ford Glass in Toledo and went on to found four glass companies. These included Glasstech Solar, in 1984, and Solar Cells, Inc., formed to develop thin-film cadmium telluride technology. Solar Cells was later bought and renamed First Solar, currently a world leader in thin-film PV.

progress being made in Toledo, and in 2007 the Ohio Department of Development awarded $18.6 million in state funding to the OAE to establish the Wright Center for Photovoltaics Innovation and Commercialization (PVIC). The PVIC now has three research locations: the University of Toledo, Ohio State University, and Bowling Green State University. Matching contributions from federal agencies, universities, and industrial partners have raised this amount to $50 million.

- State legislation: OAE, chaired by Dr. Johnston, worked hard to help shape Ohio's Advanced Energy Portfolio Standard, which mandates that at least 25 percent of Ohio's electricity come from clean and renewable sources by 2025. This standard is expected to advance several other clean energy technologies as well, including wind power. For example, National Wind LLC recently announced the formation of Northwest Ohio Wind Energy LLC that plans to develop 300 MW of community-owned wind power projects. Half the renewable energy—about 800 MW—is to be provided by Ohio assets.
- Demonstration projects: U.S. Congresswoman Marcy Kaptur succeeded in securing $6.4 million to fund two demonstration projects in Ohio, at the 180th Fighter Wing at Toledo Airport and Camp Perry. The first is a 1-MW field, the largest in Ohio, designed for simplicity and low cost of operation. Installation began in June 2008 and is now being evaluated by the University of Toledo as the prototype of a "solar kit" that produces low-cost electricity.

Dr. Johnston reviewed the founding and early progress of his own firm, Solar Fields LLC, and its new technology. Solar Fields, like First Solar, uses cadmium telluride thin-film modules, but it was formed to develop its own atmospheric pressure deposition method of manufacture. The concept was first demonstrated using a four-inch-square atmospheric generator in a laboratory at the University of Toledo. The company was formed and financed by private investors in the Toledo area to move the concept from the bench top to a larger facility in Toledo, where in 2003 a two-foot continuous manufacturing line was demonstrated. This drew the interest of the German firm Q Cells, the world's largest supplier of silicon solar modules, and in 2007 Solar Fields entered a licensing arrangement with Q Cells and then a joint venture known as Calyxo. After a four-foot-wide production machine was able to demonstrate cost reductions, the manufacturing research was shifted to Germany while the R&D work of Calyxo USA continues in Perrysburg, Ohio. Dr. Johnston expects that the technique will have many advantages over other CdTe technologies, including lower capital requirements, faster production, higher material utilization, and less downtime.

Despite these achievements, the market for solar energy products in the region has barely begun to develop, especially when compared to markets in Germany, Spain, and Japan. Dr. Johnston reviewed the reasons why PV technologies have moved so rapidly elsewhere, focusing on the feed-in tariffs discussed earlier and the utility cost differences. Using a chart of electricity costs in 1999, he showed that average cost per kilowatt-hour was 21.2 cents in Japan, 15.2

Country	Cents/kWh
Argentina	14.1
Australia	8*
Austria	16.8*
Belgium	16.5**
Brazil	12.8**
Denmark	20.7
France	12.9**
Germany	15.2
India	3.4*
Indonesia	2.5
Japan	21.2
Mexico	5.9
Netherlands	13.2
Portugal	14.1
Spain	14.3
Switzerland	13.1
United Kingdom	11.7
United States	8.1

FIGURE 4 Cost of electricity in 1999.
SOURCE: Norman Johnston, Presentation at April 23, 2009, National Academies Symposium on "The Future of Photovoltaics Manufacturing in the United States."

cents in Germany, and 8.1 cents in the United States. The low cost in the United States effectively blocked investment in solar technologies, which were not yet cost-competitive.

The U.S. Sunlight Advantage

When and if solar power gains a significant foothold in the United States, it will benefit from the abundance of sunlight. Dr. Johnston noted that even chilly Ohio has more sun than Berlin or Munich, while Florida and other warm states have far more, and even the northernmost states have adequate *insolation*. A typical home in Los Angeles, he said, needs only 234 square feet of roof space to meet one-half its typical electricity needs using a solar power system with a conservative 12 percent conversion efficiency. A typical home in Maine would need just 25 percent more roof space. "There is sun in every state," he said. "It just varies by about 25 percent."

Nor is the expansion of a solar industry in the United States limited by production capacity, he said. In northwestern Ohio alone, he said, the production capacity of First Solar is already 100 MW/yr, and will soon expand to 170 MW/yr. Xunlight Corp., which is developing wide-web, roll-to-roll thin-film modules in Toledo, will be producing about 100 MW/yr of capacity by 2010. Calyxo is producing 100 MW/yr in Germany, and is expected to complement this with U.S. production. Another CdTe start-up firm, Willard & Kelsey Solar Group, plans to begin production in Perrysburg in late 2009. By now, he said, northwest Ohio has more CdTe and glass expertise than any other region in the world. A larger U.S. market would quickly stimulate additional production.

Dr. Johnston emphasized another advantage of a PV industry, which is job creation. The projected number of jobs created per megawatt of PV power, he said, is 15, compared with 4.8 jobs for geothermal energy, 4.2 for biomass-dedicated steam, and 3.4 for wind power. He also described the economic ripple effect of a PV solar business chain that could include building construction with advanced glass, a 100 MW solar module plant employing 650 people, construction of the plant employing 250 people, solar fields connected to the grid, and new homes with fiberglass insulation.

For the time being, he said, the advantages of new solar construction have become moot in the face of the worldwide economic crisis. He estimated that over 1 gigawatt of PV material is now stored in warehouses, and solar manufacturers are beginning to reduce employment. Six months earlier, he said, customers had difficulty finding enough PV material; "now it's the other way. The industry is stagnant."

The Continuing Issue of Low Demand

Beyond the economic depression, Dr. Johnston said, looms the continuing issue of low demand in the United States. "We need funded solar projects," he said, "and I can't figure out how to do that." He suggested that building Ohio solar farms would be an appropriate use for federal stimulus funds, for example. Out-of-work automobile workers could be retrained "in two weeks, and in two months we could have tens of thousands of people putting in product that's already here in warehouses." Almost all of this product is available from U.S. manufacturers, he said, which was demonstrated during construction of the solar field at the Toledo airport, 93 percent of whose materials were made in Ohio. "The only thing we didn't have was an inverter company," he said. "So we started one, Nextronics, which is in Toledo."

Making Use of Brownfields

An additional advantage of Ohio and other rust belt states, Dr. Johnston said, is the enormous supply of abandoned industrial space, or "brownfields," available through a variety of grants and partnerships. Toledo alone, he said, has some 830 acres of brownfields, and some 10 to 30 solar farms could be built on brownfields around the state. "Look at all the sites that are shut down," he said. "Many of them are paved and have power lines already in place." He has calculated that these new solar farms would provide a market for some 56 million square feet of glass, used 4,263 miles of wire and 18 million feet of aluminum frames, create 1,500 direct jobs, and produce 300 MW of electricity. "The idea of funding this up front is a good one," he said.

Other conditions are favorable to PV projects, he said. They would qualify for school installation, for which all-Ohio content would be available. Parts of brownfields could be sold or leased to lower or reclaim costs. Utilities would be able to make use of tax credits, private investors could use grants or tax credits, and additional support is available from the Ohio Dept of Development to build solar farms. He listed a community of local companies capable of building complete solar farms, including the modules, installation, glass, R&D, land reclamation, contracting, frames, electrical systems, and inverter. "And yet the only one we've installed is the demonstration field at the airport that Congresswoman Kaptor helped arrange," he said.

Dr. Johnston concluded that despite enormous effort to launch a PV industry, it still has not arrived. "We've built our field of solar dreams and they haven't come," he said. "My message to the federal government is: If you're going to give billions of dollars to industries that have failed, you can certainly invest in one that has a bright future."

DISCUSSION

A questioner asked Mr. O'Rourke when Deutsche Bank might be ready to invest in solar companies such as those described at the symposium. Mr. O'Rourke replied that although he could not speak directly for Deutsche Bank, the problem for banks as he understood it was not a lack of good investments but balance sheets that had to be revamped. He said that the balance sheets of big banks are very complex, with many classes of assets. When the banking crisis struck in November 2008, these banks had to begin examining all of those assets and begin the process of derisking balance sheets. Every item on their books had to be examined and then disposed of or retained, so that the balance sheet could be returned to the right degrees of risk and leverage. "It's not that a Deutsche Bank or any other bank doesn't want to lend, or doesn't see value in renewable energy projects," he said. "These are very safe investments for the most part. But until bank balance sheets are reconstituted, there will be no lending. It's as simple as that."

Mr. O'Rourke was asked whether this was why he had suggested the mechanisms of government incentives and tax incentives, rather than loans. He agreed that on the manufacturing side, one issue to overcome is taxes. "Right now the playing field is not level," he agreed. "But it's possible that even if there are tax incentives to bring manufacturing to the U.S., you will find another country in Asia that's willing to forego taxes for 15 years in order to bring industry. One of the ways around that is some incentives up front that may not recover everything you would lose in profitability. We have to make these kinds of choices that determine whether we have a stagnant market, a growing market, or a rapidly growing market. The best solution to all of this is to somehow get to that rapidly growing end market."

Mr. O'Rourke added a comment about the situation in Europe. Many companies had offers that included tax exemptions for long periods. Other factors, however, such as the cost of shipping glass long distances, or the benefits of a local presence, can play a significant role in cost and siting analyses. "Once fuel costs go back up," he said, "shipping is going to be more important. So when considering how to bring manufacturing to a region, I cannot think of anything more important than having a strong local market for your product.

A questioner asked what a demonstration project would cost and what metrics could be used to evaluate it. Dr. Johnston referred to the $5 million Air Force base demonstration project that produces over 3.4 MW of power for under $4 per kWh of installed cost. "I would like to see Congressman Kaptur use her influence to help not just northwestern Ohio but the United States," he said, "and help get some of this incentive money in every state to do the same kinds of projects. We still have bridges and hotels built in the 1930s; it would be nice to look at solar fields in 30 years that still produce power."

Mr. Zweibel reiterated his belief "that the next dollar spent on PV should be spent to leverage technology leadership." He said that R&D money and technology development produce leadership, which is "right now the only thing the United States has. For everything else we have to beat someone else at tax issues or other incentives. We should not forget that we have no PV R&D program in the United States with the kind of leverage we need to move these technologies forward." He said he was referring to established technologies: crystalline silicon, amorphous silicon, thin-film microcrystalline silicon, cadmium telluride, and copper indium diselenide. "I'm not talking about plastic solar cells," he said, "or 5th-generation solar cells that are in proposals from single professors at various universities playing with beakers. I am talking about technologies that are out there in gigawatts, which have an opportunity to be half or less of today's already nearly cost-competitive cost. Avoid diversions in mainstream applied research programs. Right now, we are funding more R&D diversions than actions that will actually accelerate success."

Luncheon Remarks

Transforming the Glass City into the Solar City: Toledo's Tradition of Innovation and Entrepreneurship

Congresswoman Marcy Kaptur (D-Ohio)

Rep. Kaptur (D-Ohio) began by thanking the National Academies, and she said it was an honor to speak on a subject that "promotes economic and environmental sustainability and energy independence for our nation, which is my top priority as a member of the defense committee."

She asked, "How can it be that Toledo, Ohio, ended up leading our nation in such a key area of energy independence." First, she said, the power rates charged by investor-owned utilities along Lake Erie's south coast to Cleveland are among the most expensive in the nation and constitute "a serious impediment to economic growth in our region. It is amazing that we have the industry we have in view of these incredible prices." She said she also represented "the worst nuclear power plant in the United States," which had averaged one incident per decade over the last two decades.

"Unlike regions that have subsidized power through a federal power marketing authority like Bonneville or the Tennessee Valley Authority," she said, "we must reinvent our power future, drawing on our natural assets to be competitive in the global marketplace." She said that there were no "cushions," as there are in the government centers of Washington, D.C., and Columbus, Ohio, because she comes from "the free-market part of America. We have to grow and build wealth. We're resentful that New York, Charlotte, and other financial centers have traded that wealth away. But we know what we have to do in order to build our future and America's future."

THE GLASS CAPITAL

A second reason this region of Ohio had built a reputation as a leader in new energy technologies, Congresswoman Kaptur said, is that Toledo historically has been known as the glass capital of the world. She reviewed some major Toledo companies that had succeeded in leading the glass industry, including Libby Owens Ford (now Pilkington), Johns Manville, Owens Illinois, and Libbey, Inc. These companies were supported by the region's silica and lime reserves, and by glass physics research and generations of business leaders. Glass expertise, she said, had led to a range of skills around solar energy, including solar energy building materials, heat shields, and fiber optics.

Her own interest in renewable energy began long ago, she said, and gained depth when she served as White House policy advisor to President Jimmy Carter. "I lived the oil embargo of the late 1970s," she said, "and we all saw what it did to our country. It was the first slap in the face, really hard, and it knocked our teeth out." She recalled President Carter's message that what we endured was the "moral equivalent of war, and he remains right to this day. But the nation forgot his message."

She worked as a city and regional planner for almost two decades before running for Congress in the early 1980s. She said she was always interested in sustainability, at every level, and in building on natural assets. In the 1980s, the unemployment in her region was higher than she had ever seen it, and she realized she wanted to represent those in her community who were "up against the wall. I had to be their voice," she said, "and that's what motivated me to run."

"WOW, THEY CAN DO IT HERE"

During the Reagan administration, Congresswoman Kaptur said, federal support for photovoltaic research and alternative energy was substantially diminished, but in her congressional activities, she tried to promote photovoltaics and the research needed to make it more efficient. She recalled meeting Dr. Harold McMaster, who invited her out to a university laboratory to show her a vacuum chamber. He was about to build some of the first films for a company that has become First Solar. She was drawn to his enthusiasm immediately, and watched closely the companies he founded, which, she said, "all made money." She recalled a time when a car company charged him with building an especially difficult window. "I thought, 'You'll never be able to build it, it will crack.' On the day when the first rear window came off the line, it didn't crack. We all went, 'Wow, they can do it here.'"

"I watched this gentleman who loved our community," she said—"a great philanthropist. He and his colleagues invested in our local school system, gave millions of dollars to our university, knew what it was to build a community and a country. They respected one another and they knew they had to move America forward. I remember their boundless vision to produce a new generation of research and innovation for our country. They were both scientists and entrepreneurs at the same time, and they never quit innovating."

Congresswoman Kaptur gave Dr. McMaster and others full credit for "doing so much when America was asleep." In 2007 the *Economist* magazine described Toledo as one of the six places on earth with real strength in new solar-powered systems and one of only three in this hemisphere. "This it isn't by accident," she said. "It's because many people have given their lives to it." She said that Ohio had just recognized the two-decade-long effort pursuing innovation and R&D by funding the Wright Center for Photovoltaics Innovation and Commercialization at the University of Toledo. She praised the university for its progress in PV, and recalled that at a recent World Energy Conference in Abu Dhabi, the United States was represented by only two universities—MIT and the University of Toledo.

SOME "BRUTAL FIGURES" ON ENERGY USE

Congresswoman Kaptur reminded her audience of some "brutal figures" on energy use. In 2006, she said, a third of the U.S. trade deficit, which now approaches three-quarters of a trillion dollars, was from imported oil. "This," she said, "is a national security issue for our country." Just as the disadvantage of importing fuel is obvious, she said, so is a solution: to develop a comprehensive plan to better use our domestic resources. "We are about that full-bore in our region," she said, "to recapture that three-quarters of a trillion dollars a year of lost wealth back here at home."

She listed the technologies that can contribute to this strategy, including domestically produced biofuels, wind power ("Lake Erie is the Saudi Arabia of wind"), the solar sector, geothermal power, hydrogen fuels, wave power, and fuel cells. The potential of these new markets "is limited only by our technological and industrial imagination," she said. With half as many sunny days as Portugal, she said, the world's leading solar energy producer now is not the United States, but Germany. That country now accounts for 15 percent of worldwide sales in solar panels and other photovoltaic equipment, and has 15 of the 20 largest solar plants. "That's right," she said, "a country located in northern Europe, with fewer sunny days than Toledo, with no natural advantage, is outperforming the rest of the world—because it sees the future."

MORE SUBSIDY FOR NUCLEAR THAN FOR SOLAR

Congresswoman Kaptur compared the U.S. commitment to solar energy with its commitment to nuclear power. Today nuclear power generates a large proportion of our electricity, she said, but this happened through a concentrated and deliberate approach to broaden our electrical usage. Between 1943 and 1999, she said, the nuclear industry received over $145 billion in federal subsidies, without counting tax subsidies. By contrast, the solar power industry had received some $4.4 billion and the wind power industry $1.3 billion.

"We haven't even begun to fight," she said. "The fiscal cost of our continued dependence on oil can be measured in many ways." She said that in 2009 the United States will spend over $600 billion on defense, the largest amount in U.S. history. She said that much of that amount is spent to protect the Arabian Gulf region and central Asia, which together account for at least 64 percent of the world's petroleum reserves, 34 percent of its crude oil production, and 46 percent of its natural resources. "For each of you, as citizens of this republic, you have to ask, is this the world you want for your children," she said. "And if it is, you don't have to change anything."

Change can come, she said, through two things: First, a stable, long-term funding strategy focused on basic energy research. Second, significant resources devoted to commercialization of energy technologies. "From personal, residential, and vehicle to business uses," she said, "the commercialization of this technology is key to transforming our economy and converting technologies from the laboratory to the consumer."

This is extremely difficult to do from a local or regional base, she said. One way to start was to build the kind of demonstration project now installed at the 180th Fighter Wing in Toledo, where solar cells now produce a 1-MW research base. "We're going to keep pushing the science," she said, "and equally important, pushing the economics." The head of the base had asked her why the national guard plant was able to sell its excess power to the utility for 3 cents/kWh, while the base is charged 9 cents/kW hr when it buys power from the utility. This, she said, was an example of economics that need to change.

CHANGING OUR THINKING "FROM THE INSIDE OUT"

Another change Congresswoman Kaptur suggested was a change in thinking. She described a 5-mile corridor recently dug for a seven-foot storm-water main. She mentioned to the utilities director that he could use that same corridor for electrical power that would allow local residents and businesses to tap into a new grid. "We would invest in it ourselves," she said, "use the bonding power of our city through its utilities department, put up solar power installations, and pay for them over 25 years." The utilities official acknowledged that he had not been trained to do those things. "I told him, 'Well, you know how to dig holes, and you've got assets at your fingertips.' We have to change our thinking from the inside out. We have to think about the power we are abdicating every day and retrain a whole generation of people to live in a new energy age."

One reason Toledo had been so successful in spinning off solar technology, she said, was that it had created a close partnership between the university, industry, and government. "They're all working together," she said. "Partisanship doesn't matter to them. Science matters, business matters, energy independence matters. We have sustained our commitment to basic research as a prerequisite to the development of solar companies, and we will never stop pushing the science." At the University of Toledo, two vehicles for doing this had been the Clean and Alternative Energy Incubator and the Clean Energy Alliance of Ohio, which both educate private interests in the technologies developed in the universities.

Congresswoman Kaptur concluded with a plea for "regionalized federal efforts" to transform science from the experimental stage into commercial technologies. As the population continues to increase and make their claims on natural resources, she said, the challenge is to "sustain this country" and "be a partner in the world for a sustainable earth. Part of the answer has to be renewable energy capitalizing on the historic strengths of places like Toledo. But we all have to see that same future and that same possibility. We have everything we need right in our area, including the sun. Even the symbol of Toledo has a rising sun. It's perfect."

DISCUSSION

A participant spoke out on behalf of "a huge collaboration to get this technology moving faster and in a sustainable manner." He suggested that models, if not the actual collaborative programs, are already in place. "But I have not heard any response from the people who are already involved in solar development as to whether or not they accept the need for something as vast as these collaborations, and whether they would consider joining."

Dr. Zweibel responded that when he was at the National Renewable Energy Laboratory, his colleagues formed research collaborations that were national in scope, and some of which still existed. Researchers from many institutions met with counterparts from universities and companies to discuss their work, then returned to their home labs to work. Six months or so later they would meet again with their partners, return home again, and so on. "These collaborations had the essential element of continuity," he said. "I think collaborations are most successful when they start simply. If you want to understand solar cells, you start with knowing what you need to do on a small scale. You keep doing that iteratively on larger and larger samples and you get better and better at it. Once you have the technology in place you can go to the next level of collaboration."

Alvin Compaan of the University of Toledo thanked Congresswoman Kaptur for her comments and support for photovoltaics over many years. He referred to earlier discussions about challenges presented by East Asian and other governments that offer large incentives to solar companies, and the need to level the playing field. He asked what discussions were under way in Congress about these issues. Congresswoman Kaptur replied that she worried a great deal about whether U.S. trade policies and tax policies were fair to U.S. business, including those in renewable energy fields. She said that they were not fair, and U.S. business faced "severe disadvantages" in the global market place. As an example of unfair trade laws, she pointed to automobiles: "Fewer than 3 percent of the cars in Japan are from any other country, whereas more than half the products sold in the United States are from abroad, or from companies from abroad operating in the United States. We're the dump market of the world."

Congresswoman Kaptur proposed one possible way to help rebalance this situation. "If the federal government has money invested in a new technology, we might simply extend the patent term to allow production to occur only in the United States." She said a regulatory change would be simpler to execute than a trade or tax law, as long as it was legal under GATT and WTO. "What troubles me," she said, "is to see someone in my district trying to birth new industry, but another company can simply take all their innovation and move it somewhere else where people work for low wages. My biggest worry is that somebody's going to walk off with 100 years of effort who won't love our community like Dr. Compaan, Dr. McMaster, and Norm Johnston."

Panel V

Next Generation: The Flex Display Opportunity

Moderator:
William Harris
Science Foundation Arizona

Mr. Harris introduced the panel, praising as he did so the "sense of urgency everyone has about this issue." He expressed satisfaction that "everyone here claims to be the solar city."

NEW AND SYNERGISTIC OPPORTUNITIES IN FLEXIBLE AND PRINTED ELECTRONICS

Mark Hartney
FlexTech Alliance

Dr. Hartney said he would discuss a new kind of solar technology that brings its own new capabilities and challenges—that of flexible and printable electronics—of which photovoltaics is a component. The FlexTech Alliance was formerly the U.S. Display Consortium, initiated about 15 years ago to support R&D. It structure was much like that of SEMATECH, except that it focused on the then-nascent flat-panel display industry. The consortium was supported by DARPA, and Mr. Hartney was the DARPA program manager charged with the mission of building a supply capability in flat-panel displays in the United States. While it was primarily an R&D consortium, it focused on precompetitive aspects of the supply chain. The member companies could add their own innovations, but worked from a common ground in which they shared many tools and materials. The program brought together companies that could work together and were willing to cost-share more than 60 percent of the R&D.

For the past five years, the Alliance has been funded by the Army Research Laboratory, primarily because of the Army's keen interested in flexible displays for their own particular needs and mission requirements. Since that time the Alliance had broadened its mission area to include other kinds of flexible electronics.

Rugged, Low-Weight, Flexible, Deformable

One trend in electronic systems, Dr. Hartney said, is that they are becoming larger; they are no longer just micro- or nanosystems. They might include, for example, six 45-inch diagonal televisions, or an eight-foot display on a single sheet of glass. They must meet many performance requirements, such as a demand for displays that are rugged, low-weight, flexible, and deformable. Some of these flexible electronic systems are arranged on ultrathin steel foil; other types of flexible electronics contain millions of transistors on a glass surface to control display pixels, or transistors on a plastic transparent substrate.

Flexible and printed electronics represented "More than Moore," he said. Moore's Law in silicon electronics describes the drive toward smaller features, higher density, more complexity, and higher costs. Printed electronics, by contrast, strives for sufficient functionality at lower cost. For example, printed and flexible electronics might use thousands of transistors, where silicon and glass structures use billions. Feature sizes are typically in the tens of microns as opposed to the tens of nanometers. A fab might cost from less than $5 million to $100 million, as opposed to $2 billion or $3 billion.

The Convergence of Two Worlds

Flexible and printed electronics represent the convergence of two worlds—microelectronics and graphics printing—which brings many advantages. They use familiar printing methods, he said, such as injection and gravure printing. They allow development of new products with a low cost of entry. They produce a product that is printed on graphics equipment but serves as a functional electronic device. This convergence is possible because both worlds have changed rapidly. The graphics printing business has moved toward finer and finer feature sizes, while microelectronics materials development has led toward new nanomaterial inks, plastic substrates, and organic semiconductors. "These open new possibilities," Dr. Hartney said, "in flexible displays, flexible solar cells, and electronic newspapers you can fold in your hand."

Flexible and printed electronics have moved through three generations. The first had passive components, such as capacitors, resistors, conductors, inductors, and RFID (radio-frequency identification) antennas. These were printed on circuit boards with metal ink. The second generation, now being developed, has active printed components. It will make use of thin film transistors for e-paper and e-books, thin-film solar cells, and microbatteries. This is likely to be followed by a third generation of completely printed active devices. Printing technologies will be used to actually build memory: complete RFID circuits, rather than those requiring a chip to be attached later; color displays with TFT-driven light-emitting diodes; and SRAMs and CPUs. "We see flexible solar as a very important member of this family of printed electronics," he said.

Dr. Hartney outlined some of the global market opportunities anticipated for this sector over the period 2007 to 2017. The first and most prominent will be photovoltaics. Another important segment will be electrophoretics, he said, the kind of display that powers the Amazon Kindle and other book reading devices. This display is actually flexible, but it is put into a rigid package because it is what people are used to. It could easily be decoupled from the glass substrate, rolled or folded into a smaller package, and slipped into a pocket. Another important application is organic light-emitting diode (OLED) technology, which will be important not only for displays, he said, but for high-efficiency lighting.

In today's PV market, he said, crystalline silicon predominates, with more than 90 percent of PV shipments being silicon wafer-based material. Thin-film technologies have the highest growth rate, rising from 50 MW in 2007 to a predicted 4.5 GW by 2012. Thin film has the advantage of leveraging LCD production and its $120 billion in sunk costs, and is being used experimentally on flexible substrates. The third generation of PV products is still in the R&D and pilot stages, with some scale-up work on organic, nanostructured materials, CIGS (copper indium gallium diselenide), and other technologies that can take advantage of flexible substrate properties.

Toward Roll-to-Roll Processing

The Alliance does not focus so much on particular technologies as on the manufacturing approach, he said. Virtually all integrated circuit and display manufacturing uses discrete substrates, and these glass substrates are increasingly large, requiring batch processes with multiple steps and expensive thermal and vacuum cycling. A newer approach is to use roll-to-roll processing, which offers the opportunity for continuous flow. This technique can be modularized for different unit steps or integrated into a complete line. It enables new markets, such as building integrated photovoltaics (BIPV), which are light-weight solar materials that do not require the reinforcement of roofing before installation. He said that BIPV can even be attached to a roof with Velcro and then removed to another site.

Dr. Hartney described other roll-to-roll techniques of high potential. One, being developed by a collaboration between Hewlett Packard and Power Film in Iowa, makes use of amorphous silicon thin film on a Kapton[24] substrate. The same kind of substrate can be used to emboss and print the substrate of a flexible display. Another technique uses organic flexible printed materials developed by

[24]Kapton is the brand name of a temperature-stable polyimide film developed by Dupont which is well suited to flexible electronics.

Konarka.[25] These films have long lifetimes in the field, which is "probably more important than making the active layer a few percent more efficient."

Flexible electronics also have an impact in major fields of R&D:

- Health care: New techniques in the form of smart bandages (sensors that detect thermal or bioactivity and release therapeutic agent); real-time monitoring (to sense infection, release drugs, or signal the need for intervention); and neuroimaging (assisting in precise surgery by monitoring brain activity, providing a template for the surgeon to follow, and providing greater biocompatibility).
- Agricultural and civil infrastructures: Here, flexible electronics can be used for large-area sensor networks to monitor roadways, fields, groves, water supplies, and other places. For crash barriers, OLEDs can capture sunlight during the day and cause a crash barrier to glow at night; they can also incorporate a sensor and communication system: If someone goes through a barrier, it automatically reports an accident.
- Defense and emergency responders: Flexible electronics can be rugged enough to wrap around a soldier's uniform or used as an electronic surface on skin of airplanes. Some fighter planes must be x-rayed after every mission to ensure that its carbon fiber material is still robust, a time-consuming process; much more efficient would be an integrated sensing grid that would instantly indicate whether the skin has to be replaced. Flexible skins may help outfit the "soldier of the future," with active camouflage, threat detection, and earth monitoring abilities; integrated solar energy sources; and these technologies could serve a dual use for similar requirements needed for first responders.

In summary, Dr. Hartney said, photovoltaics presents an enormous economic opportunity. In technologies from crystalline silicon to large-area thin film, new techniques can draw from the existing and mature semiconductor and display industries. As the industry moves into flexible and printed electronics, the level of maturity is lower. Companies, universities, and government laboratories are working to move these electronics technologies closer to maturity, a challenge that can be met only through the synergies of collaboration.

He closed with four policy recommendations, including the need for (1) sustained federal and state R&D, (2) common infrastructure development, (3) early prototyping of mission needs to drive learning cycles, and (4) innovative manufacturing support. "Getting industry to buy into collaboration is essential," he concluded. "Many of the people we've talked to believe they need to do it all on their own. They haven't recognized the value in collaboration, even with people who are competitors."

[25]Konarka Technologies of Lowell, Massachusetts, makes light-weight, flexible PV that can be printed as film or coated onto surface.

ADVANCING TECHNOLOGY THROUGH MEASUREMENT SCIENCE AT NIST

Eric K. Lin
National Institute of Standards and Technology

Dr. Lin said that he would review how the diversity of approaches in federal laboratories helps advance new technologies, and photovoltaics in particular. NIST's own approach is primarily economic, since it is located in the Department of Commerce, so that its mission is focused on economic growth, and more specifically on innovation, measurements, and standards. These activities have obvious relevance to photovoltaics.

NIST was founded by Congress at the beginning of the industrial revolution in 1901, when the nation had many difficulties supporting its burgeoning new industries. For example, there were eight different "authoritative" values for the gallon. A new electrical industry had not yet developed its own standards, so American instruments were sent abroad for calibration—an obvious national security issue. At the time of the gold rush, a miner and a buyer had to be able to agree on what a kilogram or pound of gold would be. "They needed a neutral objective partner they trusted to be correct."

Promoting Competitiveness at NIST

Today, Dr. Lin said, the NIST mission is to promote innovation and competitiveness in many ways that are based on science. This is done by advancing measurement science, standards, and technology in ways that enhance economic security and improve the quality of life. The main strength of the NIST campus is that it is globally recognized as a center of scientific talent.

NIST, at a glance, consists of 2,800 employees, 2,600 associates and facilities users, and 1,600 field staff in partner organizations. More than half of them have Ph.D.s, and about 400 serve on 1,000 national and international standards committees representing U.S. interests. Major programs at NIST laboratories include the Baldridge National Quality Program, Manufacturing Extension Partnership, and Technology Innovation Program (formerly the Advanced Technology Program).

The NIST laboratories function at the "professional level of science," he said, and the level of experience and quality of NIST science make it "a national resource of great importance." The labs provide the innovation infrastructure for much of the nation's scientific activity. "Basically," he said, "we're building the 'roads and bridges' of research that industrial and scientific communities need to develop and commercialize new technologies." These roads and bridges take different forms:

- Basic science and groundbreaking research.
- Performance measures for accurate technology comparisons.

- Standards to assure fairness in trade.
- Public-private partnerships to accelerate technology.

"When NIST engages with industry to facilitate innovation," said Dr. Lin, "we really take seriously our role as a neutral, objective partner with very high standards based on fundamental science." He gave his view of NIST's role in technology development. It begins with promoting discovery and proof of principle, which relies on the principal investigator and peer-reviewed journal articles. A second level promotes the kinds of growth stimulated by the semiconductor industry via SEMATECH, the Flex-Tech Alliance, and other industrial organizations. With growth comes the need for standardization, transition to larger scale manufacturing, and finally a mature industry that focuses on efficiency and an integrated network of stakeholders.

Avoiding Silos, Addressing Broader Needs

At each level, he said, NIST has a role to play. For example at the discovery or proof of principle level, NIST has its world-class measurements and science, many high-impact publications, and input from National Academies members and Nobel Laureates. At the point of cooperation and consortia, requiring multidisciplinary programs aligned with roadmaps, a good example of NIST participation is its Office of Microelectronics. This was started about the same time as SEMATECH, in recognition that researchers should not be isolated in disciplinary silos. To counteract this tendency, NIST has mechanisms for coordinating its professional scientific staff to be most effective in addressing the broad needs of a growing industry. The Technology Innovation Program is one mechanism for catalyzing the transfer of technology to industry. For the later stage of rapid growth, NIST participates in standards development, tech transfer, and standard practices, as well as through the Manufacturing Extension Partnership (MEP), a nationwide network of facilities to support manufacturers, especially small firms, in developing their technology.

Providing Infrastructure, Expertise, and Standards

For PV and flexible electronics, Dr. Lin said, the technology is now in the first two stages: discovery/proof of principle, and cooperation/consortia. In the first stage, the industry is researching organic PV and new concepts, such as roll-to-roll manufacturing. For cooperation and consortia, the industry has the Flex Tech Alliance recently created by DoE, and PV partnerships. In both cases NIST works with the relevant parties to provide infrastructure and scientific foundation, measurements, and standards as available to support the technology.

He illustrated how NIST supports an industry through the example of organic photovoltaics. This field includes next-generation photovoltaics—printable and flexible thin film, organic, and hybrid solar cells—which rely on complex nanostructured shapes with multiple components. Some of the most studied systems, he said, are a mixture of types of materials with nanoscale structures that are not fully known. The efficiencies of devices change from line to line, under different conditions, without a great deal of control or understanding. NIST seeks to help reduce these basic unknowns through sophisticated measuring instruments that range from x-rays and synchrotrons to acoustic surface measurement and scanning tunneling microscopes. The objective is to help the technology developers better understand the materials science that underlie manufacturing behaviors.

"The main points here," concluded Dr. Lin, "are that the work is multidisciplinary, and that many problems cannot be handled by a single discipline. In addition to our own collaborations, we have a large number of open partnerships that focus on objectivity and on practicing the best science available."

FLEXIBLE ELECTRONICS

Bob Street
Palo Alto Research Center

Given the research orientation of his organization, Dr. Street said that he would discuss R&D aspects of flexible electronics. The context for flexible electronics is largely the display industry that, until recently, has been dominated by liquid crystal displays and based on conventional processing of thin-film silicon on glass substrate. Cost reduction over the past two decades had been achieved by scaling to larger sizes, with the substrate doubling every 2.5 years. The latest substrates, gen-10, are 10 square meters in area. "For a while now we haven't known when this scaling will have to stop," he said, "but it can't go on much longer. It's already an enormous challenge to make devices on that size of substrate."

Toward More Diversity in Display Technologies

The primary applications of these displays have been laptops, desktops, and TVs. Displays are a $100 billion industry, and many people foresee much more diversity in future products, including multiple functions, portability, flexibility, and embedding in other devices. This has created a push for new technology which seems likely to bring a shift in manufacturing and cost paradigms. This shift is likely to move the industry from lithography and batch printing, which are expensive, to digital, roll-to-roll printing; from glass to flexible substrates; from vacuum deposition to solution deposition in the ambient; and to new higher-performance materials and green technology.

This scenario, Dr. Street said, has many parallels with the photovoltaics industry. Many of the changes are driven by the high cost of manufacturing devices that are very large. The interest in organic semiconductors for photovoltaics, despite their low efficiency, for example, comes from the promise that they can be made very simply from solution without expensive equipment. When that promise will be fulfilled, he said, is still unclear.

He gave three reasons for the shift toward flexible electronics:

- First, they can be used to make devices that are either rugged and lightweight or that can be rolled up. These include e-paper and other portable displays; solar cells; RFID tags and smart cards; unbreakable x-ray imagers and security systems, such as truck scanners.
- The second reason is low cost of manufacturing. Roll-to-roll manufacture is viewed as much less expensive than batch processing.
- Third, they are conformable and stretchable. Promising new uses include medical sensors that can be placed on the skin like a plastic bandage; retinal cameras, which mimic the extremely efficient design of the human eye; and a variety of shaped devices. Roll-up displays and RFID tags are close to market now, and flexible solar cells are already in the market.

"Tens, Possibly Hundreds, of Different Materials"

However, Dr. Street cautioned that the business is in a fledgling stage, with most products still in development. The challenges, he said, are largely those of materials science. For example, in changing a display from glass substrates with amorphous silicon or polysilicon materials and photolithography, to a flexible printed device with new thin-film materials, many new options must be developed. Plastic, steel foil, and elastic substrates all have materials issues to be resolved, such as surface quality, barrier layers, and temperature limits. The electronic performance of amorphous silicon must be matched or exceeded when using newer materials, such as organic TFTs, metal oxides, nanowires, all of which come with their own materials challenges.

"The last 10 years have been a wonderful time for the science of electronic materials," he said. "It's all being pushed by the size of the display industry. But we now have a whole host of new issues. There are many tens, possibly hundreds, of different materials with different properties to be investigated."

Big Competition from Asia

To meet these challenges, Dr. Street said, the United States needs to be the leader in materials research. "Then, when we have a problem," he said, "we can do the research, make the prototypes, and know that they do work. But getting from there to a manufacturable technology is difficult and expensive, and we don't do that well." In Asia, by contrast, displays are not only a big industry, but one that is supported by "a whole ecosystem of equipment manufacturers, materials suppliers, and a stream of new technology that is being created in universities and research centers around the world."

He closed with a call-to-arms for U.S. industry. "Because the industry in Asia is so big," he said, "it draws in new technology—from the Palo Alto center, from universities, from start-ups. And they have the manufacturing power. We need to understand that many of the materials in the flexible electronics space are the same as will be used in the next generation of photovoltaic materials. We should ask ourselves how easy it will be for these companies to just shift into solar when the time comes and be very competitive with anything we can do. I think this country needs to take this funnel of research and technology that is presently directed toward Asia and move it back into the United States and ensure that we have an industry here that can be the manufacturing focus for the new technology."

Panel VI

Roundtable Discussion—
Key Issues and Next Steps Forward

Moderator:
Congresswoman Gabrielle Giffords (D-Arizona)

Congresswoman Giffords (D-AZ) said in her introduction that she is "incredibly passionate about solar energy," not only because she hails from Arizona, but more fundamentally because the technology aligns so well with the challenges this country faces in energy independence and climate change. She also noted its power in stimulating more technical innovation, and in helping to attract and train more of the scientists and engineers we need. "I really think solar is an incredible solution to the tough issues we face," she said. "Of course the whole world faces them, but we as a leader in technology have a lot more at stake."

Jim Ryan
Joint School of Nanoscience and Nanoengineering
Gateway University Research Park
Greensboro, North Carolina

Dr. Ryan noted that he had come to the symposium mostly because of his work with IBM, which was described earlier by Dr. Kelly. He described his special interest in industry-university-government consortia and issues under discussion at the symposium that his group had worked with.

Eric Daniels
BP Solar

Mr. Daniels noted BP Solar's "long history of perfecting the final product, the module that goes to market." He said that goals for the future must include lower cost and better performance of solar modules. He noted that R&D

subsidies "have been fantastic in bringing new people to our organization and our industry." He attributed some key patents issued in the last few years largely to new members of BP's research effort. He said that the company had filed for many patents, and suggested that "anything we might do to speed up and assist our friends at the patent office" would be extremely important. "This is a fast-paced industry."

A second goal of importance, Mr. Daniels said, was to gain a better understanding of module lifetimes. All solar cells have a tendency to degrade under the sun's rays, with thin-film panels degrading more rapidly than crystalline panels. The systems BP was installing in the field were assumed to last a minimum of 20 years in most cases and warranted accordingly. BP Solar is one of the only companies that have had products in the field for periods longer than their warranty. Levelized Cost of Energy (LCOE) modeling tools use assumptions regarding projected long term performance for solar products in order to predict the cost of solar energy for solar power systems. Actual history is available for some technologies, "but we really need to understand this better," he said. "I've spent a lot of time looking at design models, and there's an enormous amount of work ahead of us to get more precise about that."

Mr. Daniels also commented on the continuing need for lower costs. He said that much of the U.S. industry's progress had depended on the development of foreign markets. Most manufacturers, he said, have a multinational presence in site locations. "Were it not for that international competition," he said, "our prices today would not be where they are. We are now in some cases at grid parity. We can do more to continue to drive costs down."

Mark Pinto
Applied Materials

Mr. Pinto suggested that one of the most important lessons about PV development is to "remember the learning curve. We're on one. This technology continues to get cheaper. It comes from innovation; it's technology based. It's not just using bigger glass; there's real technology down to the fundamental level."

Having said that, however, he agreed with the consensus that "it's still driven by initiatives that need to happen on the demand level." For the time being, he said "a lot of creative ideas," such as those presented by Mr. O'Rourke, were needed to navigate the difficult currents of demand. But as time goes by, he said, "some of those things will go away, and the learning curve will take us where we need to go."

In terms of manufacturing, Mr. Pinto again referred to the ideas presented by Mr. O'Rourke, including some of the disadvantages for manufacturers. "We've just made an initial start at addressing that here in Washington. But it is a difficult challenge for our customers, which is one reason so many manufacturers have built factories outside the United States."

Progress in R&D, he said, would also depend on "recognizing this learning curve and not waiting for the 'next big thing' that is somehow going to make a 5x difference. If we do that we're not going to be part of the game here." At the same time, he said, there is a role for investments in future research. He referred to the lessons of the semiconductor industry, described earlier by Mr. Kelly, in building collaborations and focusing on joint precompetitive research.

In the solar industry, Mr. Pinto said, it is often difficult to form collaborations because manufacturing and technological development were still competitive. One reason for this, he said, was there were some three dozen solar start-ups in Silicon Valley developing nearly that same number of different CIGS processes, all of them competing. "Believe me," he said, "I know, because they all want equipment, and it's hard to find." But there are areas where collaboration is helpful, he said, citing the example of modeling, which all solar technologies need in order to explore optics and electronics. "You can plug in whatever band structure you want for whatever elements," he said, "and do the model from first principles. This helps to figure out what's going on and how to design these structures. Every company should benefit from that."

Beyond modeling, Mr. Pinto said, firms could also learn from the investments of the semiconductor industry in good fabs around the country. "That's something we could all stand up and do," he said. "This is a real technology industry, and we should be spending R&D the way a real technology industry does. Applied Materials spends a billion dollars a year in R&D and we're doing a lot in this area. If you look carefully at companies in the United States, and some of them are making quite a bit of money, you'll see that they spend only about 3 percent on R&D. That needs to change."

A last point, he said, was the shared and precompetitive need to develop standards for the PV industry. "This is a role where NIST can play a critical role," he said. "We all need that."

Richard Bendis
Innovation America

Mr. Bendis said he had created a new entity called Innovation America "because I believe in both: innovation and America." It is a public-private partnership that functions as an intermediary between the states, regions, federal agencies, and the investors "who really fuel innovation." The day before the symposium, the group had released a paper called "Creating a National Innovation Framework." Part of its message, he said, was that many developing countries have more integrated science, technology, and innovation plans than the United States, despite its many fundamental achievements over the decades. "I'm hearing that PV originated in the United States, but 20 or 25 years later, we see the PV everywhere but in the United States, and we have the biggest potential market for this technology."

The Innovation America paper, he said, discussed the need to create a long-term, integrated, national innovation strategy. "This does not exist," he said, "because we have federal agencies that operate as silos. They do not work and leverage resources with one another, and we have a crisis in America today." He said that every source of private investment had pulled back. Angel investing declined 26 percent in 2008; early-stage venture capital investing dropped 45 percent since the previous year; and the average VC investment was $8.3 million, far more than the $0.5 to $2 million needed by the average PV start-up.

The SBIR program is one solution, he said—one of the best early-stage investment programs in the world—but Congress will not reauthorize it for longer than four months. "We need to renew that program for six to eight years and it should be one of the cornerstones of early-stage funding in the United States. Our paper says that the United States is eighth in the world in innovation, behind Singapore, South Korea, Iceland, Ireland, Finland, and other countries. Unfortunately, our government's programs are generally geared to big business, while most new jobs are created by companies with less than 10 employees. So if we want to see the next generation of solar, PV and renewable energy leaders emerge here at home, we need a major commitment to the innovation roots of America, which is small business."

DISCUSSION

Congresswoman Giffords asked the panel to ponder how the United States can move its manufacturing forward and encourage industry to step up and invest in facilities at home.

Frank Calzonetti of the University of Toledo commented that solar manufacturing and the solar industry in general would only advance when it had the outspoken support of industry. He recalled trying to get a renewable industry standard through the Ohio state government. "The university spoke out, and R&D experts spoke out, but it was not until industry stepped forward that the legislature really noticed that this is a job-creation activity."

Spreading Interest in Solar

Congresswoman Giffords said that interest in solar was certainly spreading in her Arizona district. "We find that people are curious about solar, but they don't understand how it works—how tax credits work, how long they last. We have a 'Solar 101' course we do in conjunction with the Pima County Library, and the interest is tremendous. We need to get the message out to the consumer in our respective communities."

Marie Mapes of DoE asked for more information about consortia. Could consortia be organized by technology—with the thin-film people having one consortium and the crystalline silicon people having another? "Is there actually anything to do in precompetitive research other than the modeling mentioned by Mark Pinto?"

Mr. Pinto replied that the mechanism of consortia would not be as simple for solar as for the semiconductor business, because the latter business was unified by the same CMOS roadmap. "In solar there isn't the equivalent of CMOS that everybody uses." Certain aspects of manufacturing are very competitive, but consortia can still share work on processes such as modeling, simulation, reliability and characterization. He emphasized the importance of reliability. "No matter what BP's quality is," he said, "the whole industry can suffer if some companies with lower quality put panels in Arizona and they fail on the roof. We need to work together on ways to evaluate panels to ensure that they work for 30 or more years."

Jim Rand of GE Energy commented that the differences between the semiconductor and solar cell industries might make comparisons among consortia difficult.

Collaborating Around the Full Supply Chain

Mr. Pinto expressed his approval of consortia "for a variety of reasons," and said that they could be tailored to address specific problems and opportunities. His company commonly structures collaborations around the full supply chain in order to make sure the investments in technology upstream have a commercial outlet. They often bring in a commercial partner outside the solar energy field. He cited the example of Wal-Mart, which proved to be a valuable partner and allowed Applied Materials to "test a lot of interesting things on a rooftop." He said that "our industry has been through quite an evolution over the years, and the use of this technology is limited only by our creativity." Norway was the first solar market, he said, and it gave birth to a market for DC solar panels for cabins that still thrives today. "In the United States we worked with a consortium to develop solar-powered obstacle beacons and traffic boards. In the space of three years that entire industry went from fossil fuels to solar." Eric Daniels of BP Solar said that his company, too, was a firm believer in the value of consortia.

Roger Little of Spire Corp. said he was happy that the solar market in the United States would grow rapidly as a result of the stimulus bill, investment tax credits, and state initiatives. He expressed concern that the manufacturing capability of the United States would not be able to fill that market. "There's a tremendous shortfall," he said, "and I'm concerned the market will be satisfied by imports. I would like to see more 'Buy American' permeating the stimulus bill and the investment tax credits."

Congresswoman Giffords said that in the Congress's work to help businesses stay competitive, it did not focus entirely on a 'Buy American' approach but also on how trade agreements can be structured so as not to put U.S. firms at a disadvantage. However, she said, the best recipe for increased domestic manufacturing would be increased domestic demand. "If we can get businesses to do the installation and the investment that will spur the ingenuity and small companies." She asked Bill Harris of Arizona for comment.

The Need for Fair Trade Agreements

Bill Harris of Science Foundation Arizona said that "the Buy American thing is something we would probably feel good about, but what the Congresswoman said is right: It's a global market. It's important to encourage the countries that sell things here to have open markets as well. We've heard today that a number of countries do not, for example, allow our cars in, while they sell their cars here. There has to be political give and take, and there also has to be growth in manufacturing here if we're going to be successful."

Doug Payne of SolarTech, a California-based industry consortium, commented on the many kinds of barriers, some of them hidden, faced by the solar industry. He represents over 60 member companies, he said, and his board of directors includes Applied Materials, SunPower, and others. "We're on the roofs, looking at standards and best practices."

Institutional Barriers

He said he would try to tie the downstream issues of execution to manufacturing competitiveness, cycle time, and innovation through three data points:

- For the average residential home, the time installers spend on the roof is three to five days; behind the scenes, manufacturing takes 100 to 120 days. "We have to do better," he said.
- Of those 100 to 120 days, he said, 35 percent are consumed by institutional barriers created by utilities, cities, and other jurisdictions. About 15-20 percent of the profitability is in soft costs, human costs, and hidden costs behind that cost/watt reduction roadmap. "With billions of dollars in stimulus invested in technology innovation and products, we need to know when these things come to market how much in incremental funds to set aside to remove the downstream barriers to adoption—permitting, jurisdictions, codes, standards, financing best practices. These will be a fundamental barrier to the up-front investment that will not translate to the real rooftops and jobs."
- About 90 percent of the commercial solar market uses financing, and one transaction takes up over 200 pages of paper.

Mr. Daniels returned to the discussion of standards and their importance to the industry. "I can buy a home today," he said, "and find a place to plug in my washer, dryer, and refrigerator. I can't plug in my solar array. And there are still questions about the reliability of the electrical circuits" due to inadequate standards. The last thing the industry needs, he said, is failures of circuitry that dampen its reputation and growth.

A participant from the Rochester Institute of Technology said that the shift from semiconductors to photovoltaics had brought a corresponding increase in graduate students wanting to work in photovoltaics. Yet most of the department's graduate students come from overseas, because their studies are subsidized. Many American graduates with B.S. degrees must first pay off student loans before joining the graduate work force. She asked what could be done to increase the numbers of domestic students taking graduate studies in alternative energy.

Dr. Ryan commented that more public policy incentives could be used to encourage people to enter engineering and science, but that "the problem starts in our K-12. It's not cool to be an engineer or scientist. We have to change that perception, and get people in K-12 who can teach science and actually know what engineering is. So it really helps when the universities have outreach into the schools."

"What Kids Care About Is What's Happening to the Planet"

Congresswoman Giffords responded that after Sputnik, more than 50 years ago, the United States committed resources to science and engineering in the face of a specific international challenge. "What kids care about today," she said, "is what's happening to the planet. They care about what we've been doing in renewable energy in general. We think they will respond to this opportunity, to the legislation that's moving forward, and to the little solar institutes that are sprouting up. "

Jim Hurd of the GreenScience Exchange said that his organization was focusing on the use of stimulus funds for research, "but what I haven't heard much about is the innovation and the monetization of innovation, the things we can do that are big home runs in the next two to six years. Everybody seems to avoid this conversation, partly because no one wants to use the term 'valley of death' any more. What about picking some winners?"

Mr. Pinto said that he took a different view. He said that picking winners for small- to medium-scale ideas may have results, but larger projects have to be guided by market pull. "Picking winners like a $500 million loan guarantee I think is crazy," he said. "Big amounts for one device is really hard to understand."

"The U.S. Could Lose a Generation of Innovators"

Mr. Bendis said that in the PV portfolio were gaps in federal funding between the "early side and the late side." "Whether or not the government is picking winners," he said, "it has to be more active at stimulating innovation. This is something that will not be pushed by the states or the venture capitalists. We need to get more innovation into the portfolio so *we* have the opportunity to pick winners." He said that the United States could even lose a generation of innovators "if we don't do something on the edges." He noted that the panelists worked at big businesses now, but these had once been very small, and they had grown through innovation. "They survived because they were the winners. But we're going to lose a lot of high-quality jobs unless we come up with a plan to stimulate this innovation immediately. These innovators will go someplace else where they'll find someone welcoming them with money to commercialize their technologies."

Mr. Pinto said he did not disagree, but he did offer another point of view on VC activity. "Take thin film," he said. "Every VC has a thin-film PV company in their portfolio. We've thrown money at way too many of them. We're probably spending four times as much as we need to so that we'll have companies that work. That's where the gap comes in."

Mr. Bendis agreed that "everybody has to have one of something." He recalled the three new solar research departments at three universities in Arizona. "What would happen if those three got together and developed one world-class solar institute?" he asked. "Why not leverage resources, eliminate the 45 percent of overhead, and get more of the money into the research that can go toward commercialization?"

Mr. Hurd said that as he traveled, he heard many discussions about how people can participate in developing low-carbon fuels and the like. "What I sense is that ultimately the supply decisions in terms of which technology wins will be made by the market. What will help spur demand is to take the smart grid one step further and build around it a relationship with users so they can actually understand how they can participate."

Congresswoman Giffords closed the discussion by thanking the National Academies and the Department of Energy, and offered a "couple of parting words. One is, be bold. Now is not the time to sit back and avoid risks. And the second is, when you talk about working with consumers, we have to make these technologies approachable, easy to understand, and as exciting as they really are. And there's nothing more exciting than seeing your meter go the other way!"

III

PROCEEDINGS

JULY 29, 2009, SYMPOSIUM
STATE AND REGIONAL INNOVATION INITIATIVES—PARTNERING FOR PHOTOVOLTAICS MANUFACTURING IN THE UNITED STATES

Welcome

Charles Wessner
The National Academies

Dr. Wessner welcomed the participants. Introducing the work of the National Academies' Board on Science, Technology, and Economic Policy (STEP), he stated that a key mission of the Board is to better understand the scientific and technological elements affecting the competitiveness of the United States. "One thing we try to work on," he said, "is how to use the great research investment that we make in this country to accelerate innovation and advance competitiveness." STEP attempts to do this by convening workshops of experts, which "to a surprising extent" are reflected in actions taken subsequently by the Executive Branch and by the Congress. "One thing we do to get it right," he said, "is to ask the users of technology what they need, rather than to advise them on what works best."

Another feature of the STEP board's strategy, he said, is to pay attention to what is going on across the country and around the world. This is done, in part, though collaborative symposia with policy makers and business leaders of other countries. He invited participants to take home copies of STEP symposia, including reports on bilateral meetings with Japan, India, and Belgium, and other partners. "There are lessons to be learned from others around the world," he said, "and we make an effort to do so."

Within the United States, he said, there is also much to be learned from best practices in state and regional economic initiatives. Particularly over the past decade, the country has witnessed a surge in state initiatives, some of it quite innovative. Dr. Wessner noted that the federal government and other organizations based in Washington, D.C., are well advised to reach out for this knowledge, because cluster development is by nature a local or regional phenomenon. The federal government can stimulate clusters and local partnerships, he said, but they tend to form around cities and organizations created within the states. "Local leadership in these case is important," he said, "and not something that can be mandated from Washington." In the field of photovoltaic manufacturing, significant synergies have formed between state and federal government initiatives, including programs in Arizona, Ohio, and Colorado discussed below.

A KEY CHALLENGE: TO BRING EXISTING TECHNOLOGIES INTO THE MARKETPLACE

The key challenge, he said, is to bring existing technologies into the marketplace. What are the best ways to accelerate the innovation and to actually deploy it? One way, he said, is through partnerships among government, industry, and academia. Under the leadership of Gordon Moore, co-founder of Intel, STEP had developed a ten-volume set of reports that examine different types of partnerships for commercializing technology. The general conclusion of these reports, said Dr. Wessner, is that partnerships are extremely effective when properly structured and effectively led. These partnerships include innovation award programs, state and regional consortia, science and technology parks and clusters, and—the topic of the current symposium—government-industry-academia partnerships.[1]

As an example, he cited the experience of the semiconductor partnership known as SEMATECH that was initiated jointly by the U.S. government and the semiconductor industry in the 1980s. Without this initiative, he said, and other steps proposed by the already-existing Semiconductor Research Corporation, the United States "might well not have the semiconductor industry that we have today."

A key question for all technology-based economic initiatives, he said, is how to keep an industry in the United States once it is established. "In the case of photovoltaic manufacturing," he said, "how do we capture the benefits of the federal stimulus measures and our rising R&D budgets?" One answer, he suggested, is to use both new and existing innovation partnerships to attract and support U.S.-based firms. He said that the symposium was designed to examine programs already in place, identify additional opportunities where investments can be useful, and explore the prospects for cooperative R&D. Additional themes central to the discussion, he noted, were the importance of developing technical standards to underpin the new industry and the use of industry roadmaps, such as those which have been central to the strategy of SEMATECH.

[1] National Research Council, *Government-Industry Partnerships for the Development of New Technologies: Summary Report*, Charles W. Wessner, ed., Washington, D.C.: The National Academies Press, 2003.

Introduction

Clark McFadden
Dewey & LeBoeuf LLP

On behalf of the STEP Committee on Best Practice in State & Regional Innovation Initiatives and its chair, Prof. Mary Good, Clark McFadden introduced the symposium as one in a series to address the theme of creating and sustaining clusters of technology development and manufacturing. Such clusters, he said, had proven to be successful at generating jobs, economic growth, and productivity, and were an important objective of state, regional, and national innovation programs.

He recalled that the National Academy of Engineering had recently characterized more economical solar energy production as one of its "grand challenges" for the nation.[2] At the center of this challenge was photovoltaic technologies, or PV, the use of solar cells to convert solar energy directly into electricity. Various strategies had been tried in various countries to advance the photovoltaic technologies industry, he said, including financial engineering, project loan guarantees, subsidies, and trade-in tariffs. The symposium had been organized to focus on an additional strategy, government-industry-academia partnerships for PV manufacturing. Such partnerships, suggested Mr. McFadden, would permit a new level of "technology engineering" that would help structure, facilitate, and leverage the multiple abilities and perspectives needed to increase efficiency and reduce costs.

Successful technology partnering has many elements, he said, including the sharing of experience and information, the joint assumption of risk, and ultimately successful insertion into commercial markets. Such partnerships, he said, were likely to increase the industry's ability to assess technology obstacles, gaps,

[2] National Academy of Engineering, *Grand Challenges for Engineering*, Washington, D.C.: The National Academies Press, 2008.

and opportunities, perhaps through the use of roadmaps and agreement on technical standards. Partnerships would also provide the ability to support research more effectively through the provision of financial support, technical guidance, and performance evaluation. They could also support research directly through partners in government agencies and laboratories, universities, nonprofits, and industry.

Finally, he said, the use of partnerships could broaden the ability to transfer technology to the stage of commercialization, which is "critical to any manufacturing effort and has always characterized the most successful technology partnering ventures." One way to promote this is to provide demonstration facilities or foundries that can validate improvements in manufacturing materials, equipment, and processes. "All of these dimensions can contribute to successful technology partnering," he said, "and all are relevant to our agenda today."

He noted that the men and women attending the symposium represented many constituencies that have a significant stake in PV manufacturing:

- Many of the senior leadership of the Department of Energy, who were part of "a national mission to promote PV energy."
- Congressional members and staff, who were crafting legislation designed to advance the nation's global standing in PV manufacturing.
- Leaders of the PV industry, including both device manufacturers and suppliers of equipment and materials.
- Representatives of other collaborative ventures in technology development and manufacturing, notably the semiconductor industry.
- Representatives of state and regional governments, who were eager to attract and promote clusters of technology development and manufacturing in PV.

Mr. McFadden closed by noting that the Senate report for the 2010 appropriations act had urged the DoE to use input from this and related National Academies symposia in establishing PV manufacturing initiatives.

Opening Remarks

Senator Mark Udall (D-Colorado)

Senator Udall, who described himself as a long-time proponent of the expanded use of photovoltaic technologies, began by observing that his family used a 3.5-kilowatt PV system to generate electricity for their house in Boulder, Colorado, and that collectively such systems "can make a difference" in meeting the nation's energy demands. He said that a major part of his responsibility in the Congress this year would be to move a comprehensive energy package to the President's desk. "We are in the 21st century," he said, "and we need a 21st-century energy policy." He noted that the nation would have to accelerate its transition away from a fossil-fuel based economy, and would have to move quickly and with some focus. "There is no silver bullet for doing this. Maybe silver buckshot—with a lot of ways we can hit the target. In many parts of the country," he said, "solar is going to play a key role."

He listed some advantages of more widespread use of solar technologies, including the potential for new economic opportunities and improved national security. For the economy, he said, solar energy would be able to create "millions" of new jobs and provide a key pillar of the economy for the 21st century. Solar energy would spur innovation, he said, and create "a pathway whereby we're producing clean energy in our country."

He emphasized that despite the apparent advantages of solar energy, persistent hard work and effective communication are required to convince people of the advantages of PV. Senator Udall noted that in his home state of Colorado, he and other supporters of PV had struggled for years to pass a renewable energy standard (RES), but succeeded only after years of debate over both substance and language.[3] When he was first elected to the state legislature in 1997, he said, each legislator could introduce only five bills per term. He introduced a measure for consumer disclosure on energy use, a net metering bill, and an RES bill. When he first tried to gain approval for his RES bill from the 11-member committee, he won only two votes, in face of strong opposition from utility and fossil fuel companies.

A RENEWABLE ENERGY STANDARD FOR COLORADO

Senator Udall tried several more times, but the bill always fell short. In 2004, however, he and a Republican colleague framed the measure as a ballot initiative rather than a legislative bill, and traveled the state making the case for renewable energy. Their measure became the first voter-approved RES. It proposed the modest goal of producing 10 percent of the state's electricity from renewable sources by the year 2015, including a 4 percent portion for solar energy. The state reached that target in just a few years. The legislature then reconsidered its position and passed a bill calling for a 20 percent standard by 2020. Since the RES was passed, he said, the Colorado Solar Energy Industries Association had identified at least 1,500 new jobs created in solar energy industries.

Senator Udall conceded that this success had come in just one state and only after years of hard work. However, he had now transferred his effort to Washington, where he had been leading the fight for an RES bill in both the House and Senate. "I don't think the RES we'll pass initially will be as strong as I'd like," he said, "but it will be a big step. And I think the states will buy the idea of setting that kind of goal, which Americans are good at doing when we focus."

PV AS A NATIONAL SECURITY ISSUE

Senator Udall said that a second reason to pass clean energy legislation was the benefit of renewable energy for national security. From his perspective as a member of the Senate Armed Services Committee, he said, he saw the advantage of reducing the country's dependence on foreign oil. "We have to keep reminding ourselves," he said, "that this is a critical step." He emphasized American petroleum dependence on Russia, Venezuela, Saudi Arabia, Kazakhstan, and other countries. He also noted the "huge amount of resources" in time, energy, and opportunity costs that the country spends in defending its petroleum supply lines worldwide. He also described "a more direct tie to our national security" in the form of the daily stresses faced by the troops themselves in procuring and transporting the fuel and water they need daily. He said that attacks on American

[3] A renewable energy standard is a regulation that requires the increased production of energy from renewable energy sources, such as wind, solar, biomass, and geothermal sources. About half the states have implemented an RES, as have Britain, Italy, and Belgium.

troops in Iraq and Afghanistan often occur in convoy settings when the military is moving fuel supplies and other resources to the troops. The military itself is working hard on PV research, already issuing small solar panels, because they represent a distributed form of energy and hence do not have the same protection challenges in the battlefield. "The military knows better than any institution the need for clean energy supplies," he said.

Despite the advantages of renewable energy, he said, sustained local, state, and federal efforts are required to transform the nation's energy industry. He offered a quote from Ernest Moniz, professor of physics at the Massachusetts Institute of Technology and former Under Secretary of Energy: "The energy industry is a multitrillion-dollar-per-year, highly capitalized commodity business—with exquisite supply chains, providing essential services at all levels of society. This leads to a system with considerable inertia, aversion to risk, extensive regulation, and complex politics." To change this system, said Senator Udall, would require innovative structures, such as partnerships that were designed to perform research more efficiently, lower manufacturing costs, and help solar companies across the financial "valley of death" between the laboratory and the marketplace. Other industries had done this, he said, and provided models and analogs that could now be useful for the PV industry. One kind of model is SEMATECH, he said, which supports the semiconductor industry. Another is the Colorado Renewable Energy Collaboratory, a research consortium of universities (the Colorado School of Mines, Colorado State University, and the University of Colorado at Boulder) and government (the National Renewable Energy Laboratory [NREL]). The new collaboratory, created by the state legislature, works with private sector groups and draws on other universities and community colleges. "Anything goes," he said, "as long as it is improving energy efficiency."

He closed with the admonition that many other nations are working as hard as they can to gain an economic and technical edge in renewable energy. As an example, he cited the French minister of sustainable development's recent comment that a new French solar manufacturing project would act as a magnet to attract further solar investments and green jobs to France.

"I know we can compete," he concluded, "and we want the clean energy manufacturing base to be here in the United States. We want to sell the technology to other countries, not vice versa. We can't do anything more patriotic than driving the manufacturing, the products, and the leadership role of this new clean energy space."

Panel I

Partnering for Photovoltaic Technologies

Moderator:
Congresswoman Gabrielle Giffords (D-Arizona)

Congresswoman Giffords said that many people assumed that her strong support for photovoltaic technologies was a reflection of representing the 8th Congressional District, in the southeast corner of Arizona. While it is true that her district receives more sun than most, she said, the entire country has abundant solar energy. Yet the country leading the world in deployment of PV, she said, was Germany, "which gets about as much sun as Anchorage, Alaska. So the United States has a natural advantage when it comes to solar."

She said that she thinks about three "serious global challenges" every day on the way to work: (1) Foreign energy dependence: How have we reached this condition, and what resources do we need to break this dependence and ensure our energy supply in the future? (2) Climate change: How fast is the globe warming, and how might climate instability lead to real problems for the United States and the world? (3) How can the decline of the U.S. economy best be reversed so as to ensure our economic competitiveness?

"The great power of solar energy," she said, "is that it provides elegant solutions to each of these three critical problems." It addresses energy independence, she said, by reducing the nation's use of foreign energy; it helps stabilize the climate by producing power without increasing carbon dioxide in the atmosphere; and it promises to contribute to economic competitiveness by creating new jobs in solar-related industries.

She, like Senator Udall, emphasized that the United States was not alone in recognizing the economic potential of solar energy. The country has historically been a leader in solar technology, she said, but it is not a leader in PV manufacturing. She said that she hoped the symposium would provide guidance on how to create that leadership.

OVERCOMING POLITICAL RESISTANCE

One of the most daunting barriers, Congresswoman Giffords said, is political resistance. "The lobbyists for renewable energy are far outnumbered," she said. A survey by the Center for Public Integrity of self-identified lobbyists working on climate questions reported that only 1 out of 10 lobbyists actually identified themselves as interested in renewable energy. She summarized the amounts spent by various energy lobbies during the first quarter of 2009, as follows: American Petroleum Institute, $1.9 million; British Petroleum, $3.6 million; Marathon Oil, $3.4 million; Conoco Phillips, $5.9 million; Chevron, $7 million; Exxon Mobil, $9.6 million. The American Coalition for Clean Coal Energy has an annual budget of $45 million. For renewable sources of energy, the wind power lobby spent some $1.6 million in the first quarter, and SEIA, the solar energy lobbying effort, spent $410,000.

"This is what we're up against," she said. "I'm not putting this up so we can get discouraged, because obviously with few resources, the solar industry has made tremendous strides. But now we have to figure out how to get this technology out there and installed and making a difference for our country and our world." To do this, she suggested that supporters should "organize, advertise, and educate."

"I know that the solar resource in the United States is greater than the fossil resource," she said. "And I know that it's ecologically and economically feasible for solar to be a major power generator. But many of my colleagues don't know this—primarily because they just don't have the information." She urged her audience to communicate more directly and aggressively with Congress and others in positions of influence.

She closed by observing that much of the effort currently expended by solar companies is directed at demonstrating the strength of their own particular technologies. While this is essential, she said, the PV industry is unlikely to achieve its potential without more collaboration between all solar companies to educate the public about the solar opportunity. She said that in Arizona, her office makes education a key part of its solar strategy. They offer "Solar 101" classes to the public at schools, libraries, and other locations to explain how the average consumer can benefit from solar installations at their home or business. She has created a "Solar Hot Team," consisting of solar leaders from across Arizona that engages in weekly check-ins to share information and insights on recent developments.

"The bottom line," she said, "is that we have a lot to do. Some of my frustration with the technology folks getting into clean energy is that they have not fully appreciated how energy is different from Silicon Valley and the computing industry. Many of them have not understood the challenges of going into these very traditional energy markets, where they have to deal with regulations at the federal, state, and local levels. Add to that the fact that the lobbying power of traditional energy industries is enormous. Ensuring adoption of solar power is not just about price or level of technology; it's also about culture, politics, and figuring out ways to get into the system. People must understand all of these issues before we can make the really necessary changes."

U.S. PHOTOVOLTAIC ROADMAP: PERSPECTIVE OF THE MANUFACTURING INDUSTRY (1)

Subhendu Guha
United Solar Ovonic (Uni-Solar)

Dr. Guha's company, Uni-Solar produces flexible thin-film panels of amorphous silicon. These light-weight products, he pointed out, are well suited to large-area installations such as rooftops. He put on view a photograph of world's largest rooftop system, a 12 MW Uni-Solar installation in Zaragoza, Spain. Further illustrating the potential of thin-film panels, he also displayed a photo of the "Zephyr airship," which had set a record for the longest flight in the stratosphere powered by solar energy.

Uni-Solar, he said, wholly owned by Energy Conversion Devices, is the world's largest manufacturer of flexible solar cells. It makes its solar cells by a roll-to-roll manufacturing process based on thin-film silicon multijunction technology. The company is relatively small, with manufacturing plants in Michigan that employ about 1,000 people, but it has been growing rapidly. In 2003, it shipped less than 5 MW of product; in 2008, it shipped more than 100 MW of product.

Flexible Rooftop Products

Its flexible rooftop products are made as 18-foot-long laminate with a paper-lined adhesive on one side. When the rolls arrive at an installation site, the paper is removed and the material is attached directly to the roof or other surface, greatly reducing installation cost.

Dr. Guha reviewed some key events of the company's history and early commercialization. From the beginning, the technological concept was to pass a roll of stainless steel through machines where successive layers of the solar cell are deposited. The first prototypes were built in 1981. In 1986 came the first prototype plant, producing 500 kW of capacity a year, and in 1991 came a plant with 2 MW of capacity.

"In those days," he said, "amorphous silicon was an unknown entity, and no one knew how well the products would work." They sent samples to NREL, and found that it performed as projected. NREL continues to evaluate Uni-Solar products, which "has given us and our customers a lot of confidence that you can have product that is going to last 20 to 25 years."

At around the same time, the company started developing new triple junction solar technology to achieve higher efficiency. It built its first 5 MW production machine in 1996 using a triple junction processor, and began to see that these flexible products could be applied to rooftops. In 1997, Uni-Solar made its first building-integrated PV (BIPV) demonstration and continued to grow. In 2003, they built their first 30 MW production line, in Auburn Hills, using six rolls of stainless steel, each 1.5 miles long. In 60 hours, he said, the plant can make nine miles of solar cell. Today the company has expanded to about 180 MW of capacity, including a production line opened in Greenville, Michigan, in 2007.

During this time, the world market has grown steadily from about 1,000 MW in 2004 to more than 5,000 MW in 2008. The remarkable growth in the last three years, he said, was the product of feed-in tariffs and other incentives offered outside the United States. Of the 5,000 MW worldwide solar market in 2008, he said, just over 300 MW was sold in the United States; Germany, helped by the feed-in tariffs, sold six times that amount.

Incentives Offered by Other Countries

One reason incentives are offered by some countries, Dr. Guha said, is that solar power is not yet competitive with the large power stations producing electricity from conventional fuels. Germany offers incentives ranging from 41 cents per kilowatt-hour to 51 cents/kWh. France offers about 40 cents/kWh; for BIPV they give about 70 cents/kWh. Many of the incentives have a downward scale, dropping every year. The incentives work because they allow construction of large manufacturing plants. As these plants bring economies of scale, their costs come down. The incentive for rooftop solar systems is higher because in many urban areas there is insufficient vacant space for crystalline silicon PV installations, so this kind of incentive is meant to hasten the use of otherwise unused roof area. It also avoids transmission losses, with electricity generated at the point of consumption.

Dr. Guha made a strong economic case for PV usage. He said that deployment of 100 MW of PV to electrify 200 commercial buildings or schools could create some 2,400 green jobs. He said that Germany, which has traditionally been the auto capital of Europe, today employs fewer people in the auto industry than in the PV industry, which has created 180,000 new jobs. “And Germany has no more sunlight than my state of Michigan,” he added. “If it can be done in Germany, I’m sure it can be done in every state in the United States.”

Costs Are Coming Down

Dr. Guha repeated that the industry was not yet cost-competitive, but said that the price was coming down. In 1990, the cost of solar power ranged from 40 to 80 cents/kWh. Today, he said, costs are much lower, in some places cost-competitive with conventional electricity at peak usage times. According to the DoE, he said,

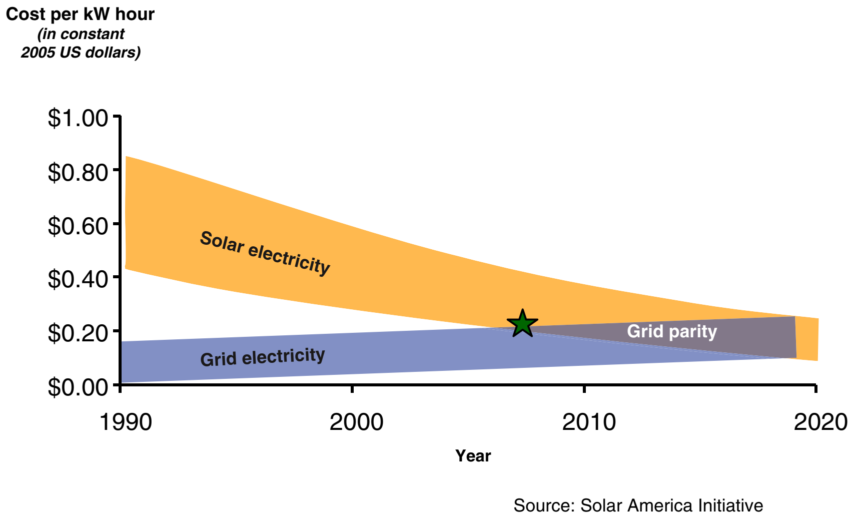

FIGURE 1 Challenge for PV: How to reach grid parity.
SOURCE: Subhendu Guha, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

PV can generate electricity in California for 20 cents/kWh, which is on a par with peak-time prices. "We are just there," he said. "For many residential users, they have time-of-day pricing that is more than 20 cents." He noted that pricing is subject to wide disparities, depending on the amount of sunshine and other factors. "But we still have to come down farther," he emphasized. "The PV manufacturers do not want to depend on subsidies. We want to stand on our own feet. We want to reach grid parity, and we have shown that we can make progress toward that goal."

The way to reduce the cost of PV, he said, is to work with the entire PV value chain. "You make the solar cell, then you make the module, which is interconnected solar cells; then the PV array, for which you need inverters and other components to convert the DC solar electricity to AC current. Finally, you sell it to the customer. Through it all, you have to hear the voice of the customer. You cannot just work on materials, or solar cells. You need the big picture. What does the customer want? Most of them want to know how much money they are going to spend to put the PV on the roof, and how much electricity are they going to get over the next 20 years. In any innovation we do, we must focus on that: how to reduce the cents per kilowatt-hour."

Crucial Role for Government

In addition, Dr. Guha said, the government has a crucial role in bringing the industry to grid parity. That role is to help create a sufficient demand base through incentives and grants. The United States can have the best technology in the world, he said, but if it does not have a demand base, it will not create manufacturing jobs. At present, U.S. companies are building plants in Europe—because the demand is there. He also stressed the need to remove barriers, develop uniform codes, and improve net metering.

He argued that industry has done its part in moving PV toward maturity. "When you talk about needing new R&D to reach grid parity," he said, "I have a bone to pick. We talk about new, disruptive technologies, about how we have to think out of the box. We have been thinking out of the box and developing disruptive technology for decades. Now is the time to build on the foundation we have established. I am not opposed to doing something new, because there is no single choice; there will be many choices. But what industry has already done to reduce costs is phenomenal. And they will continue to do that. There will be both challenges for the established technologies, and challenges for the new technologies."

To extend his discussion of building on what exists, he emphasized the system as a whole. He recalled the late 1990s and early 2000s when government focused its funding on components. Around 2005, however, the emphasis shifted to a more integrated, program-oriented approach that brought industries, universities, and national labs into collaboration. "Trust me," he said, "this was not easy. Academia does not want to be told by industry what to work on. But slowly we accepted each other, and it was a wonderful experience to see a bunch of people with diverse backgrounds working together toward common ground." Slowly what was understood, he said, was that a focus on components was not sufficient. A systems approach was needed to reduce the cost. "For the first time, the main topic was not how do you increase the efficiency of a solar cell, or an inverter. It was how do you reduce the cost of electricity, which is well underway."

He concluded by noting that "clean electricity is not a choice—it is a necessity. We cannot afford to pollute the world with greenhouse gases." He quoted the words of the historian Edith Hamilton, who wrote about Athens, " 'In the end, more than they wanted freedom, they wanted a comfortable life, and they lost both comfort and freedom.' When the Athenians wanted not to give to society," he said, "but for society to give to them, when the freedom they wished for most was freedom from responsibility, then Athens ceased to be free. We cannot afford that."

PERSPECTIVE OF THE MANUFACTURING INDUSTRY (2)

David Eaglesham
First Solar

Dr. Eaglesham said he would give the industry's perspective on both current and anticipated future conditions for photovoltaic technologies. He showed an opening photo of a 10 MW First Solar installation in Boulder, Nevada, that feeds the Southern California Edison grid. "This is an example of a type of installation

FIGURE 2 PV industry has grown to GW scale and <$1.00/W.
SOURCE: David Eaglesham, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

that's becoming possible," he said. "We can do multiple installations of this size. This is a fairly significant contribution even at today's scale."

He began with a skeptical assessment of various goals that had been suggested for solar and other renewable sources of electricity, such as a global capacity of 5 terawatts for renewable sources by 2020, projected by the International Panel on Climate Change. "Think about the growth rate you would need to get even close to that goal. If you want PV to be even a small component, it would have to grow at an astonishing rate of about 70 percent annually. I do not believe that any industry has grown at a sustained growth rate of 70 percent compounded annually. The real question is how big a piece should solar be of the U.S. energy mix, and what can we do to make PV play the biggest possible role."

The PV industry has just recently reached gigawatt size, he said. "It is still juvenile, at a technically early stage," he said, "but it has become a real industry." He said that First Solar itself is now producing a gigawatt a year of manufacturing capacity, with a fully operational 800 MW factory in Malaysia, and had surpassed

$1 billion in sales in the previous year. The company had also lowered manufacturing costs to 93 cents a watt in the previous quarter's actual results.

A Plea for Incrementalism

Dr. Eaglesham said he wanted to emphasize several messages. The most important, he said, was a "plea for incrementalism." If you hit "reset" and start the industry again from scratch, he said, then even a 70 percent compound annual growth rate would not achieve 2020 goals. It was necessary to move ahead from the current industry baseline to reach such a goal, rather than expecting some "disruptive" technology to set the industry on a new course.

"We have a technology that's in hand," he said. "I'm citing First Solar data because I'm from First Solar, but there are other companies with comparable costs, improvement targets, and expansion targets. It is my expectation that multiple companies will be able to achieve this kind of cost and scale in a short time. We have a technical solution in hand, and a cost point that gets us to where we need to be to drive toward the 2020 goal. Let's keep pushing forward in that direction."

The primary reason why First Solar is able to contain its costs, he said, is that "it doesn't change technology every couple of years." Manufacturing learning, he said, drives continuous improvement. "This is boring for academics," he said, "but critical for an industry—just regular old learning, cranking the handle, grinding on continuous improvements. It's a key piece of why you want to stick with things that leverage existing production platforms." He illustrated the company's increasing module conversion efficiencies with a graph showing a rapid rise in efficiency from 7 percent in 2002 to about 11 percent at present. (See Figure 3 on Increasing Module Conversion Efficiencies.)

Costs Have Been Dropping Steadily

At the same time, costs has been dropping steadily, with the module cost per watt lower by 43 percent from FY2005 through the first quarters of FY2009, or an average decrease of 15 percent per year. "Again," Dr. Eaglesham said," First Solar happens to be first out of the gate, but my expectation is that multiple companies in this room are going to have a downward cost curve like this, if a little behind. I think there's a clear message that you don't have to radically reinvent the technology."

He paused to clarify his message about R&D. "Long-term R&D is needed to bring the new technology for manufacturing in the year 2020, so we need to do that as well. But it's important to continue the investment in these more incremental stages."

Dr. Eaglesham turned to the company's future cost reduction roadmap, which projects the cost per watt at the module level as falling from 93 cents at present

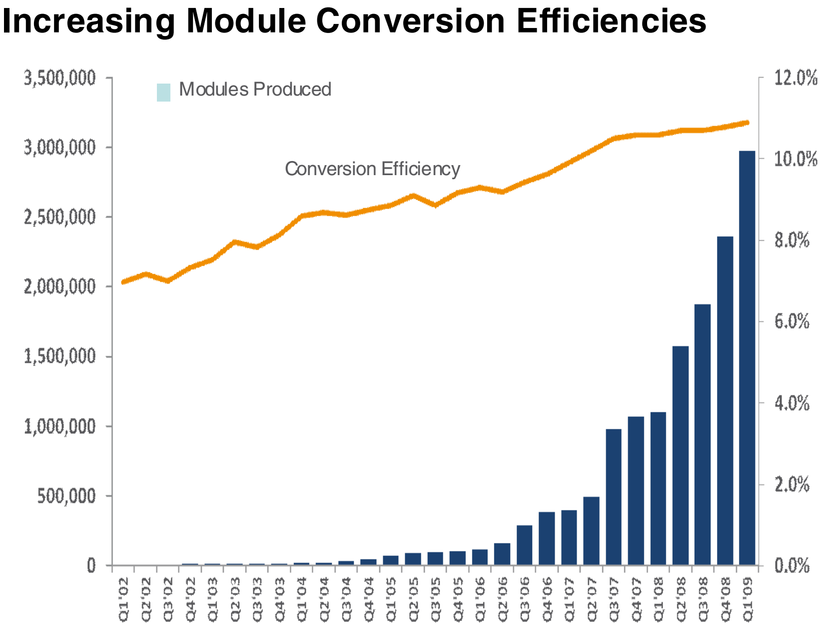

FIGURE 3 Manufacturing learning drives continuous improvement.
SOURCE: David Eaglesham, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

to about 52 cents in 2014. There is also a comparable roadmap for the balance of system components, he said. "When you add those two things, you have a business plan that gets you to where you need to be in terms of grid parity."

Toward a Sustainable Market

Dr. Eaglesham then discussed the point at which the rising global PV demand line crosses the falling PV cost line to enable sustainable markets. The lines had already crossed for natural gas peaking prices, he said. For other sources of energy, including coal, gas combined, and nuclear, the crossing point might be around 15 cents/kWh, depending on the number of sunny days per year, a price placed on carbon emissions, the cost of capital, and other factors. A critical variable, he said, stems from the value proposition inherent in all forms of renewable energy: that the consumer must pay up front for the entire system—in return for free energy for the lifetime of the system. Therefore, both interest rates and availability of financing are key determinants of the crossing point to grid parity and the rate of end-user adoption.

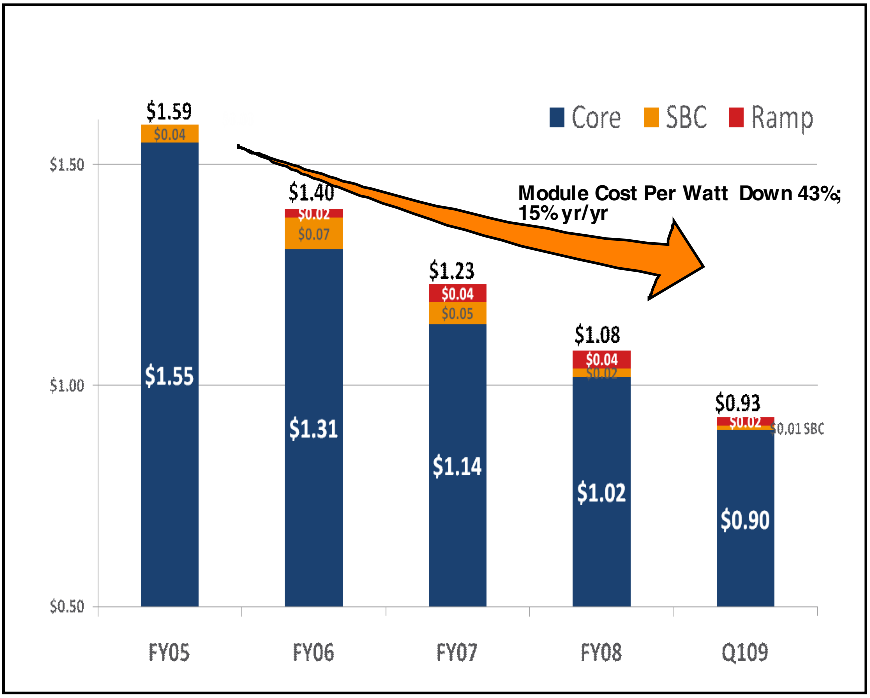

FIGURE 4 Improvements are delivering cost reductions.
SOURCE: David Eaglesham, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

He said that First Solar had already projected substantial growth in its planned or contemplated gigawatts of PV in the U.S., rising from about 50 GW in 2009 to 760 GW in 2013. "We are projecting big markets," he said. "We have a pipeline of projects already under discussion with utilities."

Another significant feature of PV development, he said, is the development timeline. This line is now quite long, primarily because of the permitting cycle, which is now about two years. He made a strong plea for government policy makers to work toward reducing this cycle so that PV can be more responsive to market demand. The government can also take other steps in setting policy, he said, including simplifying rules and regulations and creating a national renewable electricity standard (RES). Dr. Eaglesham noted that other governments, notably the European Union, China, India, and Australia, have all taken significant steps to encourage PV and other renewable energy development.

"It is already clear that the market will follow the manufacturing," he said, "and the technology is going to follow the market." Market location, in turn, is driven by the decisions of regulatory agencies in each country. It is also driven by the cost of freight, since glass products are heavy and expensive to ship. "For this reason," he said, "glass manufacturing is almost invariably done where it is going to be installed. I already have a barrier in importing product into Europe from Malaysia."

According to Dr. Eaglesham, U.S. energy policy should address the needs of three distinct phases of PV development. The first is R&D. The goal of a commercially viable technology should be supported by fundamental R&D, applied R&D, concept/pilot lines, and alpha products.

The second phase, commercialization, must support technologies of proven value. "We have to be careful here to simulate development without picking the winning technologies. This must be driven by the marketplace."

Finally, the stage of scale-up should focus on commercially proven technology. "The critical piece is to develop the programs that will pull from the market. We need markets to enable efficient scale up, execution capability, and growth capital. The federal role is to provide transparent and attractive market opportunities that do not favor selected technologies. They must also provide market longevity and volume, market price and program guidance, and incentives for project finance."

Beginning Technology Development with Market Pull

Usually, Dr. Eaglesham said, technology development is regarded sequentially; the process starts with R&D and works its way "forward" toward the market. "But for PV," he said, "if you think about how you're going to structure incentives, you want to work the whole thing backward. If you start with R&D and get to the end to find there is no market, all you have is a train wreck. So you begin with market creation so that the market pulls the technology from that side. A large, well-structured solar market drives investment and innovation."

Dr. Eaglesham offered a summary of main points:

- Current PV technologies are close to grid parity in locations of high and medium irradiance. "Our expectation is that we can drive the existing technology base to a place where it can be successful, so we want to invest in continuous-improvement pathways."
- The DoE can help relieve major challenges, such as slow and nonuniform permitting requirements, lack of grid-connection technology, and the need for federal renewable electricity standards. Other needs include incentives and loan guarantees at the utility level; demonstration-scale electricity storage programs; and nonblocking intellectual property provisions for basic research.
- DoE's support for PV should be sustained from a technologically agnostic stance, implementing programs without picking winners.
- Although the PV companies are not ready to set technology-level

standards, they can benefit by collaborating on such tasks as permitting reform and system-level development.

He closed by urging universities and national labs that would like to partner with industry to be more sensitive to the question of intellectual property. "I would urge people to think about programs where industry comes to table and directs the research toward industry problems while protecting the IP," he said. "This is a difficult conversation to have with most academic institutions right now. I only work with the ones that are prepared to work with that kind of framework."

DISCUSSION

Professor Zweibel continued the discussion of incrementalism, noting a substantial gap between developmental research to improve today's technologies and reaching for "blue-sky" findings whose payoff might be 20 or 30 years away. "What we've heard in the presentations is that there's a lot of momentum for very low-cost goals." He asked whether the panelists had experienced that disconnect in terms of how R&D is done or funded.

Building on Existing Architectures

Dr. Eaglesham agreed that disruptive device architectures will be needed in the future. "But I think there's enormous opportunity for research in materials physics and the device physics of existing architectures. In the same way, the semiconductor industry did a lot of great basic research to understand its basic materials phenomena. I would just make sure that second piece doesn't get left out."

Dr. Guha recalled that in 1875 the U.S. patent commissioner recommended the abolition of the patent office because "all the inventions had already been made. We don't want to take that path. But I also don't want to take the path that whatever has been done cannot lead us to the goal. There has to be basic research, there has to be focused research, and I think some of the programs of DoE show that academia and industries can work together toward a common goal."

Dr. Eaglesham said that the "goal" for him would be to maximize the share of PV in the mix of renewable energy forms by 2020 or 2030. "If that goal was set for 2080," he said, "it might make sense to have a larger portion of investment in finding blue-sky or radical device innovations. What makes this different for me is that we have a pressing, pragmatic near-term goal towards which we are collectively driving. I would urge people to think about how short a time that is. There is enormous value in exploring, say, the long-term nanotechnology aspects of these things, which we need, but as a country we would be making a big mistake if all we see out there is these radical third-generation things."

Congresswoman Giffords reiterated her concern that the solar industry was neglecting opportunities to communicate its message to members of Congress and other policy makers. She recalled the recent debates on the cap-and-trade bill, when the hallways outside committee hearing rooms were packed with lobbyists from traditional energy companies. "Where was the solar industry?" she asked. "All of us in this room have the ability to come down and advocate for this technology, but we were not there. We have a good goal, but we are up against some pretty powerful forces."

The Issue of Standards

Obang Yew of NIST raised the issue of setting standards for the PV industry, noting the success of SEMATECH in doing so. If the goal of industry is 70 percent annual growth," he asked, "how do you get there without standards?"

Dr. Eaglesham agreed that some standards do exist and that they are critical. "The PV industry is simply not mature enough to set some of them right now." He said that the semiconductor industry had a natural collection of standards that began with wafer size and wafer-handling equipment, "and spread out from there. The standards bodies have played a huge role in helping that industry be successful. With solar, there is no standard interface for putting a steel roll into my glass-handling equipment. It's purely a practical issue." He added that for the same reason, there were few opportunities to work together on precommercial R&D.

Marie Mapes of the DoE followed up on Dr. Eaglesham's mention of collaboration among various parts of the industry, asking him to elaborate. He said that some research on basic device models is common to different firms, such as optical modeling, as are areas of total cost of ownership analysis. But it is still difficult to find common themes in precommercial research, he said, "because this industry is still burgeoning many directions, which is a strength as well as a weakness." Dr. Guha added that the industry—especially the silicon area—could take pride in the fact that partnerships among industry, academia, and national labs had been successful. "We have learned to understand each other's language, to understand that academia can do exciting work—even though it is focused work—and that academia can help us. The main issue is respect for each other, and once you develop respect you can achieve many things."

Panel II

Advancing Solar Technologies: The Department of Energy

Moderator:
Alicia Jackson
U.S. Senate Committee on Energy & Natural Resources

Dr. Jackson emphasized the importance and the unique opportunity of bringing such a diverse group together. "There is a real sense of urgency in the Congress," she said, adding that it is important that "we don't let this opportunity pass us by—to lead not only in research and development, but also manufacturing." She noted especially the interest of Senator Jeff Bingaman of the Committee on Energy and Natural Resources. Part of his urgency, she said, was driven by rapid developments in other countries, and the desire for the United States to take a leadership role in new clean technologies.

THE U.S. DEPARTMENT OF ENERGY'S PERSPECTIVE

Kristina Johnson
Under Secretary
U.S. Department of Energy

Dr. Johnson began by stating the President's current goals for energy:

- Reducing U.S. greenhouse gas emissions by 83 percent of 2005 levels by 2050.
- Conserving 3.6 million barrels of oil within 10 years.
- Building a world-class workforce for a sustainable green economy.

She noted that her own particular passion, derived from her background in academia, was to educate the workforce, and emphasized the potential for renewable technologies to create new jobs and an educated workforce. Among the many predictions for job creation, she cited one from the Gigaton Throwdown, which projected that the global PV industry could create 1.5 million jobs by 2020,[4] or approximately three to 10 jobs per megawatt of electricity.

Toward a Roadmap for PV

Dr. Johnson said that her office was now focused on how the United States could meet its energy goals. A guiding premise, she said, was that science and engineering informs policy, and policy will promote change and technology adoption. She said her office was trying to create a framework that can integrate energy policy, science, and technology goals in an energy technology roadmap. This roadmap will have quantitative goals, on-ramps, and off-ramps "as we find technologies that can get us to the President's objectives." She said that one feature of this work is to assemble the interesting roadmaps that already existed and "put them all into the same units. This will allow us to do a meta-analysis of the roadmaps."

A second feature of this complex challenge is that "many of the roadmaps are not integrated." Therefore, her office is trying to bring a systems perspective to the collection of energy roadmaps and to break down the silos in which they were created. "By 'turning off' all other sources of energy," she said, "we can get to an estimate of where solar will be."

It can also bring some new questions about quantifying energy efficiency. For example, she said, for an estimate of how much energy can be saved in buildings through efficiency measures, there may be overlap in the way that efficiency is calculated. "For example, if we bring in heat pump systems, do we call that an efficiency as well as geothermal energy source and add them together, or would that be double counting?" She said that her goal is to put all the roadmaps together on one map, have the assumptions peer reviewed, and use the results to help guide investments in R&D. "This is one of my very first initiatives as Under Secretary," she said. A second priority is to coordinate R&D across the basic sciences and energy areas, and a third one is to organize initiatives that cut across the department and agency boundaries. "There is a big push in this administration to work across agencies," she said.

New Funding for Renewable Energy

The American Reinvestment and Recovery Act has brought about $26 billion to the DoE, which is challenged to spend those funds both quickly and well. Much of the spending is being organized under four new headings:

[4] Chad Augustine et al, *Redefining What's Possible for Clean Energy by 2020,* Full Report, Gigaton Throwdown, June 2009.

- Energy Frontier Research Centers (EFRCs)
- ARPA-e (Advanced Research Projects Agency for Energy)
- Energy hubs
- RE-Energyse

"What we're trying to do," Dr. Johnson said, "is to make sure that we have the workforce to do what we want to do. We want to invest in the kinds of technologies that will be required to meet the administration's goals and create a green economy. The Center for Energy Workforce Development has said that 60 percent of the science and engineering workforce will retire in the next five years, and these are great-paying jobs. So this is a real national crisis."

This challenge, she said, would be the focus of the RE-Energyse program. Run jointly with the National Science Foundation, it will invest $1.7 billion over 10 years to support science education from K-12 to faculty levels.

She said that she had lived through a time when workforce shortages were a barrier to new R&D. "My background is in photonics," she said, "and I was heavily involved in the late 1980s and 1990s in trying to develop components for the telecommunications display industry. A lot of us started little companies in Boulder, Colorado, and we ended up stealing each other's students as employees. This was not productive. We need to anticipate the workforce needs and invest in the right curricula, both at the community college and four-year levels."

Seeing DoE Programs Through Pasteur's Quadrant

Dr. Johnson turned to the concept of Pasteur's quadrant, which she said had been useful for her in visualizing and discussing DoE programs.[5] In the original Pasteur's quadrant, she said, basic research is visualized as occurring on the y-axis, at the upper left, while applied research takes place on the x-axis, at the lower right. The upper right quadrant belongs to Pasteur, where the activity is described by Dr. Johnson as "use-inspired" investigation. This level of activity was said to be modeled by Pasteur himself in his successful discoveries of basic information while seeking to answer practical questions.

However, in visualizing the potential interactions of DoE research programs, Dr. Johnson quickly saw the need to divide the quadrants further to accommodate cross-cutting programs. For example, one might begin in the upper left quadrant with basic research on the photoelectric effect, which had its roots in the work of Einstein. One might want to develop that discovery toward an interesting use by

[5]See Donald E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation,* Washington, D.C.: Brookings Institution, 1997. Pasteur's quadrant refers to that portion of learning which is use inspired but brings fundamental understandings. This is distinguished by the author from the traditional dichotomy of "basic" and "applied" research, a dichotomy popularized just after World War II by Vannevar Bush in his report to President Truman, *Science: The Endless Frontier*. Vannevar Bush, *Science: The Endless Frontier*, Washington, D.C.: Government Printing Office, 1945.

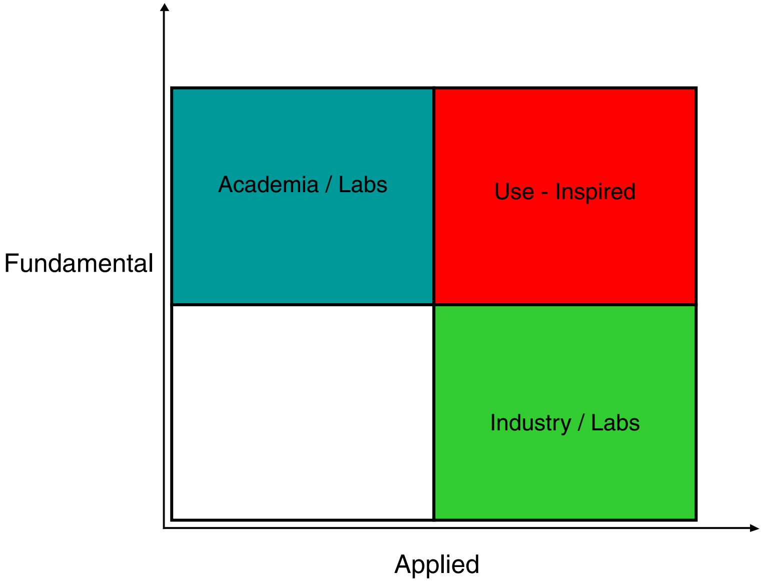

FIGURE 5 Pasteur's Quadrant applied to DoE.
SOURCE: Kristina Johnson, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

pursuing the physics further—an approach that actually led to the development of transistor technology, she said. This might be displayed in the diagram between basic and use-inspired research. If basic research, in the upper left, is represented by blue, and use-inspired research, in the upper right, is red, transistor technology might fit in a new square colored magenta. This is the kind of work visualized for the Energy Frontier Research Center (EFRCs). These centers are funded for five years and renewable for five more. Their mission is to try to produce basic research that can be developed into prototypes or demonstrations. "These programs," she said, "are looking for the next frontier of what could possibly be handed off to technology development and investment."

She experienced the same need when studying the upper right quadrant, Pasteur's quadrant, which was dedicated to use-inspired research. At some point during the exploration of transistor technology, the photovoltaic effect was observed, and uses for this new form of electricity led to exciting applied research.

"One might then say of the transistor technology," she continued, "that it is only 7 percent or 8 percent efficient as implemented in a traditional PV panel with amorphous silicon. We want something up near 40 or 50 percent. So we might ask whether the solar technologies that can generate those kinds of efficiencies are deployable at scale. Now we go to the upper right quadrant, moving toward use but not quite there.

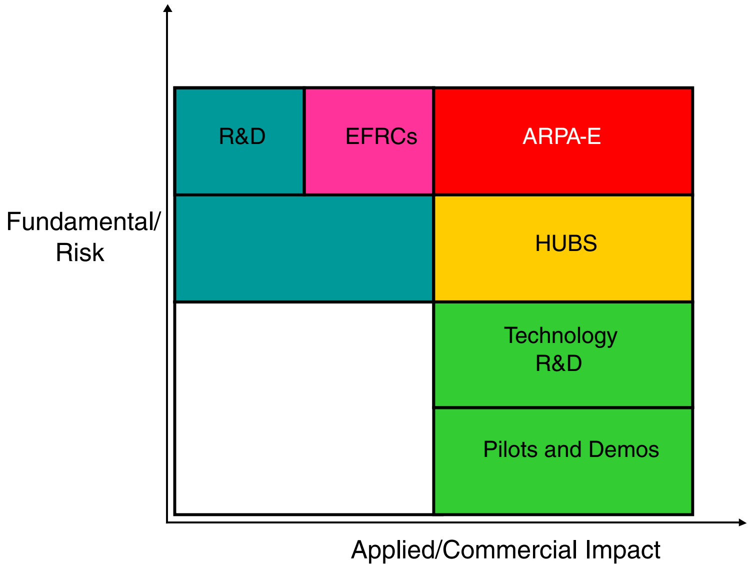

FIGURE 6 DoE cross-cutting programs.
SOURCE: Kristina Johnson, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

That's what ARPA-e is looking for—the breakthrough that will bring orders of magnitude improvement and accelerate the commercialization of technologies." ARPA-e then takes its place as the red upper portion of Pasteur's quadrant.

As applications research continues, she said, the technology moves downward through Pasteur's quadrant where the Energy Hubs are located in Dr. Johnson's diagram. "You bring people together and ask, What does it take over a sustained period and at scale to actually deploy the technology and create the market?" This is where the technology R&D passes through the proof-of-concept stage and begins to look commercializable, ready for the lower right.

"So now we have been in the upper left, the upper right, and the lower right," she said. "These are things that are high risk, but can have a big payoff in terms of the scale. We'll migrate through overlapping platforms to bring people together that can really create new industries. This is my vision of how these programs fit together."

A New Model for Research

Dr. Johnson then reviewed another cause of change in the way research is performed. In the traditional view, popularized by Vannevar Bush, research was often portrayed as two-dimensional, with knowledge flowing unidirectionally from basic research toward application, development, and eventually commercialization. But this model, to the extent that it was ever realistic, was changed by the advent of transistors, computers, and the Internet—the features of the information age. In the old model, scientists would think about how things work, and engineers would make them work. The new availability of knowledge allowed the engineers to invent new things as well. They could design more intelligently, using mathematical models. Computers brought everyone the same platform and tools, allowing not only engineers but also social scientists to become more quantitative and take more analytical approaches to the deployment of technology. "This is a fundamental change," she said, "that has not been clearly recognized."

A second thing that happened, she said, was passage of the Bayh-Dole Acts. "When I was an undergrad at Stanford," she said, "I had my first little invention. I took it to Niels Reimers,[6] a pioneer of technology transfer, and he said, in a very nice way, Kid, get out of my office, we don't do toys. Then the Bayh-Dole Act happened. I got a call back two or three years later saying, You know, we're kind of interested in your idea." The legislation had helped change the relationship between the invention and use of new knowledge. Universities had a new mandate to share and commercialize their technology. This was followed by the SBIR legislation, by which each federal agency set aside 2 percent of its R&D budget to support the commercialization of new technological ideas, preferentially by small businesses.[7]

Moving PV Toward Commercialization

Dr. Johnson suggested that both those major forces had already influenced the development of photovoltaic technologies and businesses. Freer access to information allows potential investors to learn about technology firms of interest, and the Bayh-Dole measures have accelerated the movement of new technologies toward the market place. Dr. Johnson's interpretation of the Pasteur's quadrant chart indicated her own interest in accelerating the movement of knowledge from the DoE into the commercial world. The Energy Hubs, for example, which are poised to move technology into pilot and demonstration phases, were the "secretary's number one priority." Of the eight or so topics planned for these hubs, a significant portion—electricity from sunlight, energy storage, grid modernization—are central to the advance of the PV industry.

The DoE has increased its support for solar research at every level, she said. Of the 46 Energy Frontier Research Centers funded in 2009, 6 were solar technology centers. When ARPA-e solicited white papers on energy needs, solar

[6]Niels Reimers founded Stanford's Office of Technology Licensing in 1970, which became a model for other universities.

[7]The 2 percent set-aside has been increased to 2.5 percent.

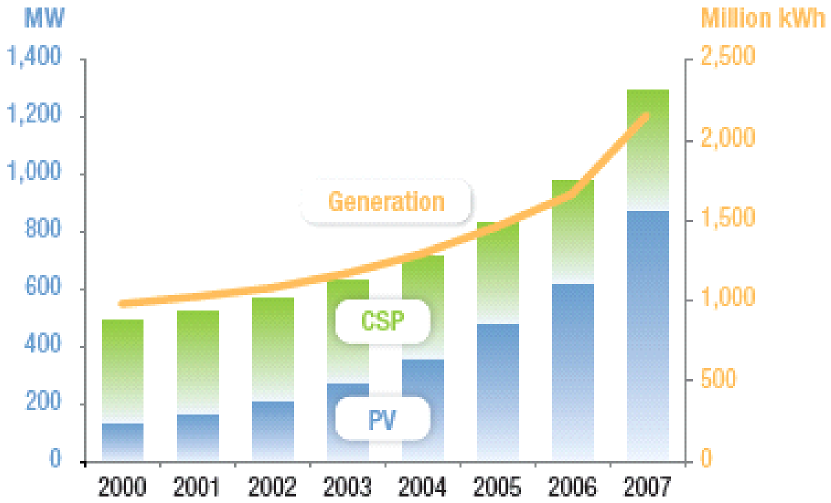

FIGURE 7 Solar energy capacity has more than doubled between 2000 and 2007.
SOURCE: Kristina Johnson, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

energy was one of largest recipients. The existing Solar Energy Technology Program had been bolstered by an additional $117 million from Recovery Act funding. Modernization of the national electricity grid is receiving billions of dollars in support.

Dr. Johnson ended by noting that the additional funding for renewable energy is also subject to the 2.8 percent SBIR and STTR set-aside, which totals about $55 million, which promotes commercialization and job creation. The majority of that amount is available for SBIR grants, she said, "and I want to encourage people in the PV area to apply for that funding."

DOE SOLAR ENERGY TECHNOLOGIES PROGRAM: ACCELERATING THE U.S. SOLAR INDUSTRY

John Lushetsky
Acting Deputy Assistant Secretary
U.S. Department of Energy

Mr. Lushetsky began by thanking the Academies for helping the DoE "work through quickly" a host of complex strategy and policy questions regarding solar energy technologies. "We are innovating in terms of the clock speed we ask our partners to work at," he said, "because we feel this is such an important topic."

He said that the DoE's Solar Energy Technology Program (SETP) was focused on reaching grid parity by 2015. "That is a slightly slippery concept," he said, "because it depends on a number of conditions, including financing terms, market pull, and local solar conditions." But he said that the DoE sees multiple technology pathways to meet this goal. The aim of the program is to allocate funds so as to maximize and accelerate market penetration.

Mr. Lushetsky said that the solar energy program was organized around four components: photovoltaic technologies, concentrating solar power, systems integration, and market transformation. Two pieces are concerned with deployment: market transformation and grid integration. He said that permitting processes and market acceptance were "at least as significant as some of the cost and technical issues." Systems integration, he said, involves how these systems are deployed at large scale, how they behave, and how they interact with energy storage mechanisms.

Rising DoE Budgets for PV

The budget for the SETP was under $100 million for six years preceding FY2007, when it rose by more than $50 million under the Solar America Initiative. In FY2009, it rose by approximately $100 million more with the Recovery Act, and $51.5 million of that amount goes to photovoltaic technologies. The request for FY2010 is similar to the 2009 total, stretching across the same four components.

Of the four technical components, photovoltaic technologies is by far the largest, receiving 65.7 percent of the solar budget, while the relative portion for CSP is growing. The two largest recipients, industry and the national labs, split the amount almost equally between them, with about 5 percent going to universities. He expressed a desire to increase university involvement, increase workforce development, and raise the investment in long-term research, which received only about 10 percent of the funding. The largest portion—some 48 percent—went to programs designed to end in less than seven years.

Mr. Lushetsky displayed the various components of the program in the form of a pipeline that stretched from early-stage research done in partnership with the Office of Science to the applied activities of market transformation, codes and standards, outreach, and utilities. "The pipeline approach aims to balance near- and long-term research," he said. "A big emphasis is on near-term commercialization."

Of the $117 million in new funding from the Recovery Act, some $22 million will be devoted to the supply chain and crosscutting technologies at universities and companies. Some $6.5 million are allocated to 13 pre-incubator projects. Another $10 million will go to PV technology incubators and $37.5 million to high penetration solar development. The amounts for market transformation will be up to $10 million for Solar America Cities Special Projects and up to $27 million, over five years, for a network to train workers in solar installation.

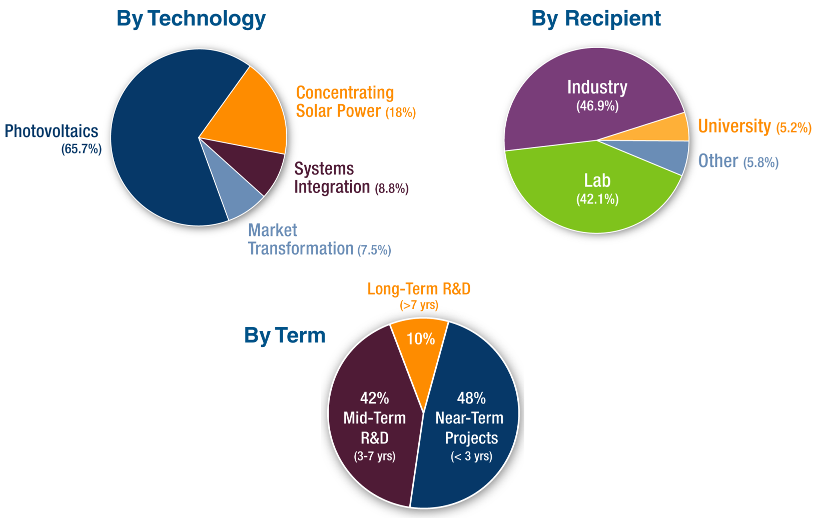

FIGURE 8 FY2009 projected solar budget.
SOURCE: John Lushetsky, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

He emphasized that early-stage research would continue to be a focus of the program. "Even though it gets only 10 percent of the budget," he said, "we continue to realize that making sure we have a robust R&D pipeline is very important. We also plan to partner with our Office of Basic Energy Science." He said that the Next Gen program represents a wide diversity of early-stage technologies, and will be carried out by partnerships between BES and many universities. In most cases, the technologies in this program will be those that demonstrate advanced, post-2015 device and process concepts.

Partnerships to Accelerate Commercial Development

Mr. Lushetsky turned to the Technology Pathway Partnerships (TPP), which are designed to promote assessments of the life cycle costs of the total PV system, with the immediate goal of driving down costs in dollars per kilowatt-hour. The program previously focused on cell efficiencies, he said; this is an important part of cost reduction, but it does not consider the system as a whole. To address this need, the DoE released a solicitation that invited teams from across the PV spectrum, including "everyone from silicon manufacturers to roofers." The idea was to stimulate knowledge sharing among people who seldom interact—something that does not need to be done in a mature industry, but is needed for the PV sector. "We'll continue to look at it to see if it's still needed," he said. "The industry has matured rapidly over the last three years, and many of you have told us that this was a key step in getting people to focus on system costs. We certainly count that as one of our contributions to helping the industry."

More recently, the department has worked to strengthen PV technology incubators. This is a generic term, he said. "For us it means to help early-stage companies get beyond the proof-of-principle stage and ramp up to initial low levels of production. To do this, DoE works closely with NREL; together they try to leverage the output of NREL labs into production, with the goal of producing about 3 MW of electrical power. If all goes well, this stage is followed by commercialization, manufacturing, and steps to scale up the process."

Broadening the Focus of Investment

Mr. Lushetsky said that the department is using a new approach to PV development. Rather than investing in successive promising cell technologies, it looks at all the cell technologies under development and tries to invest in supply chain and cross-cutting technologies that it can leverage across the whole sector. Examples of such technologies might be new methods of silicon supply, new types of substrates, or new types of encapsulation. By focusing on high-impact technologies, the department hopes to promote cost reductions across the industry. By supporting projects that tap significant expertise from related fields, it tries to develop and optimize technologies for PV. Finally, by emphasizing near-term technologies that can be inserted into current manufacturing processes, it hopes to accelerate progress toward grid parity.

Mr. Lushetsky turned briefly to the DoE's major PV labs—NREL and Sandia National Laboratory—that account for almost 50 percent of its solar energy investment. Historically, NREL has provided the bulk of the department's PV technology, working closely with experts at Sandia, Lawrence Berkeley National Laboratory, Argonne National Laboratory, and Oak Ridge National Laboratory. He estimated that the department supported more than 200 scientists and engineers with "deep solar knowledge." He encouraged symposium participants to work with all of them.

Process Development Labs to Help Bridge the Gap

The department also supports a Process Development and Integration Laboratory (PDIL), he said, which supports R&D on a manufacturing scale. Its specialized equipment allows scientists at NREL to partner with industry in developing processes that are easily transferable to the manufacturing environment. If the task is to develop a silicon wafer, the PDIL offers good process control for testing different coatings or deposition layers with a large degree of flexibility and control. In-house metrology equipment can ensure that processes are working properly. This approach bridges the gap between pure R&D on small samples and the scale needed by industry. He said that additional resources might be desirable, but welcomed inquiries and interest from industry about partnering with NREL at this facility.

Internationally, he said, the primary markets are found outside the United States, as are the manufacturing supply bases. But he said that the innovation base "is clearly in the United States," especially with regard to diversity. In Europe, most investment has been made in polysilicon and crystalline silicon PV companies. In Asia, almost all investment has gone to crystalline silicon PV. In the United States, a robust venture capital and private equity base has funded many different technologies.

Mr. Lushetsky closed by highlighting the diversity of activities in the United States. "I think this is mirrored in the technology investments that DoE has been making as well," he said, "through our TPP program as well our incubators and preincubators. So we clearly have an opportunity to capture the next generation of technologies, and that certainly drives a lot of our thinking. It's not the only consideration, but I think it is an important one."

BRINGING DEPARTMENT OF ENERGY INNOVATIONS TO MARKET

Carol Battershell
Senior Advisor for Commercialization and Deployment
Energy Efficiency and Renewable Energy
U.S. Department of Energy

Ms. Battershell said that the Commercialization and Deployment group had been introduced in response to a perceived weakness in the commercialization activities of the national laboratories. Accordingly, the motto of the team is "Out of the labs and into the market." That is, the team is charged with identifying and implementing the opportunities in technologies developed by the department's Energy Efficiency and Renewable Energy (EERE) program.

The initial tool for doing this is a Technology Commercialization Fund to help national laboratories move their promising technologies across a gap between research activities and later stage funding. Funds are restricted to prototype development, demonstration, and deployment—not further scientific research. "We've had billions of dollars going into the national labs over the decades for research," she said, "but much less going into commercialization. In conversations with the labs about what's stopping commercialization, we hear a lot about the 'valley of death'."

Finding Industry Partners

In response, the EERE has allocated $14 million over the last two years to fund technologies in 10 DoE labs. The DoE requires evidence of market interest

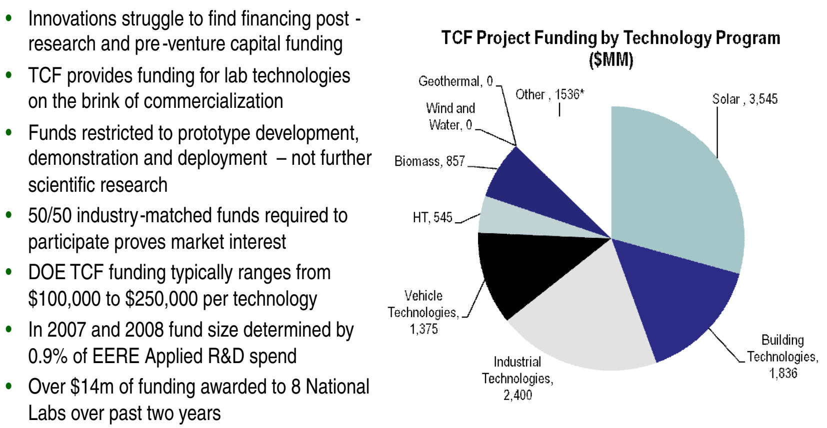

FIGURE 9 Technology Commercialization Fund.
SOURCE: Carol Battershell, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

in the technology, in the form of 50-50 cost sharing with an industry partner. In addition, this requirement leverages the government's grants, which typically range from $100,000 to $250,000 per technology. The largest recipient of this funding so far has been the solar energy sector. Ampulse Corporation is one example, which was formed to commercialize technology developed at both NREL and Oak Ridge.

Bringing the Entrepreneur into the Laboratory

The other main part of the program, Ms. Battershell said, is to "get more eyes on the technologies"—to connect investors and entrepreneurs with research in the national labs on the brink of commercialization. This effort includes several programs. One is the Entrepreneur in Residence program that connects leading scientific and business talent. An entrepreneur is selected to spend a year in a national lab, mining any knowledge that is available. This does not bring exclusive rights to lab results, but better access. The entrepreneur also commits to looking preferentially at lab technologies to commercialize. "One thing DoE wisely recognized," she said, "was that DoE does not have the ability to recruit or select the right entrepreneurs, so we partner with venture capital (VC) firms. The partnership is actually between the DoE and the VC firms, and the firms actually find the entrepreneurs."

The EERE is still testing its entrepreneur-in-the-lab concept. One thing they have learned is that the model of one entrepreneur-one lab-one VC firm does not give the entrepreneur exposure to more than one VC firms when there is a start-up idea to pitch. In the second round, said Ms. Battershell, DoE is trying to give the entrepreneur access to multiple VCs. "This is more like the real world, and doesn't lock us into one VC," she said.

"Speed Dating" for Entrepreneurs and Scientists

Another way the department is trying to "get more eyes on the technologies" is to create a "speed-dating" mechanism. Over a span of two days, they expose VCs to DoE technologies—as many as 80 technologies in a session. This is not so much an immersion in a particular laboratory as an exposure to how many technologies are potentially available and how many labs are "open for business." A side benefit, she said, was the work EERE did with the scientists in preparing for these showcase events. They found that while the scientists were good at presentations to explain projects and budgets to project sponsors, they were often not experienced at selling their ideas to the private sector. As a result, the EERE began working with the lab scientists to help them present the benefits of their technologies and to research market possibilities so these ideas can easily be understood by investors.

A New Technology Information Portal

Ms. Battershell said that the program she found most exciting was the EERE Technology Portal. When she joined DoE about a year ago, she was surprised to find out there was "not a one-stop shop for the great technologies the taxpayers have been investing in." For information about wind technologies, she said, one had to go to Sandia's site, and then NREL's site, and others, and even then was unlikely to find anything more than the patent applications. "So we're looking at a way to gather all the information on one portal." In addition, EERE has begun to write lively two-page marketing summaries of each technology. A demonstration site is now ready, and it is scheduled to "go live" early in 2010. She said that the site was designed to carry information on solar technologies, how to commercialize technologies in general, and the value of explaining the benefits of a particular technology over other technologies.

She noted that some additional Recovery Act funding would be arriving soon—from the IRS. The DoE and the IRS partnered to implement this program although the funding would not show up on the DoE site, even though it will support renewable energy technologies. It is the 48C Manufacturing Tax Credit, funded for $2.3 billion in the form of 30 percent tax credits to be taken over ten years. The 48C Program should be sufficient to support about $7.7 billion in manufacturing investments. This direction would be significant because government support for solar had focused on deployment rather than on promoting domestic manufacturing. The new funding was coming soon, she said, so that the department would have to prepare quickly for implementation.

Ms. Battershell closed by commenting on the question of whether government is seen to pick winners. "How does the government provide assistance for commercialization and yet not pick winners?" she asked. "I think we're walking that line well, but I would like to hear what people think."

DISCUSSION

Reducing Costs

Dr. Guha said that the industry was not where it wanted to be in system costs, and asked the DoE's view on that. "I'm a little concerned that while we are hearing about revolutionary devices and thinking out of the box, I want to assure you we have been reducing the costs. There has been a lot of smart work. And I'm worried that we've spent time developing a technology that will always remain the technology of the future."

Mr. Lushetsky said that he would not place risky research in opposition to incremental cost reductions. "Our program, combined with the Office of Science program, needs to be funded significantly. I've been in DoE only a year, having spent all my career outside government, so I appreciate all the comments made here today about the need for incremental improvements, on the scale of investment required, and on the time horizon for these investments to bear fruit. Over time, significant gains can be made, and we can't predict when they might flatten out. Throughout history, people who have predicted the end of technologies have always been wrong. As Dr. Johnson commented, there has been a lot of attention to early-stage work, and also a lot of work on bridging any perceived gap between basic and applied work."

A questioner asked Mr. Lushetsky whether the DoE might better help reduce costs by a national procurement strategy than by some recent programs, such as grants in lieu of tax credits.[8] "If we buy $26 billion worth of PV and put them on every government installation, how much can that drive down the cost of producing these technologies, as opposed to other programs?"

No Single Strategy

Mr. Lushetsky said there would be no single strategy. "If you look at grants in lieu of tax credits," he said, "it's uncapped. So from an appropriations standpoint, my guess is that it will distribute tens of billions of dollars, if not $100 billion, when all is said and done. Certainly, we need a government investment in solar and renewable energy technologies. For the manufacturing tax credit,

[8]The Department of the Treasury and the Department of Energy announced in July 2009 a program to provide direct payments in lieu of tax credits to businesses that invest in renewable energy. <*http://www.treas.gov/recovery/1603.shtml*>.

while it is capped, there is a similar argument. I think that both approaches are being pursued."

Ms. Battershell added that there were targets within the government for a certain level of renewable energy production. "It's not prescribed in terms of particular technologies, but I think the government investment in measures like grants in lieu of tax credits is huge."

B. J. Stanbery of the HelioVolt Corporation said that his company had bridged the valley of death, and offered a lesson from an NSF experience. He said that the Process Development and Integration Laboratory (PDIL) was an opportunity is to solve the fundamental problem of bringing a technology to market scale. That must be done across the whole manufacturing equipment supply chain, he said, and can be seeded in the PDIL by borrowing from the NSF its practice of funding equipment-targeted experimental programs, with funding for both developmental equipment and process development. "This is not quite adequately balanced in your portfolio now," he said.

Mr. Lushetsky agreed that it was not balanced, and that there was disagreement about whether the PDIL was the best place for it. But he agreed with the need for discussing how DoE should interact with the tool suppliers and others to enhance process development.

Communicating Among Agencies

Dr. Jackson of the Senate Committee on Energy & Natural Resources, referring to Secretary Johnson's desire to lower barriers within the DoE, asked how this could be done between agencies, especially between NIST and DoD. Mr. Lushetsky said that his agency did communicate with colleagues at NIST, and said that those discussions should continue, especially on the topics of manufacturing and commercialization. "We have not gone as far as I think we could," he said, "and certainly the dialogue process is a key part of this overall discussion." He said that DoD, in terms of government deployment, renewable energy, and energy efficiency, is "the DoE's biggest ally," with its mission-critical needs to reduce energy use, ensure fuel supplies, and reduce the logistics requirements for both. He added that within DoE, he is responsible for the Federal Energy Management Program (FEMP), which communicates with other government agencies about implementing efficiencies and renewable energy technologies. Finally, he urged the industry to recognize that DoD can be a very early adopter of new technologies. He cited DARPA's high-efficiency solar cell program as an example. "DoD is a great launching point for new technologies," he said, "for getting things out there, and moving them to the wider commercial market."

Ms. Battershell cited two other examples of interagency cooperation, which she called "a bit of a forced marriage with some Recovery Act funding." One was the grant in lieu of tax credits program, managed by the Treasury Department with DoE technical expertise. The second was the manufacturing tax credit mentioned earlier, with money from the IRS and the technical expertise of DoE. "While these partnerships should be seamless and invisible to the public," she said, "getting those agencies to work together that quickly, meeting deadlines on both programs, was pretty remarkable."

Dr. Wessner encouraged the DoE to make more use of the SBIR program. Although the DoE had led the government in working with small companies that responded to SBIR solicitations, he encouraged DoE to do additional solicitations for firms wishing to use technology that was already in DoE labs. "That can act as a catalyst for licensing and adopting the technologies," he said. "So a program you already have at DoE can be an even greater asset."

Panel III

Facilitating Solar Innovation: Contributions from Other Federal Agencies

Moderator:
Richard Bendis
Innovation America

Mr. Bendis opened the panel by saying he had observed an indirect but substantial benefit of the symposium: new conversations, both between people working in the same agencies, and those in different agencies. "The format is giving people an unusual opportunity to hear about gaps in understanding and new ways to leverage resources more effectively within the federal technology investment portfolio that already exists," he said. He applauded the DoE for taking the lead in bringing other agencies into the discussions.

MEASUREMENT AND STANDARDS: THE ROLE OF NIST

Kent Rochford
Acting Director, Electronics and Electrical Engineering Laboratory
National Institute of Standards and Technology (NIST)

At NIST, said Dr. Rochford, "we are very broad, but we focus like a laser on measurement science." NIST also helps develop standards and promote technology. He called the institute "fairly small," compared to DoE labs for example, with about 2,800 employees and almost that many affiliated associates, postdoctoral students, and guest researchers from companies, universities, and metrology institutes. About 400 NIST staff work with more than 1,000 bodies to help set standards. Among the Institute's ongoing programs are the Technology Innovation Program, the Malcolm Baldridge Quality Program, and the Manufacturing Extension Program. He said he would focus on the laboratory programs, which were organized by discipline, including several that bring measurement science to bear on the photovoltaic technologies area.

The Goal of Measurement Traceability

Why do measurements matter? They make possible the research collaboration and commercialization of products that underpin innovation and trade.

To illustrate his answer, Dr. Rochford described the recent international comparison of solar module ratings. Published three years earlier, these ratings were based on an experiment by NREL that sent solar modules to major laboratories around the world. These modules were of four kinds: monocrystalline silicon, thin-film silicon, cadmium telluride, and cadmium-indium-selenide (CIS). On the CIS system, a measurement spread of almost 9 percent was found about a mean. "The graph has taken eight participants' measurements and assumed that the mean is the right value. That's not necessarily true." He also said that the accuracy was not sufficient. "Our role is to create measurement traceability," he said. "As the National Metrology Institute for the U.S. our job is to be able to trace measurements to the international system of units. By providing measurement traceability, we can strengthen comparisons of measurements across companies, nations, and laboratories. To facilitate trade, the companies, vendors, and other participants have to agree on what a product is, and agreement is based on measurement. Also, if you want to innovate efficiently, you have to be able to accurately measure product characteristics throughout the R&D process so you can share results and perform reproducible engineering production and even reproducible research." For these reasons, he said, NIST provides traceability to many places, for example NREL, which does PV measurements for a variety of vendors. At the top level, NIST ensures that all the units are traceable internationally by working with international partners and other national metrology institutes.

In addition to the high-level metrology, NIST also offers develops measurement science and services. For example, the Building and Fire Research Laboratory (BFRL) seeks to improve measurements needed to certify and model net zero buildings. Recently the Institute developed a new high-speed radiometer to measure the performance of PV panels, allowing the industry to move away from over-reliance on a single standard artifact. In some industries, he said, metrology is often limited to a single "golden sample," in the assumption that a certain test piece is of adequate quality, stability, and suited to the measurement problem, but this makes broad applicability very difficult.

BFRL, he said, is building simulation tools to improve evaluation of energy usage in buildings. Because solar energy is just one aspect of this challenge, the lab has gathered data and modeled buildings in a variety of applications to bring a better understanding of how to perform simulations. This will enable better economic and energy budget analyses of buildings.

He said that photovoltaic technologies R&D must be viewed in the context of a variety of electronics and power-conditioning systems, a broader area NIST has worked in for many years. “This isn’t your standard CMOS stuff,” he said, “this is semiconductor electronics that can convert the DC power of a solar panel into the AC power used by the house and the grid. We’ve taken a leadership role in some of those measurements and developed measurement traceability to help that sector produce more powerful conditioning systems.” In this effort, he said, NIST also leads interagency groups in semiconductor measurements with DoD, DoE, and other partners.

The Need to Guarantee PV Lifetimes

Dr. Rochford emphasized that the service life of PV modules is critical. “For PV to make sense,” he said, “you have to be able to sell a product that has a guaranteed lifetime in order to get the expected return on investment.” NREL and other labs are working on service life, which he said is “not a trivial problem.” NIST has built a device that simulates accelerated aging at known humidity and temperature, but to predict accurately the lifetime of a product, it is also necessary to understand the processes that degrade it. This requires a microscopic and nanoscopic understanding of aging. NIST has found that some tools developed in the semiconductor industry can be adapted for us in photovoltaic technologies. For example, researchers have showed that defects generated at the silicon dioxide interface of PV have a mechanism similar to electrical stresses in MOSFETs.[9]

Developing Next-Generation Tools

In the future, Dr. Rochford said, NIST planned to leverage some current capabilities into later-generation PV, such as using inhomogeneities or nanostructures to increase efficiency. “But clearly, to make those work,” he said, “there will have to be better understanding of some processes.” As examples, he mentioned carrier generation, carrier transport, and electron hole band diagrams at the smallest scales. “By developing measurement capabilities that can be applied to next-generation work,” he said, ”we will have the tools to better understand reliability and defects in today’s manufacturing at the same time we are advancing the learning curve.”

A final point of involvement with PV manufacturing is solar-related documentary standards. In the U.S., he said, these are not handed down by the government, but produced through a collaborative process. NIST’s role is to send experts to those making the decisions. “Because we are technology agnostic and are not trying to make a profit,” he said, “we can provide participants with unbiased

[9]A metal-oxide-semiconductor field-effect transistor, or MOSFET, is a device used to amplify or switch electronic signals.

technical information and assessment." NIST intends to start a mapping exercise in 2009 to look at any gaps in the documentary PV standards and advise on where additional work may be needed.

He concluded with the comment that NIST is also active in developing standards for "smart grid, an area where the documentary standards effort is just huge. This requires a lot of input from the PV community, because the whole point of smart grid is to be able to use intermittent and renewable sources. As the PV community grows, we'd be very interested in any type of consortium on standards where we think we can help."

THE NSF MODEL: THE SILICON SOLAR CONSORTIUM

Thomas W. Peterson
Assistant Director
NSF Directorate of Engineering

Dr. Peterson said he would discuss three aspects of the National Science Foundation (NSF). First, he would describe some of its renewable energy research, conducted primarily in the engineering (ENG) and mathematics/physical sciences (MPS) directorates, and also throughout the foundation. Second, he would discuss specific examples of PV research, and again primarily in two directorates. Third, he would end by talking specifically about translational research and engineering and how that supports renewable energy.

He said that NSF is not strictly a mission agency, but rather has the broad mission of supporting basic research and education in science and engineering. At the same time, its portfolio of programs does contain extensive energy investments. One example of renewable energy research was the Green Gasoline Project, developing direct conversion of cellulosic materials to hydrocarbons or feedstocks for gasoline. This project, based at the University of Massachusetts at Amherst, uses fast catalytic pyrolysis to generate hydrocarbon feedstocks directly from cellulose.

Liaisons with Industry

The NSF, Dr. Peterson said, had an extensive program that emphasized aspects of energy manufacturing, systems engineering, and industrial engineering related to production of alternative energy devices. This program supported a project whose goal is to extract energy from ocean waves via linear direct drive generator buoys. This is done in collaboration with a small company in a new program called GOALI, Grant Opportunities for Academic Liaison with Industry.

There are also renewable energy programs in a number of NSF's Engineering Research Centers (ERCs), which he called "one of the jewels in the crown." These are large-scale operations involved multiple institutions, almost all of which are partnerships with industry. Four projects have energy components: North Carolina State University is the lead institution for a project on smart grid issues; Iowa State University on biorenewable chemicals; Rennsalaer Polytechnic Institute on smart lighting; and the University of Minnesota on compact and efficient fluid power.

Another program that supports energy research is outside the disciplinary divisions: Emerging Frontiers in Research and Innovation (EFRI). The objective of EFRI is to support high-risk, potentially high-return research. Unlike most of the foundation's proposals, which are unsolicited, EFRI designates its solicitations for specific target areas. During its four-year history, EFRI has focused on a number of topics, but in the last two years, half have been energy related. The energy programs have supported work on resilient and sustainable infrastructures, hydrocarbons from biomass, and for 2009, both renewable energy storage and engineering sustainable buildings.

Within ENG and MPS, the following projects focus specifically on PV research:

- Center for Powering the Planet, headed by Harry B. Gray at Caltech; developing components for solar water splitting. The objective is to generate hydrogen that can be used in fuel cells.
- Nanoparticle Catalyst for Fuel Cells, headed by P. Strasser, University of Houston; developing nanoparticle catalysis for application to fuel cells.
- Solar Cell Material Surface Structure Observed, Angus Rockett, University of Illinois at Champaign-Urbana; coordinates studies of the material properties of surfaces used for solar cells. It seeks insights into the nature of the semiconductor junction to help explain why some solar cells work and some fail.
- Renewable Energy Materials Research Science and Engineering Center (MRSEC), Craig Taylor, Colorado School of Mines; materials research on PV materials and fuel-cell membranes, from fundamental physics of electronic excitations to applied aspects of PV cell efficiency.
- Optoelectronic Processes in Materials for Solar Energy Conversion, University of Central Florida; nanosystems of conducting polymers and fullerene-based material; single-particle spectroscopy studies reveal that the states of the aggregates affect material function.
- Self-assembled Biomimetic Antireflective Coatings, University of Florida; novel templating nanofabrication platform to mass-fabricate broadband coatings for solar cells. Coatings mimic antireflective moth eyes and super-hydrophobic cicada wings.
- Nanostructuring of Silicon Surfaces for Photovoltaic Devices, Georgia Tech; molecular lithography is used to pattern silicon substrates with features that depend on the size of the molecules used, instead of on the lithography tools. This technique is thought to herald a breakthrough in manufacturing efficiency and cost.

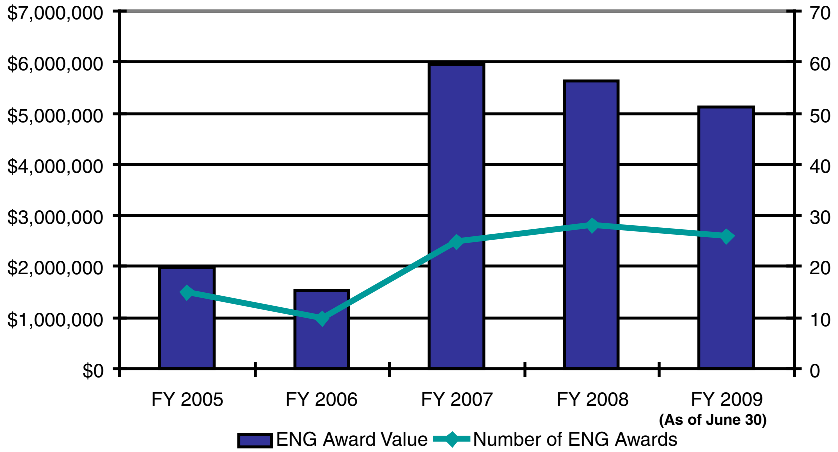

FIGURE 10 ENG investment in photovoltaic research.
SOURCE: Thomas Peterson, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

He showed a rough graph of what ENG had invested in PV. Compared to the total DoE investment it is a small number, he said, but growing. He expected it to be over $6 million in FY2009.

Increasing Emphasis on Translational Research

NSF places heavy emphasis on translational research—again, mostly within ENG. In the realm of renewable energy, this means both basic research and research that has industrial and commercial potential. It is almost always interdisciplinary, involving primarily teams of universities, but also of companies and government agencies. By definition, translational research relies on partnerships and is expected to deliver clear benefit to society. Programs considered to support translational research include the Science and Technology Centers, the Engineering Research Centers, GOALI, MRSEC, the SBIR program, EFRI, and the Industry/University Cooperative Research Centers (I/UCRC). The emphasis of these programs spans the squares of Pasteur's diagram, from discovery mode through involvement with small and large businesses.

While the majority of NSF funding continues to support basic research, the I/UCRCs represent an increasing emphasis on application and commercialization of knowledge. The basic model for them, he said, was to enable discovery and innovation through collaboration. "The model works almost like a research franchise," he said. "The NSF seed money is small and intended to act as catalyst, while the foundation takes a supportive role throughout the life of the center. The

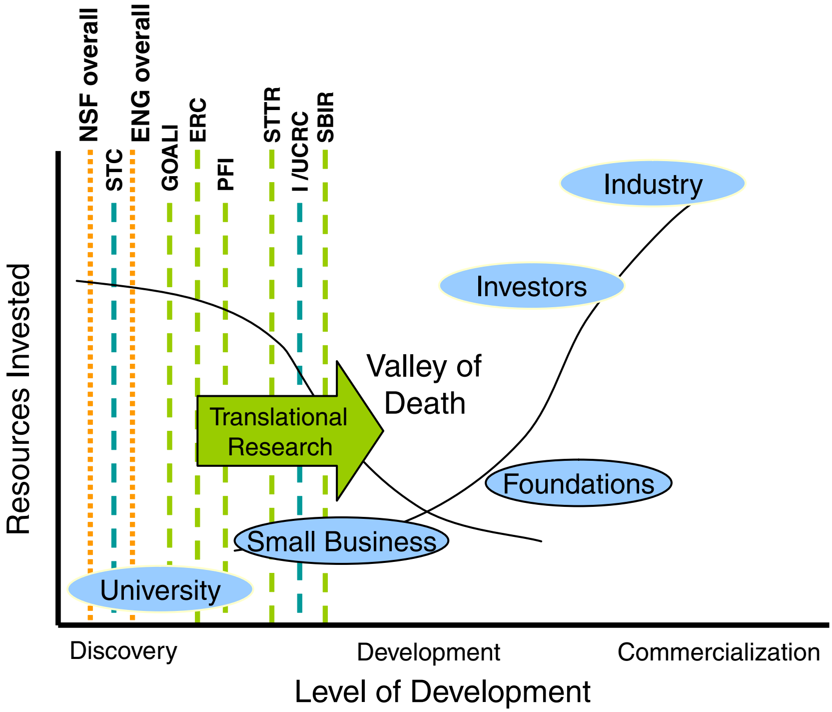

FIGURE 11 Filling gaps.
SOURCE: Thomas Peterson, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

I/UCRCs consist of one or several universities, but they are funded primarily by industry, and its Industry Advisory Committee is the critical component. It is a specific management and structural model with independent evaluation tools." Over the past two decades, the program has supported some 35 to 50 centers each year, with a total of about 100 sites throughout the country.

A specific example of I/UCRCs is the Silicon Solar Consortium, or SiSoC. It consists of four universities (North Carolina State University, Georgia Tech, Lehigh University, and Texas Tech University), several national labs, and 15 industry partners. Its objective is to reduce costs and increase performance of silicon PV material, PV cells, and PV modules while developing novel breakthrough designs and processes. Two main research foci are metrology and wafer breakage. Being an academic program, the primary technology transfer mechanism is to educate graduate students who can later move into the industry.

Dr. Peterson closed with the following summary:

- The NSF has a broad renewable energy portfolio, which includes photovoltaic technologies.
- Although the mission focus of NSF is basic research, the ENG research portfolio includes strong translational research programs.
- I/UCRC is an important element of the foundation's growing commitment to translational research.
- SiSoC, a multiuniversity, multicompany research program, is an excellent example of NSF's approach to translational research in photovoltaic technologies.

PHOTOVOLTAIC MANUFACTURING IN THE UNITED STATES: A UNIVERSITY PERSPECTIVE

James Sites
Colorado State University

Dr. Sites opened by saying that he would discuss how research universities can contribute most effectively to PV manufacturing in the United States. He expressed no doubt that the universities, after many years of fundamental contributions, were well positioned to continue their contributions into the future, both to manufacturing research needs and to the broader development of the PV industry.

University researchers are well suited for the advancement of knowledge in this and any other field, he said. They have a high level of intellectual vitality; they tend to be creative by nature, they are well versed in the literature, and also skeptical, and interactive. At the same time, there are various challenges in combining the respective cultures of academia and industry. It was their mutual responsibility to do so as effectively as possible.

Some Challenges in Working with Industry

Potential challenges for the university working in partnership with industry can be seen in their different understandings of research and education. One university approach of high value to industry is foundational research. Foundational research, he said, is basic research directed toward specific problems. Some examples in photovoltaic technologies are:

- Analysis of optical losses.
- Minimization of forward-current losses.
- Control of uniformity and stoichiometry during fabrication.
- Identification of unintentional energy barriers.
- Correction of degradation problems.

When foundational research is done in universities, it typically includes such activities as development of unique fabrication and measurement equipment, quite time-consuming and fundamental activities. In the university setting, such research, in addition to looking toward the goals of better manufacturing, must allows for thorough exploration of questions that are encountered during a project. Because much of a university's PV funding now comes through industrial subcontracts, the breadth and independence of university work may conflict with industry's emphasis on short-term manufacturing goals. A related issue is that a student in training may soon be working for a competitor of a company that is funding research at that university.

Similarly, a university's understanding of its educational function differs from that of industry. The education of graduate students is a primary function of the university, he said, and should be encouraged on fairly large scale. PhD students in particular tend to be sources of creative ideas of value both to their advisors and, later, to their employer should they proceed to a career in PV manufacturing. At the same time, their education does not proceed at an industrial pace. Ph.D. students, to do their job right, need stability and time to do their research, which typically takes three or four years.

In addition, the value of academic freedom is central to graduate education, and universities want to preserve for their graduate students the ability to disseminate the results of their research. They also prefer a thesis schedule that can proceed smoothly over those three or four years.

Suggestions for Working Together

"I would make a couple of suggestions," Dr. Sites said. "The country should fund a solid base of university PV research and its students directly. This does not preclude the possibility of additional industrial contracts at universities; in fact, those investments can bring positive synergies for the funder. Also, we should expand opportunities for research students at our universities to do part or all of their research training at a national lab."

One thing a university culture encourages, he said, is information exchange and collaboration with other research institutions—in part, because a single university rarely has the resources and expertise to fully investigate a complex problem on its own. A collective approach to PV research problems involving universities, national labs, and industry will cross-fertilize and synthesize new ideas that may elude individual investigators. "The sum is likely to be greater than the parts," he said. There are already strong regional collaboration centers and nationwide networks of researchers in specific technologies. "I would suggest constructing proposal solicitation to encourage collective and consortium submissions. Also, we should support topical workshops in different PV technologies, meeting regularly. A lot of collaborations form when people can get together and chat about their work individually."

Universities are also qualified to bring leadership to large PV manufacturing questions, he said. "We all do a fair amount of strategic planning. Universities have expertise that can help at the national scale. At same time, faculty are skilled at evaluating people and research proposals. We tend to have that skepticism, a healthy thing to integrate into review." He acknowledged the potential for conflicts of interest when most faculty are also submitting proposals, a conflict that is hard to avoid, especially when the number of qualified reviewers is small. "My suggestion is that we lighten up on this a little," he said. "I know the NSF manages this fairly well, as do journal editors. We should manage rather than try to eliminate conflict of interest."

For the PV manufacturing industry, he suggested that an issue of vital importance is its relationship to other countries. The United States has fallen behind as a manufacturer of PV over the past 20 years, he said; it has also fallen behind in foundational research, particularly with respect to the European Union. "So as we build up our industry in the United States, there is a question: Do we view other countries as partners, or competitors, or both? How can we most effectively come to terms with them?"

Filling a Research Gap

Dr. Sites raised a final specific issue, a gap in our research emphasis. "We have a habit of investing in highly fundamental research, with pretty long-term horizons. We also tend to invest in industrially driven research. But between them lies a gap: foundational research related to current technologies." He suggested moving effort and money into this gap to advance PV technologies for the 2015 time frame.

He gave the rationale for this change by describing PV in terms of three generations. During the first generation, he said, crystalline silicon was dominant, producing high efficiency at reasonable cost. The second generation has included thin films, with low cost and reasonable efficiency. The third generation is "a little more vague"—either very low cost *or* very high efficiency. "I would be skeptical when people try to change that 'or' into an 'and.' In any case, all these generations need foundational research and they also need critical review. Directionality—that is, the idea that new generations will replace the old ones, which then die out—cannot be assumed. We need all three generations at once, each of them a comprehensive whole with continuing possibilities."

He closed by mentioning a difficulty for some universities in forming PV partnerships. "We've been burdened a bit with cost-share requirements from some parts of DoE," he said. "This requirement, typically 20 percent, can be a disincentive for some of the more creative faculty who might otherwise work in a PV area. I hope we can take another look at that policy."

Panel IV

Advances in Photovoltaic Manufacturing: Intermediating Institutions

Moderator:
Pete Engardio
BusinessWeek

Mr. Engardio introduced the panel by observing that it was "no longer sufficient for the United States to be ahead in R&D, especially in areas like PV, when the capital markets will not fund new entrants that don't have proven ability to manufacture and to scale up." He reaffirmed that the preeminent challenge now facing the U.S. PV industry was to move its expertise more quickly from the lab to the manufacturing environment. He suggested that certain lessons and solutions from the semiconductor industry may be helpful in this transition for photovoltaic technologies.

A SOLAR PRODUCT DEVELOPMENT CENTER

Stephen Empedocles
SVTC Solar

Dr. Empedocles said that he agreed with the need characterized by Mr. Engardio, and said he would describe one particular solution for the photovoltaic industry.

"That need," he began, "is to help companies transition from a lab-scale prototype to a fully qualified manufacturing process ready for funding by the capital markets or the DoE loan guarantee program." He reviewed the standard options for PV companies seeking to finance their manufacturing process. New PV start-ups typically begin with an effort to raise $10 million-30 million to carry out their R&D and prove their concept. Then they return to the capital markets for an additional $50 million-70 million to build a pilot plant and develop their manufacturing process. Finally, they return a third time for some $200 million-300 million to build their first manufacturing line. During the "bubble" (i.e., 2008), the capital markets supported these enormous funding requirements to "try out" a new PV technology; but now, while there are many companies that have raised a significant amount of capital to do the R&D portion of this process, the capital markets are have stopped supporting the middle tranche for product development and piloting. Companies might find support in the loan guarantee program, but still only after the technology has been "de-risked" by showing 6 months of manufacturing data. This funding to support a new PV technology transitioning from an R&D prototype into a final product and qualified manufacturing process represents the new "Valley of Death" for the photovoltaic industry.

Companies Pay Only for the Equipment They Need

SVTC Solar proposes a way to bridge this valley of death through a solar product development center that offers the necessary manufacturing tools, infrastructure and engineering expertise to advance each company's technology. SVTC will offer companies working residence at the facility, and the resources to develop a fully qualified manufacturing process quickly. This strategy could cut development costs for companies because they do not have to outfit a full facility; they pay only for the equipment they need and the time they use to develop their specific process.

This strategy will also cut development times, he said, because companies would not have to grapple with set-up challenges already familiar to the industry but which the company itself has never faced before. Instead, they can leverage the expertise within the center. The goal is to de-risk the technology so that it becomes finance-worthy, whether through public or private mechanisms. A parallel goal is accelerated ramp-up of production, after producing a qualified manufacturing process that can be replicated at scale.

Dr. Empedocles said that the model for their center had grown out of eight years of experience as a manufacturing development center for CMOS semiconductor companies. SVTC now plans to extend this successful model to PV manufacturing, and hopes that their participation will help PV manufacturing to stay in the United States.

Dr. Empedocles emphasized that the SVTC center is different from a research center. "The United States already has great PV research centers," he said. "We are the leaders of the world in PV R&D. But that's not what our center is for. We are a product development and piloting center. We take the output of the R&D centers —research prototypes—and convert them to final products. Eventually we hand them off to the cell and module makers who do the large-volume manufacturing." He said that SVTC would work closely with organizations like NREL and university labs, as well as the new DoE Innovation HUBS and other DoE solar programs to transition new PV technology from the lab to the manufacturing line.

Working "Hands-on"—With Help as Needed

Dr. Empedocles made the point that the SVTC model is not a typical "user facility," such as a university lab; nor is it a "foundry." He called it "a mix of the two. With a user facility, a customer goes in, uses the tools, and hopefully knows how to run everything correctly. With foundries, you give them a recipe and, a few days later, they bring out your product; but you don't have any interaction with the process." SVTC, he said, invites customers into the fab where they can work "hands-on" with the tools, but with SVTC operators to assist. "Companies can get in there and do 'hands-on' development," he said, "but use our expertise where it's valuable." This lets a company keep the touch and feel of development without having to hire an entire team of experts in areas outside the company's core expertise. As the company's needs change, so can the staffing.

Keeping IP Safe

The key elements of a solar development center, Dr. Empedocles said, begin with enough product development and manufacturing tools that multiple companies can use them. At the same time, each company has the flexibility to innovate within that tool set. Also, there must be a complete "manufacturing culture." This includes advanced materials, which are a big part of PV research. It also includes analytical services and certification, which are important for rapid feedback. Finally, IP ownership and security are critical. Unlike semiconductor manufacturing, where companies share baseline process IP and differentiate at the circuit level, companies in PV have no such circuit level. PV companies rely on baseline process IP as their primary asset, and they need the comfort of knowing that their proprietary technology is safe. "Sharing IP," he said, "is not something I've seen any small PV company willing to consider." Finally, he said, the center has to service multiple types of customers—not just cell makers, but companies throughout the supply chain.

The first three elements—manufacturing equipment, leverage across tools, and flexibility to innovate—all go together, he said. The goal is to establish a baseline set of tools and the standard manufacturing process around which people will innovate. SVTC will accommodate proprietary tools, which can be installed in secure bays where no one else has access to them. In some cases, a company may chose to open them up after their research is complete, so that other companies can use the tool. The facility will also have specialized tools that are standard to the industry, such as contactless printing, as well as engineers and engineering services to do the develop steps companies need, plus a standard process library so companies do not have to reinvent processes that already exist. Finally, the facility will offer a variety of peripheral services, such as modeling and analytical services, failure analysis, reliability, and certification.

The Ability to Focus on One or Two Process Steps

The initial SVTC center, he said, is focused on wafer-based technologies, with plans for a thin-film center as well. He offered an example from the baseline wafer process to illustrate how the elements of a center work. For wafer-based PV cell fabrication, beginning with surface texturing and repair, the next steps would be dopant diffusion, followed by etch and antireflective steps; metallization to bring the current out; and isolation, test, and sort. Each of these steps requires its own tool. Several weeks ago the company announced an agreement with Roth and Rau for a 30 MW turnkey manufacturing line in the SVTC facility in San Jose, California, and the facility will have these tools. The difference between the SVTC facility and a standard manufacturing line from Roth and Rau, he said, is that the robotics will allow the user to run the standard baseline process, producing the desired cell efficiency, but will also allow wafers to be diverted after each tool, so that they can be processed on alternative tools. "That's where innovation occurs," he said. "That means you don't have to build, maintain, and run the tools that are the standard parts of your process. For most wafer-based development, a company innovates in one or two process steps, and the rest are standard."

Dr. Empedocles said that a common question was whether appreciable innovation was being done in wafer-based technology. He said that when he looked closely, he was surprised at just how prevalent it was. He said that innovation starts at the most basic levels of wafer creation, with alternative types of feedstock, surface texturing and repair. It goes on to include new tools, printing, types of junction, surface coatings for antireflection, and types of metallization in architecture and processes. "At every step people are innovating," he said, "and our process lets a customer do all the normal steps and then one proprietary step or two. And for most cases that works."

Creating a Manufacturing Culture and Expertise

Dr. Empedocles said that their goal was to promote manufacturing culture and expertise. Many of the center's staff have manufacturing experience, so that synergies with NREL's PDIL come naturally. SVTC currently runs 52 materials through the CMOS fabs, rather than the standard 12, and have never had a contamination problem between customers.

He returned to the question of IP ownership, giving the philosophy as, "Your IP is Your IP . . . Always." He said, "Coming to work at SVTC should be the same as working in your fab. You should be able to bring your IP into the fab, work with it safely, and leave with it when you're done. Over eight years we've built a reputation for IP security, even in the extremely paranoid field of PV."

Easy Access to the "Rest of the Process"

Finally, Dr. Empedocles reviewed the types of customers who might benefit from the SVTC center. "It isn't just about cell makers," he said, "it's about the entire industry. Obviously, cell makers are the primary beneficiaries, but we will also support new feedstock makers and consumables makers. If you're going to develop a new conductive ink, you need to qualify it and get the data you need to sell to the industry. A lot of people are trying to do that, but doing it without access to the rest of the process is very difficult."

Getting process feedback from another company's process line that you don't control is also difficult, he said. "Access to modified cells, to accommodate new panel architectures and assembly processes, is really important. Where can you go to get an industrial supply of modified cells? We can provide that and help you make the modifications you need." SVTC provides an environment for control and feedback systems for manufacturing, along with the needed tool set and baseline process. "Working with the SVTC team gives you the ability to learn how to become a manufacturing expert," he said, "so that when you leave, you're ready to do it on your own."

He concluded by reviewing the SVTC timeline. The company had had its facility on hold for some time, but had just announced it would commence operations with the new 30 MW line in San Jose. The tools would be installed in the next quarter, with customers expected by the end of the 2009, and full line operation and services that will be brought up in phases starting in early 2010.

He closed by summarizing the benefits of the SVTC process. "There is faster start-up, because you don't have to build a fab, and faster development, because you can leverage the expertise of the center. There is no up-front capital expense and significantly reduced operating expense, because most companies only use 10-15 percent of their development line's capacity. With us, you pay for just the 10-15 percent you need. You still retain that hands-on development, IP security, and independence. Our goal is to allow companies to focus their resources, cash, and expertise on their unique innovation. Let us provide the rest and get you to market quickly."

INDUSTRY-UNIVERSITY PARTNERSHIP FOR PHOTOVOLTAIC TECHNOLOGIES

Nolan Browne
MIT-Fraunhofer Center for Sustainable Energy Systems

Dr. Browne began with a sketch of the parent Fraunhofer Gesellschaft in Germany. It takes its name from founder Joseph von Fraunhofer (1787-1826), a Munich researcher, inventor, and entrepreneur. Today it is a large semigovernmental research facility with 15,000 employees, mostly scientists and engineers, and a research budget of $2 billion. As one of world's largest nonprofit contract research organizations, it works in all fields of applied research.

Fifteen years ago, it extended its model to the United States, where Fraunhofer USA developed centers in six applied fields: automation, coatings, digital media, lasers, software, and vaccines. The six centers have 200 employees and a $45 million operating budget.

Combining Basic with Applied Strengths

The MIT-Fraunhofer Center for Sustainable Energy Systems (CSE), based in Cambridge, Massachusetts, is its newest venture, an alliance between the two research institutions. It combines the more basic strengths of MIT with the very applied strengths of Fraunhofer. The new lab has two primary foci: Solar PV modules and building efficiencies. "We find that these are two areas where we can make dramatic differences over a five-year period," said Dr. Browne. "Today I want to talk about how to form these university-industry partnerships, because I think that it leads to tremendous innovation."

In operation, the CSE begins with start-up ideas from MIT, national labs, or other sources. The group takes these ideas from modeling to design and has a prototyping unit that can build a technology, as well as an incubation unit to begin business development. "Our mission," he said, "is to help grow these ideas to the point where a VC is ready to start funding."

He said there was a great need for such industry-university collaboration in the field of PV, as well as for nonprofit applied PV research centers. "In the past," he said, "this lack has led to slow or premature commercialization for some technologies. Without a smooth handoff, you can generate unrealistic expectations in the market. If you think of compact fluorescent lighting, electric cars, and some other good ideas, with sound technologies, they risk being pushed into the market too quickly. This can slow them down for a long time." He said that the lack of collaboration could also lead to misallocation of resources, when commercial investments made prematurely. "You're asking the company to make money before it's developed the technology far enough. This means that promising technologies can fall by the wayside. It means we're funding fewer ideas, and not making the most efficient allocation of capital."

Constraints That Limit University R&D

Dr. Browne suggested that photovoltaic R&D is artificially limited at the university level by constraints such as proprietary processes and national security issues with dual-use technologies. Also, universities lack the equipment needed to prove out ideas at the industry level. "Ultimately," he said, "universities are all

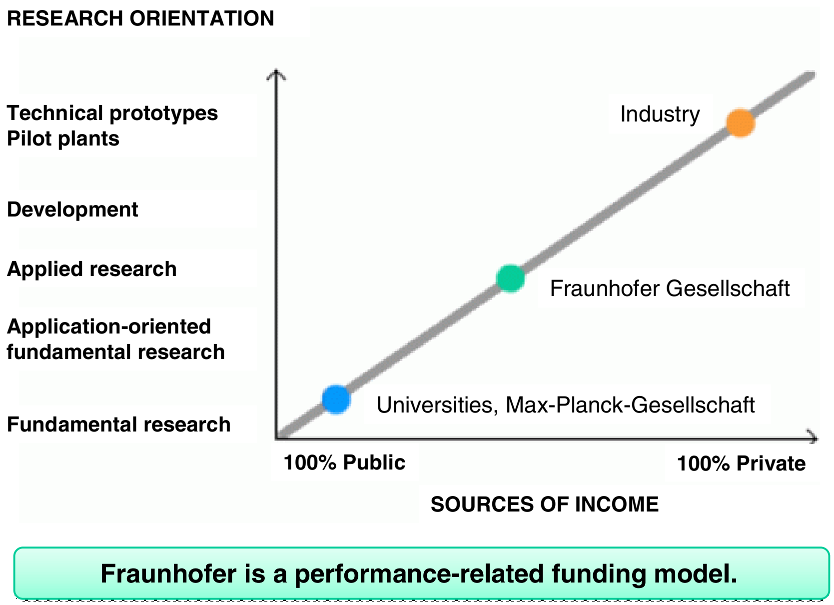

FIGURE 12 Fraunhofer's place in the R&D ecosystem.
SOURCE: Nolan Browne, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

but excluded from all but the most basic PV R&D. If we want to help leverage the talent base and investment made in higher education, we have to bridge that gap. We feel that unleashing it will yield major progress."

The first reason universities are excluded, he said, is confidentiality. "This is hard to maintain at the university," he said. "Universities are more open, and it is hard to assign responsibility for disclosures. Generally, this makes a company uncomfortable. There are also national security concerns, like ITAR."[10]

The second problem, he said, is resource mismatch. Aside from the equipment issue, university-sponsored research tends to be "a little inflexible." That is, it may be difficult for an industry partner to work within the normal academic schedule of a graduate student. "You have to carve out some work that is thesis-sized, or about five years long," said Mr. Browne. "It can start only when the graduate student gets there, and it ends when he graduates. This puts some friction into the system."

[10]The International Traffic in Arms Regulations can affect university research activities because it prohibits noncitizens from having access to ITAR-protected technologies or data.

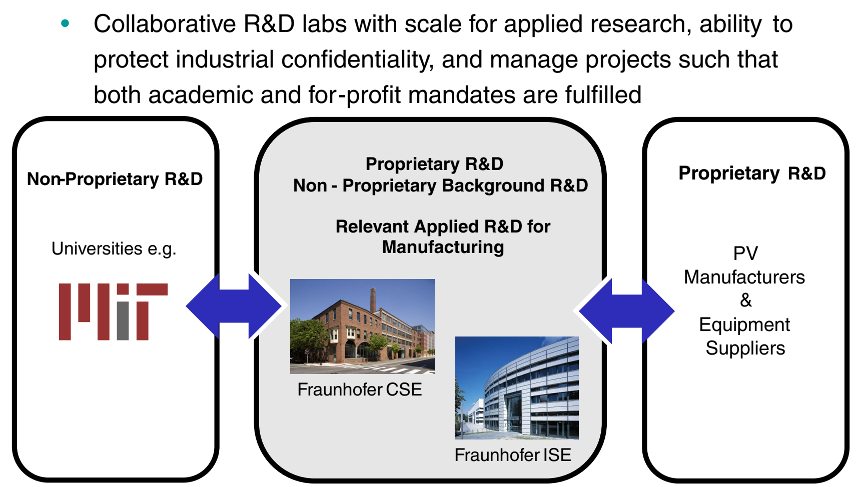

FIGURE 13 Designing the university-industry interface.
SOURCE: Nolan Browne, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

Problem three is "mission mismatch." The issue of publication is central, he said. "There's an extreme difference. MIT or any university would prefer to publish. An industry would very often prefer not to."

Dr. Browne said that the Fraunhofer system removed much of the inter-institutional friction. "We want to bridge the valley of death by linking research to both sides of the valley," he said, "and can accommodate both their needs." In Germany, there are three sectors: industry, a private, for-profit entity; the universities; and the Max Planck institutes, which are primarily public.[11] Fraunhofer gets 30 percent of its income from public sources. It is designed to be "an aggressive applied research lab," he said. "We have to go out to industry and ask them, what do you need? If industry is not interested in paying that other 70 percent, we have to cut staff. So it forces us to be clear about our mission."

In Fraunhofer USA, he said, a university aligns with a Fraunhofer center. In the case of MIT, the scientific director has a faculty position at MIT. There is a professional team, internal to Fraunhofer, which allows in-house research that is not part of the university, including the confidential or ITAR research. A large body of work comes from students who do their thesis work for the university in the CSE laboratory. To accommodate this, the center has three sets of labs:

[11]The Max Planck Society for the Advancement of Science, founded in 1948, is an independent nonprofit association of nearly 80 German research institutes. About 84 percent of its funding comes from the federal and state governments.

confidential labs, shared labs, and open labs. This division, he said, is based on the German model.

The Challenges of the German Model

There are challenges, he acknowledged, in bringing the German model to the United States. "My job over the last year has been to adapt it," Dr. Browne said. First, they forged an MIT-Fraunhofer framework agreement between the two presidents. This addressed the problems listed above as follows:

- Confidentiality concerns: "Fraunhofer controls the terms of how the labs are run," he said. "Some research is more open and can be published; other research is confidential and won't be published. The client agrees to all this. This helps us determine how to segment a project into nonconfidential and confidential components. Often what you need to keep secret is just 25 percent, the 'secret sauce'. The trick is to break up a project and manage it so you can leverage university resources while keeping certain parts confidential."
- The resource mismatch: "We basically identify how to share the R&D resources across both institutions. We have a joint R&D template that we use when we go out as to win contracts from industry, and our work with industry is a joint venture."
- The mission mismatch: "We as a partnership can provide the flexibility necessary. We preserve the educational mandate of the university while giving industry what it needs."

Different Tuition Structures

Several key challenges remained, Dr. Browne said. One is the difference in tuition structures. In Germany, students can work in a Fraunhofer lab without cost to the lab. "In the United States, universities see a student as a profit center. They're paying $50,000 a year to have that graduate student and they need a return." The center addresses this through a Fraunhofer-MIT seed grant program. Students are funded jointly to work in the Fraunhofer lab and earn their Ph.D.s there.

Second, universities must learn to accept relationships with intermediary institutions. In Germany, this is not a consideration, because Fraunhofer has existed for 60 years and works with all major firms. For the United States, the new model will require "some success stories" to establish its reputation.

Third, the Fraunhofer model was set up to work with medium and large companies, largely because there are few start-ups in Germany. The United States, by contrast, counts on start-ups for much of its innovation, especially in the Cambridge area. The center will have to develop the custom of interfacing with start-ups.

Dr. Browne said that policy makers could help support this model by providing industrial scholarships to pursue this kind of academic research. "There is currently a bias in universities against applied research," he said. "The intermediary model could change the whole paradigm.

He also said that just discussing the model could encourage more universities to engage with intermediaries. If applied research capabilities were recognized as desirable for winning government grants or publishing papers, for example, professors would have more incentive to work with such laboratories.

He summarized by saying that the direct interfaces between university and industry can be challenging, but that it is critical to do and "will be very rewarding." By addressing the confidentiality and research mismatches, he said, "the intermediary institutions can unlock the university resources and support industry." U.S. policy makers could help develop this model further by addressing the tuition problem and encouraging universities to pursue the partnerships. "In the future," he said, "to grow these things out, there has to be a sizeable investment from the U.S., because this is the market it's going to serve in the long run."

THE SEMATECH MODEL: POTENTIAL APPLICATIONS FOR PV

Michael Polcari
SEMATECH

Dr. Polcari began with an overview of SEMATECH, of which he is president and CEO. It is a member-driven organization of semiconductor companies, he said, that share the goals of technological innovation and manufacturing productivity. It approaches these objectives by addressing questions throughout the supply chain.

He said that the decreasing cost per function was another way of looking at Moore's Law. It combines the technology challenges of increasing the number of transistors per area with the productivity challenges of decreasing the cost per area. In the past, he said, driving technology innovation had come mostly from shrinking lithography dimensions, but the emphasis at present is shifting to new materials and device structures.

The Goal of Accelerating Commercialization

A key objective of SEMATECH, Dr. Polcari said, is to accelerate the commercialization of technology. This does not necessarily mean the invention of new devices or structures, but putting in place the infrastructure that allows the semiconductor industry to practice those things: accelerating tool development and materials development, understanding whether all the elements of a technology are ready, and making sure the ones that are lagging are being driven. "In the end," he said, "that is what accelerates the commercialization."

Reducing the cost per function is actually done by attacking productivity challenges, he said. For semiconductors, this can be done in two ways: to increase the area size, which happens about every 12 or 13 years, and to reduce the cost per wafer. "There are a lot of analogies for PV in what we do to drive down costs in semiconductors."

The SEMATECH Story

Dr. Polcari turned to the background of SEMATECH. In 1987, he said, essentially two proposals came out of government and industry (from the Defense Science Board and the Semiconductor Industry Association) that coalesced in driving an organization with the features of SEMATECH. These proposals came out of the sharp loss of market share to Japanese companies. By working together, the two sectors were able to set up SEMATECH as a national, not-for-profit consortium to address the problem.

At the beginning, all participants understood there was a problem, but there was no consensus on what it was. About a year was spent in discussing what the group should try to fix, beyond trying to regain market share.

SEMATECH was finally established as a joint industry-government partnership, with each contributing $100 million to the effort. In hindsight, some of the factors that led to success were

- Commitment from top-level executives, both in government and industry, to take this step. Without that commitment, he said, nothing would have happened.
- Industry leadership: This was vital because only industry could identify the problems they needed to solve.
- A clear precompetitive mission: The group needed to work together on the U.S. technology infrastructure.
- Achieving a broad representation of partnerships from industry and government, involvement of the national labs, including NIST, and leveraging of government funds.

A central factor leading to success, he said, was that SEMATECH was member driven. Members decided what the problems were, set the research agenda, and apportioned resources. "It is essential that the people whose problems you're trying to solve are the ones who decide what you work on," he said.

Some Successes of SEMATECH

Dr. Polcari listed some of the successes of the strategy. SEMATECH helped the industry to achieve parity and regain the market share from Japan during the late 1980s and early 1990s. Since then, he said, the U.S. industry has been healthy.

An important mechanism behind success, he added, was the semiconductor roadmap, a guide to plans and actions. The roadmap coordinated the industry through several multibillion-dollar transitions:

- Developing next-generation patterning, using advanced technology development, equipment, and materials (193nm dry immersion and EUV).
- The transition to the next wafer size, providing materials readiness and equipment performance metrics.
- Screening and characterization of new materials, including more than 350 material systems for high-k metal gates and more than 500 low-k materials.

"This has allowed members to share not only cost but risk," he said. "They can see all the results and decide which are the few they want to pursue."

He described several other benefits of the program. One was to help member firms by finding the "dry holes. Understanding those things that aren't going to work can be as important as success," he said. Also, the organization itself attracted other businesses, creating jobs first around its headquarters in Austin, Texas, and today around Albany, New York, near the new College of Nanoscale Science and Engineering. This attraction has even led to the name "SEMATECH effect" for the process of high-tech job creation. Finally, members have seen significant return on the investment in the consortium. The average member's ROI has been calculated as about a 5.4 to 1 for what they invest in the form of dues and other payments.

Increasing the Size of the "Ecosystem"

Dr. Polcari noted that the reach and size of the SEMATECH "ecosystem" has grown appreciably. "With a large and diverse number [of semiconductor manufacturers] you can set an agenda driven by a consensus. People know this will result in something the industry will utilize." In addition to increasing the number of semiconductor manufacturers, the consortium has added equipment and materials suppliers, who help set and drive an agenda that interests them, broadening the reach of the group and helping it to be more productive. One advantage of this breadth, he said, is that it convenes a large network around individual problems and brings solutions more quickly. It also facilitates partnerships with universities and government labs, especially NIST and Lawrence Berkeley National Laboratory.

The heart of the program, however, is manufacturing productivity, which is addressed on both strategic and tactical levels. Strategically, companies need to know the most productive architecture for a factory of the future. Tactically, they need to continuously reduce costs in today's fabs and manage ever-increasing capital, manufacturing, and R&D costs. There are also sustainability challenges, such as how to reduce the industry's environmental footprint, find safer materials, and conserve consumables. "All of these challenges," he said, " are also relevant to photovoltaic technologies."

The Importance of Benchmarking

The way SEMATECH works on those challenges, Dr. Polcari said, is by doing "a lot of benchmarking, where members request data and than have to share it in nondisclosed ways." They also have a Manufacturing Methods Council that develops and shares best practices, aided by equipment productivity teams, where members identify common problems on a tool or tool set and work together with a supplier. "This turns out to be more efficient than working independently. We also run workshops and 'councils' to address common problems, such as finding second sources of spare parts."

He discussed benchmarking in more detail because of its importance to members. SEMATECH has developed a system of "blind benchmarking" in which companies have developed 50 metrics they share with each other on a nondisclosed basis. Each knows which data refer to their own company, but not which data refer to other companies. Once the data they want are collected, members have to share data to get data back. Some of them ask for benchmarking on mundane things, such as the cost of electricity. One member, after seeing the utility bills of other companies, approached their power company, demonstrated that their rates were not competitive with those of other companies, and won a reduction. The benchmarking is useful for everybody, even without specific attribution, because every company wants to improve productivity every year. "When you can see that your 10 percent improvement still leaves you behind by 50 or 60 percent," he said, "you realize you have to do something different."

He also cited one company's experience in saving money through energy conservation. In looking at the performance of a particular tool, they found that most of its power was consumed by the pumps. When they realized how much energy they could save with the pumps in idle mode, they identified which pumps could be idled at various times. They were then able to work with equipment suppliers to adjust the idle modes for maximum efficiency. This information was made available to all members.

Dr. Polcari concluded by saying that a review of the history and present activities of SEMATECH was likely to yield numerous practical lessons for the photovoltaic industry. He said that the SEMATECH model had application not only in technology development but also manufacturing productivity and collaborative strategies that could benefit all participants at the precompetitive level. "Certainly our experience in organizing and recruiting consortia has helped to bring a lot of cost reduction to the industry."

THE SEMICONDUCTOR RESEARCH CORPORATION (SRC): A PROVEN MEANS TO FUND RELEVANT RESEARCH

Larry Sumney
Semiconductor Research Corporation

Mr. Sumney began with a review of Semiconductor Research Corporation (SRC), which was founded in 1982. The immediate impetus for forming SRC was a 1981 Hewlett-Packard study of the reliability and yield of integrated circuits being manufactured at that time. This study concluded that integrated circuits (ICs) produced in the U.S. were inferior in reliability and yield to those from many other countries. A number of reasons were cited: Industry did not have sufficient research capacity; the federal government was reducing funding for and, therefore, universities were not interested in silicon-based IC research. "It was a challenge to generate a pool of faculty with experience in manufacturing and design," said Mr. Sumney, "or to find educated students familiar with silicon ICs."

The research needs seemed to be greater than any single company could address alone. In order to reduce cost and risk of the needed research, industry decided to organize, and pool their resources. This was not an easy step, because the industry was—and is—extremely competitive. Still, they decided they could collaborate on precompetitive, generic research that would help all of them without jeopardizing their competitive positions. They decided to form and join the Semiconductor Research Corporation.

Partnering with Government and Academia

By around 1986, it became clear that SRC would be more productive if all three societal sectors were included—industry, academia, and government. "Looking to the government to leverage the investment of industry has been a major key to ongoing success," Mr. Sumney said. "And the culture in universities has totally changed since SRC started. We now have university centers that collaborate with other universities. The outcome of this collaboration is excellent, relevant research results."

One measure of success has been the publication rate. For example, Mr. Sumney said, in 1981, universities produced only 180 publications on silicon topics, and industry produced 304. In 2008, universities supported by SRC produced 2,226 publications on silicon research. "This has had a tremendous impact over time," he said. "Each paper has one or more graduate students associated with it, many of whom are hired later by one of our members. So the valley of death is bridged by recruiting students into jobs in industry where they continue to work on research often related to their dissertation."

Between the Blue Sky and the Market

Mr. Sumney noted that both industry and universities now have long experience with the basic format of SRC. The research activities of SRC are focused between "blue-sky" basic research and early product development. In general, industry is more tightly focused on nearer-term research, while universities have more autonomy and time to pursue longer-term research. The collaborations are all governed by research contracts, with milestones jointly worked out with the principal investigator. "Negative progress is fine," he said; "we just need to know about it. In such cases, the partnership has a choice of either changing direction or allowing the work to continue a little longer. The strategy works out well."

Over the years, SRC has invested over $1.3 billion contributed by members and government; it has supported more than 7,500 graduate students through 3,000 research contracts, 1,700 faculty, and 241 universities. This support has resulted in more than 43,000 technical documents, 326 patents, 579 software tools, and work on 2,315 research tasks or projects. "The task level is where results come from," he said. "These may be integrated into a center, or they may be a single professor and several grad students."

SRC was recently a recipient of the National Medal of Technology "for building the world's largest and most successful university research force to support the rapid growth and 10,000-fold advances of the semiconductor industry." It was also praised "for providing the concept of collaborative research as the first high-tech research consortium, and for creating the concept and methodology that evolved into the International Technology Roadmap for Semiconductors."

Agreeing to Collaborate: A Key to Success

Mr. Sumney reviewed the reasons for SRC's success. The first, and most important, was that competitors agreed to collaborate. "That's key," he said, "and it didn't happen quickly. In our early meetings, you couldn't get anybody to say anything, because they were afraid of giving out secrets. They had to learn to trust. The CEOs first made the decision to do it, but it took a while to trickle down to the technical people. Today this is one of our strongest features—the collaboration that occurs at technology meetings among our members and involving universities. Our strategic ideas now come from our members, and we are a member-driven organization."

Another reason for success was that the research was precompetitive and the IP was shared. The universities own the IP, but they provide SRC members with royalty-free, nonexclusive access. "We make sure there's no blocking IP," he said. "We look at everything in the beginning. It took universities a while to get used to this, but a blue-ribbon panel came up with language on IP in 1997 and 1998, working with the presidents and deans of universities. Since then we've had little difficulty." When selecting research topics, SRC first solicits white papers from the academic research community. If they get 100 to 150 responses, they choose the best 10 or so, solicit full proposals, and work with industry to select the best one or two.

Representing the Whole Value Chain

Because of the way the industry has evolved, SRC represents all parts of the value chain. At the outset, all the members were integrated device manufacturers. Next to join were equipment manufacturers and software providers. Industry began to restructure as fabs became more expensive. Several integrated device manufacturers began to change to "fab-lite" or fabless. Foundries evolved. We now have involvement with all sectors of this evolving industry.

SRC is also accountable to its members, he said. It is evaluated every year by industry members, and periodically by universities. Among universities it is often the "funder of choice," he said, "having risen from second or third to first for many of them. Member companies consistently rate the organization at about 4.5 on a 1-5 scale of value."

Relevance for the Photovoltaic Technologies Industry

Mr. Sumney suggested that the way the semiconductor industry has followed roadmaps and Moore's Law may have great relevance for the photovoltaic industry. SRC began by securing industry agreement on major needs in all areas: devices, processing, interconnect, packaging, and design. "What Moore's Law has done," he said, "is to give the research process a cadence. You try to get from one node, or minimum feature size, to the next as fast as possible. That has served to excite the industry to beat the roadmap, and they have done that. It wouldn't have happened without that expectation or cadence that Moore's Law provides. We feel that for PV, this kind of expectation could also be used, along with a roadmap developed with DoE and others."

He said that SRC had evolved as a family of distinct but related programs:

- The Global Research Collaboration ensures the vitality of the current industry, supporting shorter-term research (a 7- to 14-year time frame) with traditional CMOS technology.[12]

[12]The complementary metal-oxide-semiconductor (CMOS) transistor is used to manufacture most of the world's computer chips. While CMOS chips have become steadily smaller, the International Technology Roadmap for Semiconductors (ITRS) predicts that the size limit for CMOS technology is likely to be 5 nm to 10 nm, which may reached in 10 to 15 years. Researchers cannot yet predict which new materials or techniques will allow the rising performance and shrinking size of computer chips to continue.

- The Focus Center Research Program, with a 14- to 20-year time frame, is focused on breaking down barriers to extend CMOS as far as it can go.
- The Nanoelectronics Research Initiative seeks to identify the next information element beyond CMOS.
- The SRC Education Alliance (SRCEA) is a private foundation that provides fellowships and scholarships and supports various programs in physical science and engineering education.
- The Topical Research Collaborations (TRC) is a new SRC research vehicle to apply the collaborative model to new technical areas. One is "The Energy Research Corporation" or TERC, which has a program in photovoltaic research. This will begin with an effort at Purdue University to model and simulate different PV structures to assess their viability. Members currently include Applied Materials and First Solar. A second TRC, "National Institute for Nano-engineering (NINE)," is a joint program with Sandia National Laboratories and interested member companies such as Intel, Exxon Mobil, and Goodyear.

Applying the Collaboration Model

Mr. Sumney suggested that the collaboration model developed for ICs could easily be applied to new technical areas, such as PV. "One reason we're working on such things is that they bring SRC new members we normally wouldn't

	1 Global Research Collaboration	2 Focus Center Research Program	3 Nanoelectronics Research Initiative	4 Topical Research Collaboration
Time Frame	7 - 14 yrs	14 - 20 yrs	> 20 yrs	Variable
Technology	Traditional CMOS	Limit of Traditional CMOS	Beyond CMOS	Selected Topics
Purpose	Narrowing options	New options	Revolutionary discoveries	Topic Specific
Industry Participation	✓✓✓	✓✓	✓	✓✓✓
Government Participation	✓	✓✓	✓✓✓	✓✓✓

FIGURE 14 Our four major research programs.
SOURCE: Larry Sumney, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

have. For example, Exxon Mobil would not normally join SRC's semiconductor program as it exists, but it is interested in PV technologies. Goodyear is another example. Existing members such as IBM and Intel are also interested in TRCs. We're hoping that this leads to new innovation, new methodologies for collaboration, and valuable results from the universities."

PV and semiconductor manufacturing share many features, he said, including

- Common materials, such as silicon ingots and wafers.
- Common equipment, such as tools for etching, sputtering, chemical vapor deposition, metrology tools, defect inspection, testing and assembly.
- Common processes, such as wafer handling and deposition of material and coatings on substrates.

He also described potential technology overlaps, such as thin films, flexible substrates, and novel semiconductor materials. And both sectors of manufacturing research focus on increasing efficiencies and reducing costs.

A Consortium, with Industry Taking the Lead

A possible collaborative model for PV manufacturing research would have many of the same features as SRC. It would bring together industry, universities, and government, including the DoE and NIST labs. These would be well positioned to develop roadmap and technology assessments that identify gaps and common challenges; focus on precompetitive research and the underlying technology needs; and make the research results broadly available to all participants.

This would be done through several approaches. One is to develop an "evolved, high-quality Web site" that would make research results available to the industry membership before publication. Another is to build relationships between the member companies and students, including a mentoring program, opportunities for students to deliver papers at technical meetings, and potential hiring sessions with companies. Coordinating research can minimize overlap, leverage government and university work, and increase the efficiency of the dollars spent.

"In summary," he said, "we see collaborative research as being much more efficient than people working on their own." A consortium, can bring the sectors together with government in a PV manufacturing research "ecosystem." Industries take the lead by jointly identifying the most urgent R&D needs at the precompetitive level, and government can inject incentives through co-funding research. "Given the diversity of participants, this ecosystem can be distributed but very coordinated. We see a flow of related ideas and technologies moving in both directions between industry and academia, with government playing a major role."

PV TECHNOLOGY ROADMAPS AND INDUSTRY STANDARDS: AN ASSOCIATION'S APPROACH

Bettina Weiss
PV Group

Ms. Weiss began by defining the PV Group, which had newly emerged from the larger group SEMI, which, in turn, was founded nearly 40 years ago as a global semiconductor industry association. Most of approximately 2,000 member companies represent the semiconductor-manufacturing sector. Over the years, the group has expanded into the fields of flat-panel display and micro-electromechanical systems, and related technologies. During the past two years, it has moved into photovoltaic technologies as well and established PV Group as its global photovoltaic initiative. "PV Group captures the 30 percent or so of SEMI's members that are active in PV," she said, "and provides services and products in the area of public policy, market research, standardization, industry collaboration, education and events"

Unique Challenges of PV

PV presents unique challenges, Ms. Weiss said. The field is "very policy driven," especially in the United States. The industry structure is still not well defined, with a mix of very small to very large companies operating in different technologies and markets and focusing on different manufacturing targets. The industry suffers from deployment bottlenecks and very high logistics costs, especially for transport of modules and panels. "It will be a while before all this shakes out," she said, "and as an association maybe we can lend a calming voice to the fray. We feel we can best address these issues if the industry stakeholders work together."

She said that the PV industry is likely to " benefit tremendously from the chip experience." The PV segment within SEMI has grown significantly, largely because semiconductor and flat panel display equipment and materials suppliers have moved into the PV space, and cell and module manufacturers have joined the discussion and begun to actively contribute and weigh in. "We're supporting those members, and we also see an influx of pure players in the PV industry. The combination of those two has generated a lot of ideas about what has to be done in standards, public policy, and other areas. The end goals for all participants," she said, "are the same: to accelerate commercialization, reduce manufacturing costs, and shorten the path to mass deployment of solar energy to the greater population."

Current Opportunities for the Industry

Ms. Weiss said she would focus her comments on how the PV Group could help expand core competencies in the PV industry. She said that opportunities exist in several key areas:

- Industry standards that reduce cost and spur innovation.
- Industry information that guides investment and planning decisions.
- Industry advocacy and promotion.
- Buyer-seller collaboration on critical issues.
- Developing a greener and more robust supply chain.

"Overall," she said, "it is about effective buyer and seller collaboration, and finding commonalities where we can do more together faster and better."

The PV Group strategy is guided by SEMI's international board of directors and, more directly, by PV Advisory Committees representing equipment and materials suppliers, cell and module manufacturers, and other interests. Because the PV industry is global, an objective is to align U.S. interests, based on global trade conditions and developments. "To build the U.S. industry," she said, "collaboration among U.S. firms is critical, as are global partnerships. We need these to strengthen the U.S. supply chain and bring the 'green-collar jobs' we desperately need." The position of PV Group, she said, is that collaboration between industry and government will improve global partnerships as well as national ones. But available funding now should be directed toward strengthening U.S. manufacturing platforms and their member-driven organizations, including SRC, SEMI, PV Group, and others.

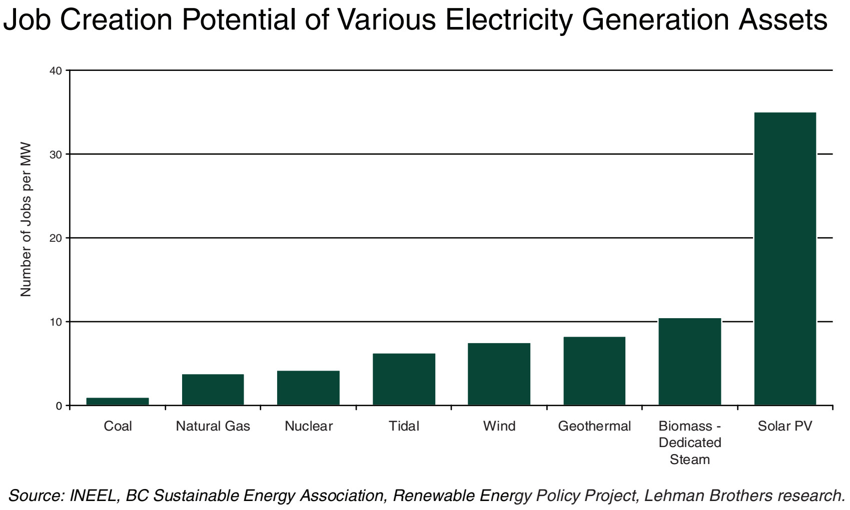

FIGURE 15 U.S. solar job potential.
SOURCE: Bettina Weiss, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

Early Discussions of a Roadmap

Referring to a joint PV Group-DoE workshop held in San Francisco in July 2009, Ms. Weiss noted "an appetite, a readiness" in the United States to develop a domestic or even international roadmap, perhaps modeled on ITRS of the semiconductor industry. The workshop broke into groups represented different sectors of the supply chain, and each was asked to consider three questions:

- What are the key barriers to success in the U.S. PV industry?
- Which ones would benefit from a collaboration approach?
- Would a roadmap be the right tool to do that?

She said that the answer to #3 was a resounding yes, with a unanimous show of hands. She also noted that this should have further validation from the cell and module communities, which were underrepresented. Attendees and others were now considering how to structure, fund, and govern this process.

An Urge to Kick-Start Standards

The first topic that PV Group's members wanted to kick-start was standards, she said. "We know from the ITRS experience that many hundreds of standards and safety guidelines have been generated because of the semiconductor roadmap and the information it provided." These standards helped improve interfaces, tool-to-tool communication, process and materials efficiencies, operating risks, environmental contamination, and other parameters.

She gave a short history of SEMI, which was established in 1970. Its standards program was established three years later, primarily to address the issue of wafer specification. There were then about 2,000 wafer specs in use, she said, and the industry saw that this was causing too much waste at a time of silicon shortage. "This propelled us into the standards business," she said, beginning with an agreement to use a single size of wafer. Standard setting has evolved over the years as members have moved into other areas, such as flat panel display, MEMS, and now PV.

For PV, standards were the first initiative that SEMI members wanted to work on. She said that about 400 people were working on this globally, beginning with a PV Standards Committees formed in Europe in 2007, followed by a group in North America later that year and Taiwan and Japan in 2009. SEMI has published almost 800 documents on test methods, specifications, equipment and materials safety, and other topics. The PV Group had concluded that about 64 out of SEMI's 80 major categories were applicable to crystalline silicon-based PV, including hundreds of specifications and test methods, so that existing semiconductor standards can be applied directly to PV. "The PV industry can derive immediate benefits from using existing standards now," she said.

Moving Up a Steep Learning Curve

Among priorities and gaps, Ms. Weiss said, were automation, environmental health and safety (EHS), and the conversion of older facilities, such as 200 mm fabs. All could benefit from dissemination of standards and best practices. She emphasized the need for further discussion of the EHS challenge. "I think we're dealing with a lot of really nasty substances in the manufacturing line," she said. "We need to talk more about how to reduce volume, make them safer, develop better emergency response systems, the end-of-life cycle, recycling, and helping business take back its tools so that nothing ends up in the ground or in the air."

She concluded with the "message that the learning curve we are all on is a very steep one, but it can be accelerated by collaboration. We invite all of your organizations to talk to us at PV Group. We're willing to help, and we have national as well as international arms we can utilize."

DISCUSSION

Comparing Semiconductors and Photovoltaic Technologies

Dan Josell of NIST drew a contrast between the role of SEMATECH and the condition of the PV industry. With SEMATECH, he said, "We were starting with a technology that was top of the line, with high profit margins. Here you're starting with something that's basically a commodity. Energy is already provided by half a dozen dominant technologies, none of which is solar. So are there differences in trying to get together industries that are trying to compete on margins where there will soon be many others on these same price lines."

Dr. Polcari replied that there are memory suppliers who collaborate today, including Toshiba and Samsung, both of which work with IBM. "The question is, can you collaborate on things early on that can save dollars on manufacturing," he said. "If there are areas they all need to work on, there's no point in everyone working separately unless there is a competitive edge. There always seem to be areas like that, such as vacuum systems and air handling. These may not be the best examples, but the right ones will likely come out of roadmapping."

Mr. Sumney said he agreed, using the example of Micron, a commodity memory manufacturer that has been involved in SRC's Focus Center Research Program for 12 years. "We're holding a memory workshop in October," he said, "and they were one of the first companies to sign up. So I see that the commodity manufacturers are getting enough out of this to be very interested."

PV as a Commodity Industry

Dr. Empedocles noted that PV has lower equipment requirements than the semiconductor industry, which indicates both that "it's more of a commodity industry" and is also an industry that requires a much smaller investment. He said that SVTC Solar had met with more than 100 PV companies, and their largest concern was the investment community's reluctance to act during the early months when there are still uncertainties about "whether the technology will be manufacturable." Even though the funds required might not be large compared with the semiconductor industry, they are large for individual PV companies. "This is a real barrier that a shared facility can help with." He noted that standardization would be difficult while the industry is divided into the two categories of thin-film and wafer technologies, but that the industry would probably need to standardize more as it matures.

Mr. Engardio recalled the earlier accounts of how fast the industry as a whole is moving down the cost curve. "I guess the question is, could this be accelerated through collaboration."

Dr. Wessner said it was important to note that both joining and contributing to earlier consortia had been voluntary. "If there's willingness to join, there is clearly a perception of common good," he said. "But I think we have to be careful talking about commodity industries. Oil is described as a commodity, but as Mexico and Iraq demonstrate, it's difficult to maintain production without the latest technologies." He noted that Micron is a commodity company whose production excellence enables it to compete globally—and yet they choose to participate in the SRC. He said it would be interesting to know how well such a company would do without access to these institutions.

Panel V

Building a Solar PV Roadmap

Moderator:
Clark McFadden
Dewey & LeBoeuf LLP

Mr. McFadden opened the panel discussion by commenting on the controversial nature of a solar PV roadmap. Although the concept seemed straightforward, he said, it was commonly misunderstood and even resisted by some participants. He welcomed the presence of a "knowledgeable and experienced" panel to examine the function of roadmapping, and whether it can be useful for the PV industry.

BUILDING A SOLAR ROADMAP

Ken Zweibel
George Washington University

Professor Zweibel said that the purposes of building a roadmap for the photovoltaic industry had been well stated: to accelerate PV progress to meet critical national needs, do so in a cost-effective manner, and reduce deployment risks. "If we're going to be deploying terawatts of renewable energy," he said, "including terawatts of solar energy, we want to do that as robustly and cost-effectively as possible." And a roadmap capable of guiding robust deployment, he said, would need to address both technology push and market pull.

The Challenge of Setting Goals

Professor Zweibel began with what he saw as a misunderstanding about setting goals for PV research. Within the federal government, he said, much of the PV R&D is "futuristic," in the sense that it is focused on the next generation of technologies. The organizations supporting this "blue-sky" and "transformational" research include the National Science Foundation, and the Department of Energy's Basic Energy Sciences and Office of Energy Research, and DoE's ARPA-e. The DoE's EERE program, by contrast, had long supported the technical work in PV that is not futuristic, work that has led to a multibillion-dollar industry in the U.S. and to world leadership in some technologies.

Here, he said, is a disconnect. "Some people are still fighting the last war," he said, "answering the questions from 5, 10, and 15 years ago. To them, PV is an industry that is not cost-effective. They are not seeing that the goals in their minds, like a dollar a watt cost per module, have already been achieved. We're in a world where things have changed. Some of us are making choices to focus on futuristic things when they should be enthusiastic about the out-of-the-box successes of existing technologies." He said that one reason for this disconnect is that PV is such a fast-moving field; the technology has progressed even as people have worried about it.

Toward a Stair-Stepped Program

Professor Zweibel also saw a danger in placing too much emphasis on the "magic" of start-ups. "We're still in the belief phase, where start-up work is so wonderful and it's all going to work overnight," he said. "That just hasn't been true historically." The lesson of 25 or 30 years of work in this field, he said, and in other fields of technology, is that even well-funded start-ups seldom have immediate commercial results. "We should be doing a stair-stepped program, where we have faith in today's technologies, good understanding of their potential, and room for other technologies as they mature. We should not abandon key technologies just because they are commercial, because they still retain huge knowledge shortfalls. We are just getting on the first step of the stairs with leading PV options like CdTe, CIS, and even crystalline silicon."

He suggested, therefore, that the first solar roadmap be designed to help the Congress, DoE, and the new administration understand the immediacy of the solar opportunity in existing technologies. These technologies have already proven they can reduce costs steadily to levels appropriate for cost-competitive electricity. "If we're going to be doing futuristic work," he said, "we should acknowledge that those ideas will take another 20 years, and we should plan accordingly. We should not act as if all these good ideas of the last 30 years didn't occur and are not important."

Costs Really Are Coming Down

Turning to actual costs, Professor Zweibel reminded participants that "generation one and two" technologies—silicon and thin films—were going into large systems at $4 a watt. A few years ago, they cost $6 a watt, and a few years before that, $10 a watt. "Those are phenomenal cost reductions," he said, "and the goal

Organization	Style	Purpose	Timing
NSF	University "blue sky" and "transformational"	Education and a new generation of solar technologies	Futuristic
DOE Basic Energy Sciences, Office of Energy Research	National Lab and university "blue sky" and "transformational"	Education and a new generation of solar technologies	
DOE ARPA E	Cross-cutting "transformational"	Bright ideas and a new generation of solar technologies	
DOE, Energy Efficiency and Renewable Energy, Solar Energy Technology Program	Applied and goal oriented (Corporate, university, National Lab)	Progress with existing solar technologies	Now

FIGURE 16 Government R&D 2009.
SOURCE: Ken Zweibel, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

of $2 a watt seems certain. I want to bite my tongue when I say that, but enough people have said it that it seems to be coming for a big installed system." He mentioned advertisements by solar installers already offering $3 a watt at installations of megawatt size, and said that progress to $1.50 or even $1.25 a watt seems possible with existing technologies.

"I want to say that 30 years ago, when we at NREL started developing these cost analyses, we were regarded as stupid and naïve when we said that $1 a watt systems did seem possible. I want to tell you that we were just naïve (due to the time and money it would take to get there). The fact that we might be getting close to $1 almost stops my heart, it really does. But it seems like it can really be stated now, after 30 years."

Generation two, he went on, would include both thin films and concentrators,[13] both of which are at or near commercial status. Generation three, he said, should be regarded as tools that eventually cut costs in half again. "We should think about systems at 50 cents a watt and below; we should make it a hard goal, not a duplicate of the goal that is already happening. Also, new technologies can be integrated into existing systems. We already do this with nanoparticle inks and

[13]Concentrating solar power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam.

we have for 15 years. We can do special nano absorbers in these materials to raise their efficiencies. But expecting that some kind of weird thing is going to come out of the blue and make everything different—that's naïve again, for the same reason—time and money." Deployment of third-generation technologies could be 25 to 40 years away, he said, though it will happen. But more importantly, "we do not need them for PV to become cost-competitive."

A PV Roadmap with Two Levels

With these considerations, Professor Zweibel suggested a PV roadmap with two levels. The main funding would go to the first level, and would include existing EERE-supported commercial technologies with proven potential to make low-cost goals. These include crystalline silicon PV, cadmium telluride, copper-indium-selenide (CIS) alloys, gallium arsenide multijunctions for concentrators, and thin-film silicon. The second level, with much less funding, would be a smaller category of post-proof-of-concept cell results for third-generation options like plastic cells whose progress has been sufficient to attract initial private support. The content of this category would be outside the EERE portfolio and would change steadily, which he called "important for program evolution." But this support should not outweigh the applied R&D support of the leading commercial technologies, because these are just starting their cost reduction phase, where such funding would be highly leveraged. "Society expects us to succeed with these technologies, not dither away the opportunity."

He suggested several points as a "technical roadmap philosophy." Cost goals, typically in cents per kilowatt-hour, had always focused first on module development, because modules and their efficiency account for most of the system cost. This goal is currently about five cents/kWh. Below the module, he said, was the secondary cost goal of about a few pennies per kWh for the inverter and BOS designs, grid integration, sustainability, ESH, and other less-technical sectors. A significant nontechnical goal, he said, was to reduce the procedural delays prior to actually putting PV in the ground. It can take 18 months or so in immature markets like the U.S. for the permitting process, he said.

In addition to addressing cost objectives, he said, goals should be "high-level and light-handed." They should include efficiency, cost per unit area, and reliability, and reaching them should "allow creativity just below the top-level goals. Don't tell people how to do things, ask for their best ideas. Be aware of the breadth and patience needed to achieve them, not the immediacy of the expectations of less-experienced evaluators." He said that a roadmap process should include the element of continuous improvement and criticism. There should be open meetings, he said, where "people could throw brickbats at the current roadmap. Instead of defending ourselves against new ideas, we should enjoy and incorporate them. This could prevent the roadmap from becoming onerous, because there would always be opportunities to change it."

Identifying Pinch Points Along the Critical Path

Any good roadmap should identify not only the critical path, Professor Zweibel said, but also key "pinch points," whether for a module technology, a BOS, or permitting procedures. These can represent a consensus within the technologies. For example, for cell efficiency, pinch points might be voltage, doping, and contacting, as in CdTe PV. For a module, they might be interconnection resistance and maximum active area. Once the roadmap is laid out, the funding organization can develop an RFP by understanding both the pinch points and capabilities necessary to meet them. The RFP would go nationwide to universities, national labs, and companies.

In conclusion, he said that the first—and most important—high-level roadmap should be one that the DoE, the Obama administration, and congressional committees would be able to understand, "especially in regard to the message that we do not need to start from scratch with revolutionary technologies. We can succeed through incremental progress on the technologies we have now. That is the crucial question to get clear, because right now we are spending a lot of time and effort on other things."

The second roadmap would be a high-level technical roadmap, he said, which will be continuously improved. Its purpose is to give guidance to groups that want to respond to critical problems and pinch points. This roadmap, or something like it, is needed to reenergize near- and mid-term government-funded research. "I think that many of us who do this research think the government really just wants far-out ideas. If you go talk to 100 PV scientists who helped make this industry what it is today," he concluded, "they will say this: that the government just wants far-out ideas. I believe that is because the key decision makers are not sophisticated in PV and have not been provided with the most critical insights about past successes."

OBSERVATIONS ON BUILDING A PV ROADMAP PANEL

Doug Rose
SunPower

Dr. Rose offered an overview of the points he would make:

- First, he agreed with Professor Zweibel's message that PV is poised to become a significant source of cost-effective renewable energy without needing "some far-out, next-generation technology."
- Second, he believed that a SEMI-like equipment technology roadmap would not be appropriate for PV.
- Third, there are many ways the DoE and federal government have and can continue to accelerate the growth of the PV industry and thereby help the United States in both the near and long term.

He began with the observation that the PV industry now is about where the semiconductor industry was in the mid-1980s in annual sales. "That was when a lot of the roadmapping was done to move the industry ahead," he said. "But some of that analogy falls apart. One difference is that PV is already a much more manufacturing-intensive industry than integrated circuits (ICs)." More than a year ago, he said, the crystalline silicon (c-Si) PV sector used more silicon than the entire IC industry, and it has grown rapidly since then.

A Shared Ability to Lower Costs

Semiconductors and PV, however, have shared an ability to drive costs down. Dr. Rose showed a graph of c-Si cost beginning in 1979, when it was $33 a watt for a module. After declining steadily, cost increased briefly around 2007-2008 because worldwide demand rose faster than the output of the polysilicon industry. A healthy consequence, however, was that it caused the industry to be more efficient with silicon use and be innovative and drive down cost in the balance-of-system portion. Now that the cost of polysilicon is dropping again, the industry is ahead of even recent price projections (it was $3.17/W in 2008 and is expected to reach the $1.40/W price well before the projected time of 2012). "At current prices for c-Si," he said, "we can drive the levelized

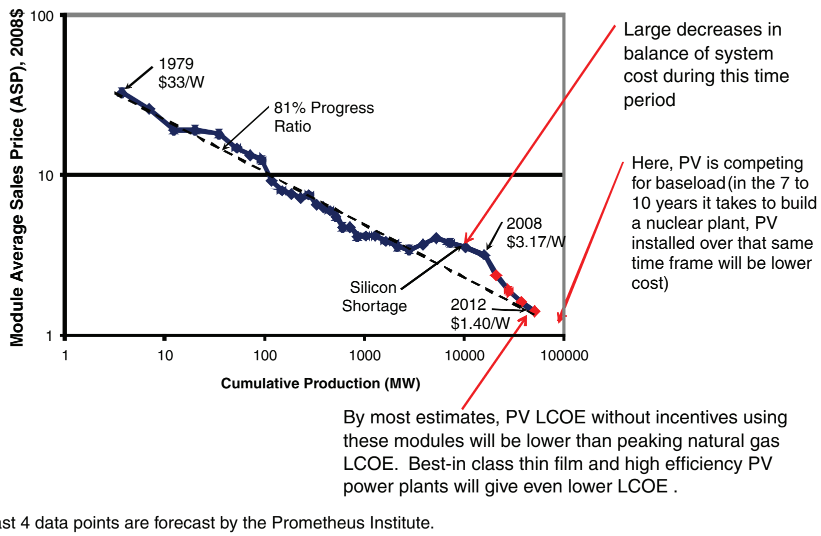

FIGURE 17 c-Si PV industry back on cost learning curve.
SOURCE: Doug Rose, Presentation at July 29, 2009, National Academies Symposium on "State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States."

cost of electricity lower than peaking natural gas plants and then be competitive with even base load plants."

Turning to technology and equipment roadmaps, he acknowledged that there is much for the PV industry to learn from the successes of the IC roadmaps, but he was cautious about applying lessons directly. Among some "very big differences" between the PV industry and IC industry, he said, was that the IC industry had a natural split of intellectual property between processing and chip design, and there was a shared interest between those two groups of companies in geometry shrinks and other advances that came on a predictable schedule. "There is no analog to that in PV."

Second, he said, most of the PV value chain has less in common with the IC industry than it does with construction, building materials, automotive, and consumer electronics. He agreed that PV might benefit by communicating a very high-level roadmap to the rest of the industry, or Congress, on such major features as costs and volumes.

Next, porting over some of the IC-industry-derived standards could increase costs because they were developed in an industry with different characteristics. In PV, equipment costs must be kept low in order to grow cash-flow positive at greater than 40 percent per year.

The next warning is that some approaches to a roadmap could undercut the existing collaborative infrastructure in PV or undercut guidance from organizations that are more familiar with PV. And it could delay the needed U.S. market development if it results in waiting to take action until the roadmap is in place.

Avoiding Detailed Prescriptions

Dr. Rose also listed many examples of why a roadmap needs to avoid detailed technological prescriptions. That is, the PV industry is highly diverse, and that diversity is needed. Within each of the major categories, multiple companies are using different technology approaches, and roadmaps that tried to normalize these would discourage competition and innovation. In c-Si, for example, some companies are using variations on the legacy cell architecture and others are using disruptive approaches such as all-back-contact or hetero-junctions. Some of these cell architectures have the lowest cost with five-inch (flat-to-flat) wafers, while others architectures have the lowest cost with six-inch or eight-inch wafers. Some approaches use polycrystalline silicon; others use monocrystalline silicon. The biggest risk would be that standardizing on one architecture would pull resources away from the innovations that are possible and reduce the diversity that will allow systems to be optimized for different applications.

For CIS technology, there is wide diversity in deposition: sputtering, co-evaporation, electrodeposition, nanoparticle ink printing, the FASST reaction process, and ion-beam assisted. He also expressed the general concern that a roadmap could pull resources away from potentially valuable opportunities, because module development is moving so rapidly. For example, modules might be cylinders for roof mounts, or a flexible material applied directly to roofs, or large modules for lower-cost ground mounting. He made the same points regarding CdTe, amorphous Si, and high-concentration PV technologies.

He then pointed out that the diversity that he had covered was just the semiconductor portion. For traditional c-Si, the semiconductor portion that is similar to IC processing is only about 11 percent of the value chain, and there are a lot of innovations in the rest of value chain. Then he described multiple and fast-changing approaches, such as how to optimize efficiency and module size for different applications, and how to cut wafers—by improvement of wire saws or a new cleave processes with no material loss. "The point is that diversity is actually needed for maximum success of the industry. The competition, innovation, and private funding for these different approaches drives cost reduction and optimization for different applications. The success of multiple approaches will also give faster total growth because the different approaches will have different constraints in their value chains. Just as we don't have one type of consumer electronics, we won't have one type of PV module."

The Diversity of PV Offerings

Dr. Rose described some of the diversity of systems developed and deployed by SunPower itself. He said that while SunPower does have number one market share in the United States in both residential and commercial segments, and number one or two in power plants, it is still remarkable to see the diversity from just one company using one cell architecture. Solutions in the residential market varied from (1) integrated systems for new homes to (2) systems applied to existing structures to (3) various innovations that decrease the cost of installation or add value for the customer, such as smart-mount systems and monitoring packages. For the commercial market, the company offered the original nonpenetrating horizontal mount as well as new assembled systems with tilt, and more recently a solution where the module, frame, and mounting are all integrated. The latest product was developed under the DoE TPP that SunPower leads. There are also products such as solar carports that add value to the customer beyond the energy produced.

In power plants, modules with at least medium and preferably high efficiency enable cost effective tracking, and the cost of tracking has dropped by more than 50 percent in the last few years. Tracked systems have advantages beyond their reduction of the levelized cost of energy because they increase the delivery of energy at the times that the utilities most want it. A SunPower single-axis horizontal tracker in Las Vegas has a capacity factor of about 39 percent in summer, with good delivery in the late afternoon. Utilities are becoming aware that PV has a better match to their seasonal and time-of-day peak loads compared to other sources of energy.

A Need for Public-Private Partnerships

Dr. Rose ended his presentation by describing the importance of public-private partnerships in moving the PV manufacturing industry forward. Market development will have the biggest impact. Local markets with multiyear demand drive local module manufacturing and installation, and those areas have the majority of the jobs in the value chain. It also builds downstream infrastructure, with the low cost of installation in Germany an excellent example of the near-term benefit of that. That infrastructure also has lasting benefits, allowing for faster, more cost-effective deployment of future technologies. Long-term policies, commitments for PV purchase, and carbon taxes all can contribute to market development. The greenbank, and other efforts to improve end-project-financing, which is a key constraint now, is another area that would have a big impact. Finally, bringing down some of the barriers for PV penetration, such as slow permitting, grid access, and local ordinances, is important.

Programs that directly encourage development and manufacturing are also needed. This has been one of the big areas of success for the DoE program. Funding for PV programs at federal labs and universities, as well as development support for small and large businesses, manufacturing tax credits, and technology partnerships in select areas, all can have a big impact.

Other areas such as development of a module energy rating and developing a high level roadmap which will communicate expected volumes and costs could also be useful.

DISCUSSION

The Scope and Purpose of the Roadmap

Mr. McFadden said he agreed that a roadmap imposing standardization should be resisted, and that in fact a roadmap should reflect the healthy diversity of industry activities. But he also said that many of the roadmap criticisms made by Dr. Rose were not necessarily endemic to the concept of roadmapping. For example, he said, the semiconductor roadmap had been a success largely because it reflected the input of all the knowledgeable players in that industry, and had a major impact because it was a "realistic reflection of that particular landscape." Thus it informed people who were focused on one or two areas about the broader opportunities, obstacles, and gaps in technology generally. Beyond these broad guidelines, companies were "left on their own to figure out the most imaginative ways to approach problems, decide what else to focus on, and choose where is their specific effort and the broader industry effort would best be placed." He acknowledged that the semiconductor industry had "a lot of advantages, such as Moore's Law and a more predictable kind of momentum," but he said that the roadmap process itself seemed to be illuminating for virtually all the players in the industry.

Dr. Rose replied that those were "great observations for the IC industry. The process and success there shows it can be done for that industry. It was not easy there; the success was a testament to the intelligence and dedication of the people working on it. But if you look at differences between the industries, it falls apart. The IC industry was driven by the people who shared in the benefits of standardization. Everyone I've talked to in the PV industry has given the input; we don't want this type of roadmap."

Professor Zweibel said that "we might be confusing two things. First, there's certainly value in supporting development of existing technology at companies and advancement in their manufacturing. And second, there's certainly value in doing university research and foundational research to understand the fundamentals of how these things work, and building a science and technology base. Beyond those two, there's certainly value in bringing universities and NREL together with industry as well as possible and protecting IP. We welcome participation of the federal government and various political constituencies who want to support that, and we will make sure that the money will be as well spent as possible."

Early PV Roadmaps

Discussants noted that the topic of a PV industry roadmap was not new; an early version was generated in 2002. Dr. Guha noted that "many of us participated in it vigorously." He said that a subsequent roadmap was also generated, describing goals and objectives of the industry, which he called a success story. He said that one goal was to reach an installed cost point of $4.50/kWh by 2010, a point that had already been passed. "Certain things the industry did collectively are working," he said. "We don't need to try to fix that when it is not broken."

Dr. Guha continued in deploring "this fascination with doing something totally out of the box. I've been there. I've done innovation. I've done commercialization. And it is not trivial what we have done. Every day we meet challenges and we do innovation. And suddenly thinking I am going to do something new which is going to fix everything, is utopia."

Dr. Rose said he agreed with Dr. Guha's points, and that he wanted to clarify what he had said. "My negative comments about roadmaps," he said, "were not meant to be a general statement, but to refer only to a semiconductor-modeled technology/equipment roadmap. We participated in that 2002 industry roadmap, and it was a tremendous document that had a lot of benefit for the industry. Continuation of that kind of exercise and the ones Professor Zweibel mentioned would have a lot of value."

Dr. Stanbery of HelioVolt said he was also familiar with the earlier roadmap, and that some of that roadmap became a constraint to some activities. In particular, he said, it tended to channel development toward some of its major conclusions. For example, he said, after the roadmap described supply chain weaknesses in thin-film manufacturing equipment, thin films were not included in the DoE's subsequent funding plans.

Avoiding Too Much Detail in a Roadmap

Dr. Eaglesham agreed that "we're not smart enough build a roadmap that specifies the technology direction you should take. The constraint you have in the system is that technology that fails to intersect the cost roadmaps of the incumbents will die. I would strongly discourage us from an exercise that goes into too much detail, and gets into picking winners, which I think we're not ready to do."

Mr. McFadden reiterated that his sense of the semiconductor roadmap was that it was not intended to pick winners. "It was designed to provide a realistic view of the technology challenges."

Dr. Eaglesham replied that "a winner had already been selected. At that point CMOS had won. All the other technologies collapsed into a very simple 200mm roadmap. It was a different world from where we are today. It's not clear that in an industry of this scope there's going to be single solution."

Professor Zweibel said that what he had learned from roadmaps was how to listen to others, how to work together, how to deal with IP, and how to get around intransigent organizational problems, "which are lessons we all need. We don't need this exact kind of roadmap model, but we need to learn. The point is that we can make cost-effective PV. We've had great results up to now, both in industry and the government programs, and yes, we welcome the renewed vigor in political support for solar energy."

Elaine Ulrich of the House Committee on Science and Technology, who worked with Congresswoman Gifford, said that her committee would like some further guidance from the participants. She asked for feedback on where the solar industry was, and what the industry's primary needs were. "We need guidelines," she said. "We need to have something to turn to. If you have investments from the government, what should guide those investments? I would like to have the input from the actual members of industry. What kinds of discussions need to happen to effectively support this industry?"

A Need for Long-Term Consistency in Government Policy

Dr. Gay of Applied Materials said that one response to that offer was to say that "we need long-term consistency, and we need predictability in government policy." He said that, for example, PV could contribute a certain percentage to the energy base by a given year as long as there is predictability, and if a roadmap helps us quantify the value of distributed generation, time of day opportunities, and other industry targets. With a solid business case and continuity of policy, he said, banks will finance PV. The banking community needs to have confidence, he said, that when a company enters into a power purchase agreement, the policy stability will allow the agreement to hold up for a certain period. That framework would lead to R&D, manufacturing, and commercialization.

The Central Importance of Market Pull

Dr. Gay added that while the discussion had focused on the technology roadmap, the central issue for the PV industry was really market pull. This was demonstrated in Germany, when in 1990 a small rooftop program in Aachen became, under the influence of Hermann Sheer,[14] a countrywide goal, driven by the feed-in tariff. “The policy said that for 20 years the electricity from those arrays would provide a cash flow, which was a more solid return on investment than most financial instruments.” The policy also created 100,000 jobs, he said, greater than the number in the famous automobile sector. It also created a manufacturing base, many R&D centers, the Fraunhofer Gesellschaft, and a steady stream of educated people.

“At the end of the day,” he concluded, “this is all about jobs. Those jobs begin with the universities, the pipeline of know-how, and they end up in the marketplace. I think it would best serve us to start our roadmap with that market pull.”

[14]Dr. Scheer, an early supporter of Germany’s feed-in tariffs, is a world leader in the development of the photovoltaic industry.

Roundtable

Next Steps for Government-Industry Collaboration in Photovoltaic Technologies

Moderator:
John Lushetsky
U.S. Department of Energy

Panel Members:
Doug Rose, SunPower
Charlie Gay, Applied Materials
Kevin Hutchings, IBM
John Gloekler, Apogee Solar
James Moreland, SolarWorld

Panel members were asked to characterize the role of their company in the PV industry. They responded as follows:

Dr. Rose: SunPower is the leader in most PV markets in the U.S., with a worldwide workforce of about 5,000 employees.

Dr. Gay: Applied Solar, part of Applied Materials, makes equipment used to manufacture solar panels around the world; the world's largest producer of equipment for panels; about 1,500 employees in the solar business.

Kevin Hutchings: IBM is "at the center" of several semiconductor collaborations and has supported SRC, SEMATECH, and others. With its experience, skills, and intellectual property in semiconductors, IBM has much to offer the PV industry.

John Gloekler: Apogee Solar is developing a 50-micron solar cell and has developed a fabless process to totally outsource manufacturing to existing facilities.

Jim Moreland: Solar World of Oregon, with headquarters in Bonn, Germany, is expanding and hiring in a state with 10 percent unemployment; working with silicon and multicrystalline silicon.

THE ISSUE OF A PV ROADMAP (CONT'D)

Mr. Lushetsky thanked the panel members and asked them to continue the discussion of a PV roadmap. He said that contrary to the impression of some, this discussion was "not part of a DoE plan to exert control over the industry." In fact, he said, much of the conversation was initiated by materials suppliers who had approached DoE and asked for guidance in understanding where the industry is going. They said that they were used to dealing with roadmaps in the semiconductor industry and suggested that DoE could play a role. "What would you say to those suppliers," he asked, "that could help them be suppliers to you, and ultimately help you to be more competitive?"

Dr. Gay clarified that despite the name of Applied Materials, it is not a materials company but an equipment company that works closely with materials companies like Dow Corning and DuPont, and with the producers of feedstocks. He said what they can do is combine the tool with the material in a way that reduces cost for the PV customer. They have met with the raw materials suppliers, he said, and described their strategic plan around the roadmaps.

A ROADMAP TO GUIDE THEIR BUSINESS

"Everybody has a roadmap that guides their business," said Dr. Gay. "This is what allows them to receive financing and to establish their identity. We've brought together a lot of folks who want to help. In PV we relate to things that are in our past, so it's exciting to have people from the IC industry here wanting to help. What I think we can do is have a helpful exchange about what is similar and what is different. One thing that is different is technology half-life. In IC, the technology half-life is about 18 months, when another node is reached—Moore's observation. In PV, the technology half-life may last a decade. So in PV we do need to plan, but part of it is a set of ideas about how to bring in financing."

Dr. Gay said that the two industries sometimes seemed more similar than they were. He recalled the comment by Dr. Rose that PV may use 5-, 6- or 8-inch wafers. "You know where the idea of a wafer came from?" he asked. "From the IC industry. We got from them the notion that the form factor needed to look round like a wafer, instead of like a rectangle or something else. People start to differentiate around those fundamental ideas. What we want to do is lay the foundations for the long haul, and get the time constants right. We need to have the universities link in here." He referred to an earlier comment by Jim Sites about enabling students and faculty to engage in ways that allow innovation to emerge.

REACHING OUT TO THE BANKING COMMUNITY

Dr. Gay also noted that one of biggest barriers to the PV industry today is in the banking community. "They look for consultants to guide them on what technologies in PV to invest in. I've been a consultant," he said, "when I had no job. Banks rely on other people, when they should be calling Jim Sites. Part of the networking that could be helpful here is to be aware of the fact we're bringing in a lot of new stakeholders, and then call the Jim Siteses. It takes the IC world, the materials supplier world, and the banking community to actually create the financing models that could allow this industry to scale. We have a chance here to aggregate a lot of stakeholders, because we want to change the situation of where we get energy."

A ROADMAP TOWARD COMMON GROUND

Dr. Gay noted that PV stakeholders also have a lot of work to do in educating the pubic about the need for renewable energy. "We need all of you, and all the stakeholders we can possibly engage to try to get together. Whether we call it a roadmap or something else, this process of getting together and forming partnerships in setting goals on how much clean energy can be adopted and how much solar can be adopted would be a great thing for us to build on after this conference. Finding that common ground is very difficult, but it's up to each of us to find partners with whom we can cooperate."

Dr. Rose agreed with the need to gather and communicate this information. "Having the new companies learn more quickly where they should look and be able to communicate information upward is essential. But I want to caution against the idea of a roadmap that gives what some of the materials suppliers want—the roadmap they're used to in the IC industry. Every industry is different. The makers of parts for jet engines are probably used to dealing with two or three customers, but that would not make sense for the IC industry, and it certainly would not make sense for the PV industry. We deal with some suppliers who are really uncomfortable because it is different from what they are used to, but they see that here's an industry that could grow extremely rapidly, and they'll deal with the complexity of it in order to participate."

GUIDANCE FOR SPENDING LIMITED R&D FUNDS

Mr. Hutchings said that one benefit of a roadmap for the photovoltaic industry was that it could help extend the value of limited R&D money. "A company can't do everything," he said. "We discussed giving people the freedom to pursue all kinds of ideas, versus a narrow view. But limited money for R&D is the reality. One benefit of a roadmap is to make sure those limited R&D dollars are spent well. Whether or not you take the high-end, top-level view of cents per kWh, which makes a lot of sense, you'll ultimately have to figure out how to get there. You'll get into discussion with suppliers who say: I only have this much money to spend, where do I spend it? That's coming—especially if you believe this is all about how to strengthen manufacturing in the United States. If so, you have to look at the cost per kilowatt-hour, and say is that coming down fast enough for us to compete globally. And once you can answer that, you'll find out whether the roadmap is adequate, because it should tell you where to spend these limited R&D dollars." It is the same for the DoE, he added, which also has limited money, and has to decide where to spend it. "You need some guidance. I think there's a need for roadmaps. There are details that have to be worked out that are unique to the PV industry."

WHY COMPANIES NEED STANDARDS

Dr. Guha added an argument in favor of standards. "Companies need standards to get involved and grow the critical mass of this industry," he said. "Without standards, how do I know [that] I can have a market for my product and my R&D dollars?" Citing his own experience, he noted a time when there was no market for Wi-Fi; "But there were six standards before there was any market. As the market came, one standard emerged: 802.11b. This was followed by 'g,' and then 'n.'" Knowing those standards in advance, he said, gave companies the ability to invest in new technologies with lower market risk.

Dr. Moreland said that his company has to be able to talk to its suppliers with or without standards. "What I've found," he said, "is that they have their own idea of what PV is and what PV needs. They try to help us but end up hurting us in terms of the quality of the materials. So that conversation has to happen, and maybe, to some low level, at least some standards would be useful."

DECADES OF WORK ON STANDARDS

Dr. Gay said that he didn't want anyone to leave the symposium thinking there were no standards. Since the early 1980s, he said, a consensus process had been at work throughout the industry to agree on standards as they were needed. The process of setting PV standards is organized by the International Electrotechnical Commission (IEC), and followed by manufacturers of modules, installers, and others in the industry. "This is always evolving and improving," he said. "A lot of people have worked for a very long time on this, especially the technical committee on PV[15] charged with assuring the quality, durability, electrical integrity, safety, and so on for the PV industry. "In addition," he said, "NREL, Sandia, Brookhaven, and others have worked on environmental, health,

[15]The International Electrotechnical Commission (IEC) is a global organization that has prepared and published international standards for all electrical, electronic, and related technologies since its formation in 1906. Its technical committees are charged with preparing standards on many electrotechnical topics; e.g., TC 47 concerns semiconductor devices, and TC 82 concerns solar photovoltaic energy systems. TC 82 holds a plenary meeting every 18 months where working groups are charged with writing standards on many topics. TC 82, created in 1981, has recently considered standards for such topics as flat-plate PV modules, concentrator PV modules and assemblies, and installation and safety requirements for PV generators.

and safety standards and served as an independent third-party validator of safety standards. All of this," he said, "is to ensure the global integrity of what is being offered and warranted for the customer."

OPPORTUNITIES FOR PRECOMPETITIVE PARTNERSHIPS

Mr. Lushetsky added perspective on the difference between the PV industry and the semiconductor industry. "Put simply," he said, "the IC industry is one materials set with an infinite number of circuits; the PV industry is one circuit with an infinite number of materials." He said that that formulation helped him to frame the issue for himself. "Where the IC industry was able to collaborate on materials, we clearly run into differences in PV." For other technical issues, however, such as metrology, material handling, and deposition tooling at a high level, he suggested that opportunities for precompetitive partnerships might be found. Another opportunity for collaboration may be installation cost, which dominates total system cost.

Dr. Rose said that he, too, could see areas for productive collaboration, and there are some ongoing now. For inverters there is a standard now in place that addresses anti-islanding, interconnections, and safety, but there is also intense development and standards activity to integrate inverters with the smart grid, providing information and voltage support to the grid while increasing power point matching within the array and decreasing installation time. In addition, there are "areas that the industry has poked at but hasn't closed on." This included the module energy rating. "This is one I'd love to see good collaboration on," he said, "so consumers can know that if they buy a particular module, and put it in a particular climate, they can expect a certain amount of energy production." He suggested that many areas naturally invite collaboration, but he proposed letting those areas "develop organically while the major emphasis goes to the big picture roadmap that we communicate up to the Congress and other constituents."

A ROADMAP AROUND A CORE OF INSTITUTIONS

Dr. Gay suggested building a roadmap around a core of institutions, such as the partnership that currently exists among NREL, the Colorado School of Mines, Colorado State University, and the University of Colorado at Boulder. "There's a model that works well," he said, "and we could replicate it around other national labs." He said that one area of emphasis for a roadmap should be integrating PV into the grid, and within that area, to improve the communication of grid information to the utilities. "The United States lags China by a decade in this," he said. "We get grid information late because our systems gather and aggregate data only every 15 minutes. It's one reason we've had blackouts in the Northeast and Northwest." He said that the electrical grid in China has real-time detectors that display the waveform constantly so that operators can act immediately on current information. He also said a roadmap should plan how to integrate renewable power into the grid, moving PV-generated power from the Southwest throughout the nation, just as wind generation companies are planning to move power "from North Dakota to places where it's needed. It's the same paradigm the rest of the world is already working on," he said, "and they are ahead of us. So I'd vote for pulling in the national labs more closely, building the relationships to the universities, and expanding how we think about real-time use and where we link solar with the grid."

Mr. Hutchings raised the issue of whether individual PV companies would be willing to raise the money needed to achieve a roadmap. The industry would first have to decide whether the rate of improvement is now adequate for the companies and the United States. If it is not considered adequate, U.S. companies may decide a roadmap is desirable. This may cause them first to address the issue of what is precompetitive and what is not, he said. Then they may have to pool resources, "which is what happened in semiconductor industry for different reasons."

A LACK OF TRAINED PEOPLE

Dr. Gloekler said that one of biggest challenges to the U.S. solar industry is that it has been unable to commercialize technology rapidly enough, especially when compared to Chinese firms. This, he said, was due to a lack of people skilled in commercializing technologies. And it is true for many industries, he said, where the United States has advanced technologies, but the transfer from lab to full-scale production proves to be more difficult and time-consuming than estimated. He said that it was not a question of more spending, but of bringing more talent from the semiconductor industry. As an example, he said that Dick Swanson, the founder of SunPower, credited the six months he spent in Austin at SEMATECH with grounding him in essential principles of silicon manufacturing. "There's a very large challenge in doing baseline processes and developing reliability around process development that's not in the industry today," he said. "We need the talent pool in here from experienced bases that can help us drive these technologies a lot faster to market."

Dr. Moreland said the industry also needs to expand the pool of young talent. One way, he said, was to work through a consortium like the Silicon Solar Consortium (SiSoC), where industry members form partnerships, determine what is competitive and what is precompetitive, and develop their own working relationships. At the same time, they can stimulate and help students gain experience in PV so there are more knowledgeable people to hire.

START-UPS UNDER PRESSURE

Mr. Lushetsky asked Dr. Gloekler, because he represented an early-stage start-up, to describe the current challenges to his firm and compare them with the challenges of 12 months ago when financing and other issues were more favorable. Dr. Gloekler said, "I can tell you there's almost no investment out there today. VCs consider solar a commodity, which is the death knell any time you're trying to raise money." He said that it was very hard to get VC interest "even if you have innovative technologies that can shift the game." He said that the VCs "really want capex[16] efficiency. One, we have to show that there's essentially no technology risk. Two, our time to market has to be one to two years. Three, we need to run it on a lean model overall. You can only achieve that as a start-up if you have the ability to use an SVTC or some other type of prototyping facility that allows you to take your one area of technology, prove it, and sell it with the entire supply chain intact." He also said that "the standardization of equipment interfaces is going to be pretty fundamental to us, so we can sell to many manufacturers. Start-ups are under a lot of pressure right now."

WORKING WITH UNIVERSITIES

Mr. Lushetsky asked how companies could work more closely with universities, and Dr. Moreland said that in Oregon he had significant relationships with a consortium of universities, some of which were good in characterization and some in engineering. One university sends interns at the undergraduate level to work with the firm for about nine months, and the students use that experience to write papers that help them get their degree. Another university sends masters students to work in the factory, and they write their thesis based on the work they do. They are considered employees, and the company has a realistic setting in which to evaluate them. "If they're good," he said, "we hire them. Win-win."

Dr. Gay said that Applied Materials worked with about a dozen universities on specialized projects, typically electronic or optical modeling tasks, and is also part of the SRC program and the consortium headed by North Carolina State University. "We participate in working with universities either directly or through these consortia. We see that as a critical part of building up the talent pool." He said that many of the faculty at partner universities send their graduate students to his company when they complete their studies. "Those labs and those students are how we've been able to go from five employees three and a half years ago to 1,500 employees today. Five or 10 years ago that would have been impossible to do. We need those students to be in the pipeline."

DISCUSSION

More Partnering Between Agencies

George Rozgonyi of North Carolina State University said that he would like to see more government partnering between agencies. Referring to the request by Elaine Ulrich of Congresswoman Gifford's office for some action items to present

[16] Abbreviation for capital expenditure.

to the Congress, he suggested that participants forward a more complete list of needs. "I have my personal list," he said. "If I look at my colleagues in the states who need graduate students, I would say we need a competitive program to support applicants to graduate school and make it attractive enough for people to apply." The universities also need equipment, he said—specifically enhancements to existing university equipment so it is more useful to industry, including diagnostic and processing equipment (NC State), computer simulations (Texas Tech), and equipment in the DoE center at Georgia Tech. "We need to have a focused action item for enhancing these PV-oriented university programs. I think the government and NSF program should be recognized for what it is—an industry/university cooperative research consortium—and better coordinated with DoE and DoD and NIST and the national labs." Ms. Ulrich thanked Dr. Rozgonyi for this request, and asked the group for more, especially "what you all feel you need collectively."

PV Will Be Successful; Will the United States?

Dr. Rose agreed that the need for more student funding for PV is a good example of the bigger picture referred to by Dr. Rozgonyi. "When I was at NREL, and when I was at First Solar," he said, "I used to worry that if we didn't reduce costs, PV may never fulfill its potential; it would always be the technology of the future. The good news is that that's no longer the case. PV in the rest of world is going to be very successful. And a few U.S. companies will be part of that success. The challenge before us is what can we do in the United States to have large-scale manufacturing and use in this country? It will take actions on a big scale, because that is what other countries are doing. If we compare the level of U.S. funding on PV to the importance of it and to what other countries are spending, the gap is evident. We need to better coordinate the labs, pull in more labs that are working on other things, and build the downstream channels, for instance by aiding demand with a green bank or other mechanisms. When we put that whole list together we'll have the action plan that will make the United States the leader in clean technology—instead of wondering why those other countries were so successful."

Richard Bendis said he would like to make a "closing comment that's positive." He reported that he had just heard of a $75 million award from a consortium of VC firms to a new company formed to manufacture PV panels. He expressed the hope that this news heralds a positive note for the solar industry at large, especially since many companies have had a tough time securing VC funding during the height of the recent recession.

A Closing Word on the Value of Roadmaps

David King, who said he had worked both with NIST and a range of private firms, offered a closing comment on the value of roadmaps, especially of the type developed by SEMATECH. He focused on three points: One, roadmaps are powerful instruments for federal agencies to use in planning disbursement of federal funds for programs viewed as germane and with commercial potential. Two, they are powerful tools for companies inventing and developing technology—not only new materials but also new manufacturing equipment. Because the roadmap goes to companies beyond a particular sphere of influence, it can bring in partners who find the technology germane and judge it a timely fit with market conditions. And three, a roadmap is a powerful tool for people to study if they're in graduate school or even high school and planning a career. "When will this technology be ready?" he said. "Clearly, if it's going to be 15 years before you are creating new jobs, that's not a place for me to be. If job will be there in three to five years, the roadmap will tell me—and I can get myself ready."

IV

APPENDIXES

Appendix A

April 23, 2009, Symposium
The Future of Photovoltaics Manufacturing in the United States

Biographies of Speakers*

MICHAEL AHEARN

Michael J. Ahearn has served as the CEO and chairman of First Solar since August 2000. He served as president of First Solar from August of 2000 until March of 2007. From 1996 to 2006, he was partner and president of the private equity investment firm, JWMA (formerly True North Partners, LLC), the majority stockholder of First Solar. Prior to joining JWMA, Mr. Ahearn practiced law as a partner in the firm of Gallagher and Kennedy. He received both a B.A. in finance and a J.D. from Arizona State University.

Mr. Ahearn currently serves on the boards of First Solar and the German Marshall Fund of the United States. He is also active in community activities and currently serves on the board of GPL (Greater Phoenix Leadership). He had previously served on the boards of Arizona Technology Enterprises, Arizona State University Research Park, Homeward Bound, and the Arizona Science Museum.

RICHARD BENDIS

Mr. Bendis has distinguished himself as a successful entrepreneur, corporate executive, venture capitalist, investment banker, technology-based economic development leader, and consultant in the technology and health care industries.

He currently serves as the founding president and CEO of the Bendis Investment Group LLC, (BIG), a global financial intermediary and consulting firm headquartered in Philadelphia. Mr. Bendis has a joint venture management

* Biographies as of April 2009, distributed at symposium.

agreement with Drawbridge Special Opportunities Advisors LLC, an affiliate of the Fortress Investment Group (NYSE, FIG), and a consulting agreement with Laurus/Valens, an alternative asset manager. Under these agreements, BIG is responsible for the sourcing, due diligence, acquisition, origination, management, servicing, disposition of investments (including debt, equity, and other assets) located in BIG's network.

Previously, Mr. Bendis served as chairman, president and CEO of True Product ID, Inc., a global publicly traded anticounterfeiting technology company (NASDAQ, TPID) headquartered in Philadelphia, which he relocated to Beijing, China. Mr. Bendis also founded and served as the first president and CEO of Innovation Philadelphia (IP), a public/private partnership dedicated to growing the wealth and workforce of the Greater Philadelphia Region. IP managed an umbrella of programs under four distinct areas: Direct Equity Investment/Financing Assistance; Technology Commercialization; Global and Regional Economic Development; and Market Research and Branding. Mr. Bendis continues to serve on the IP Board.

Previously, Mr. Bendis successfully leveraged a career in the private sector (with Quaker Oats, Polaroid, Texas Instruments, Marion Laboratories and Kimberly Services) and the venture capital industry (RAB Ventures) to build the Kansas Technology Enterprise Corporation (KTEC). As its president and CEO, he developed KTEC into a globally recognized model for technology-based economic development. Mr. Bendis also successfully built an Inc. 500 health care software company, Continental Healthcare Systems, Inc., which he took public on NASDAQ and later sold to an international conglomerate. In addition, Mr. Bendis managed his own venture capital fund, RAB Ventures, which made 15 investments in early-stage technology and healthcare companies.

Mr. Bendis is a frequent, international consultant and speaker to the United Nations, NATO, and the European Commission, national and international technology-based economic development industry organizations and other global enterprises. Mr. Bendis serves on several not-for-profit boards including the National Association of Seed and Venture Funds (NASVF) and the State Science and Technology Institute (SSTI), both of which he was a founding board member. He was a nominee for the 2005 Ernst and Young National Entrepreneur Supporter of the Year Award (EOY) and was the 1996 recipient of the Regional Ernst and Young Entrepreneur of the Year Award; he currently serves as an EOY National Judge. He also serves on the board of FlagshipPDG (NASDAQ, PDGE).

ERIC DANIELS

Mr. Daniels is currently the vice president of technology for BP Solar and is accountable for programs that span the development of alternative sources of

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silicon, optimized and next-generation casting and wafering, cell, module and optimized systems technologies. These programs are supported by the U.S. Department of Energy's Solar America Initiative, various EU technology support initiatives and are conducted n partnership with universities around the world. Mr. Daniels' experience includes manufacturing and over 15 years in commercial roles. He began his solar career working on the development of low-cost solar cell technology for Solarex Corporation under a DoE R&D grant. The success of this work led to the start up and management of production lines in Maryland and Europe.

Previous to his current role Mr. Daniels served as vice president of component sales for BP Solar and was responsible for merging and building global distribution sales following the merger of BP Solar and Solarex. Previous to this Mr. Daniels worked for Siemens Solar and was responsible for marketing, utility sales, and product development/management. In addition, as vice president for strategic marketing and technology with IPC Westinghouse, he was responsible for the commercialization of solar, wind, diesel hybrid power supplies for rural electrification, oil and gas industries, communications, telemetry, security, defense, residential, and utility power markets.

STEVEN C. FREILICH

A native of Philadelphia, Pennsylvania, Steven Freilich received his B.A. in chemistry from Amherst College in 1978 and a Ph.D. in chemistry from Harvard University in 1983. He joined DuPont Central Research and Development (CR&D) in 1983, working principally in photoconductivity of polymers and polymer-metal adhesion. In 1987, Dr. Freilich was appointed research manager in DuPont CR&D, leading various groups in the fields of thin film physics, information storage materials, organic photochemistry, scientific computing, and particle science. He joined DuPont Titanium Technologies in 1997 where he served in various positions, including technical service manager, global business manager, and global technology manager for new business development. He returned to CR&D in 2004 as the director of materials science and engineering. In addition to his current assignment, Dr. Freilich was appointed in 2008 to the position of chief technology officer of the DuPont Electronics and Communication Technologies Platform. He has served on the boards of the United States Display Consortium and DuPont Photonics Technologies, and currently serves on the Materials Science & Technology Council External Review Panel for Sandia National Laboratory and is the vice chair of the Advisory Panel for the Center for Revolutionary Solar Photoconversion in Colorado.

* Biographies as of April 2009, distributed at symposium.

GABRIELLE GIFFORDS

Gabrielle Giffords is the U.S. Representative for the Eighth District of Arizona, a diverse area that covers 9,000 square miles including a 114-mile border with Mexico.

Congresswoman Giffords serves on the House Armed Services Committee and the Subcommittees on Air and Land Forces and Military Readiness where she fights for our military men and women and their families and the installations she represents at Fort Huachuca and Davis-Monthan Air Force Base. On the House Science and Technology Committee and the Subcommittee on Energy and the Environment, Cong. Giffords promotes an agenda of energy independence and solar initiatives in an effort to make Southern Arizona the "Solar-con Valley" of the nation. On the House Foreign Affairs Committee and the Subcommittee on the Western Hemisphere, Cong. Giffords monitors our country's positions abroad, especially relationships in the Western Hemisphere and their impact on comprehensive immigration reform in the United States.

A third generation Arizonan and the youngest woman ever elected to the Arizona State Senate, Cong. Giffords represented her hometown of Tucson in the Arizona Legislature from 2000 to 2005. During her service in both the House of Representatives and the Senate, she worked on legislation to expand health care coverage for Arizona families; to create and attract high-wage jobs to Arizona; and to protect Arizona's environment and open spaces. She served on the Appropriations, Commerce and Economic Development and Finance Committees.

As former president and chief executive officer of El Campo Tire, Inc., Cong. Giffords was able to utilize her experience as a small businesswoman with a broad background in national and international economic development. A 1996 graduate of Cornell University with a master's degree in regional planning, she is also a graduate of Scripps College where she was awarded a William Fulbright Scholarship to study for a year in Chihuahua, Mexico. Between her undergraduate work and her master's she worked as a researcher in San Diego studying the effects of Operation Gatekeeper II on the San Ysidro Port of Entry.

Experienced in international relations, Cong. Giffords served as president of the Atlantic Association of Young Political Leaders, represented the National Committee on China-U.S. Relations as a Young Leader's Forum Fellow and was a German Marshall Fund Manfred-Worner Fellow. In 2005 Cong. Giffords was selected for the inaugural two-year class of the Aspen-Rodel Fellowships in Public Leadership.

For combining her strong business background with a powerful commitment to public service, Cong. Giffords was named Woman of the Year by Tucson Business Edge in 2005; the YWCA named her Woman on the Move the same year. For her commitment to protecting the environment, she was named Legislator of the Year by the Arizona Planning Association and Most Valuable Player by the Sierra

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Club. She was awarded the Top 10 Technology Legislator of the Year award by the Arizona Technology Council for three straight years—2003, 2004, 2005. She was named the Legislator of the Year in 2004 by the Mental Health Association of Arizona. She was also recently named one of America's Eight Young Leaders Worth Watching by Gannett News Service.

Congresswoman Giffords' commitment to her community has not been limited to her service in the legislature. She has devoted her time as a member of over a dozen boards including 162nd Air National Guard Fighter Wing Minuteman Committee, the Metropolitan YMCA, the Anti-Defamation League, the Breast Cancer Boot Camp and the Tohono Chul Park. She is also a member of Congregation Chaverim.

With her family living in southern Arizona, Giffords has strong ties to Tucson and Sierra Vista. Her father served on the school board in Tanque Verde District and her mother is an art conservator. Her grandparents lived in southeastern Arizona and are buried in Ft. Huachuca. Cong. Giffords and her husband Mark Kelly enjoy hiking and spending time in the canyons and desert of Arizona.

WILLIAM HARRIS

Dr. Harris is the president and chief executive officer of Science Foundation Arizona (SFAz).

Prior to joining SFAz, Dr. William C. Harris was in Ireland serving as director general of Science Foundation Ireland (SFI), a new Irish agency that helped facilitate tremendous growth in Ireland's R&D sector during Dr. Harris' tenure. Immediately prior to going to Ireland, Dr. Harris was vice president of research and professor of chemistry and biochemistry at the University of South Carolina (USC). There, he oversaw research activities throughout the USC system, several interdisciplinary centers and institutes, the USC Research Foundation and sponsored research programs.

Dr. Harris served at the U.S. National Science Foundation (NSF) from 1978 to 1996, including as the director for mathematical and physical sciences (1991-1996). He was responsible for federal grants appropriation of $750 million. He also established 25 Science and Technology Centers to support investigative, interdisciplinary research by multiuniversity consortia. Earlier in his career, he catalyzed the Research Experience for Undergraduates program in the chemistry division and it became an NSF-wide activity.

In 2005, Dr. Harris was elected a member of the Irish Royal Academy, and received the Wiley Lifetime Achievement Award from California Polytechnic State University. He has authored more than 50 research papers and review articles in spectroscopy and is a fellow of the American Association for the Advancement of Science.

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* Biographies as of April 2009, distributed at symposium.

Dr. Harris earned his undergraduate degree at the College of William and Mary, and received his Ph.D. in chemistry from the University of South Carolina.

MARK HARTNEY

Dr. Mark Hartney joined FlexTech/USDC in June 2007 as chief technical officer. As CTO, Mark manages all technical activities of the FlexTech USDC, including: working with industry on the proposal and selection process of technical projects; management of project contracts; communication with government sponsors; chairing the Technical Council; and all other activities involved with fulfilling the organization's technical mission, including as managing director of the 3D@Home Consortium.

From 2005 to 1996, Dr. Hartney worked as a market strategist for semiconductor, consumer electronics and storage companies—first at dpiX, a display and sensor company, next at Silicon Image, an electronics developer and manufacturer, and finally as principal with Table Talk Consulting.

From 1992 to 1996, Dr. Hartney worked in a variety of positions in Washington, D.C., executing federal policy and managed projects on both semiconductor manufacturing and displays, at the Defense Advanced Research Projects Agency (DARPA) and the White House Office of Science and Technology Policy (OSTP). Dr. Hartney also held positions at MIT Lincoln Labs and AT&T Bell Labs.

Dr. Hartney is a graduate of MIT (B.S. and M.S.) and earned his doctoral degree at University of California at Berkeley. He has over 60 technical publications, 100 conference presentations and 4 issued patents.

KEVIN HURST

Dr. Hurst works on policy issues related to energy and climate change technologies, including renewable energy, sustainable buildings, efficient manufacturing, carbon capture and sequestration, smart grid, biofuels, and advanced transportation technologies. His technical background is in electrical engineering, with a bachelor's degree from MIT and a Ph.D. from Georgia Tech. His first job was division officer on a U.S. Navy submarine tender in New London, Connecticut. Prior to joining OSTP, Dr. Hurst worked as a senior engineer for Sundstrand Aerospace and General Motors, where he led development of power converters for, respectively, aircraft systems and hybrid vehicle systems. He began work at OSTP as an American Association for the Advancement of Science policy fellow (2000-2001) and subsequently joined the OSTP regular staff.

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* Biographies as of April 2009, distributed at symposium.

NORMAN JOHNSTON

Norman Johnston currently serves as CEO and president of McMaster Energy Enterprises (MEE), vice chairman of Calyxo GmbH and chairman of Ohio Advanced Energy (OAE). MEE includes a number of companies primarily developing alternative energy products, including Solar Fields LLC. These products range from on-board hydrogen from water supplemented conventional engines to various coated glass products, including solar panels.

Dr. Johnston holds a Ph.D. in polymer science and has authored over 60 marketing and technical publications and patents. Over his career, Dr. Johnston has been director of planning and director of research for Owens Corning, president of Building Products, and vice president of technology and engineering for Libbey Owens Ford, CEO and president of Solvay Automotive, a major producer of plastic automotive parts, and CEO and president of Jancor, a producer of windows and plastic building products. Dr. Johnston has also served on the boards of several multinational companies and numerous local organizations.

MARCY KAPTUR

Congresswoman Kaptur, of Polish-American heritage with humble, working-class roots, mirrors the boot-strap nature of her district. Her family operated a small grocery where her mother worked after serving on the original organizing committee of an auto trade union at Champion Spark Plug. Congresswoman Kaptur became the first family member to attend college, receiving a scholarship for her undergraduate work. Trained as a city and regional planner, she practiced 15 years in Toledo and throughout the United States before seeking office. Appointed as an urban advisor to the Carter White House, she helped maneuver 17 housing and neighborhood revitalization bills through the Congress during those years.

Subsequently, while pursuing a doctorate in urban planning and development finance at the Massachusetts Institute of Technology, her local party recruited her to run for the House seat in 1982. Congresswoman Kaptur had been a well-known party activist and volunteer since age 13. Though outspent by 3 to 1 in the first campaign, her deep roots in the blue collar neighborhoods and rural areas of the district made her race the national upset of 1982.

Congresswoman Kaptur fought vigorously to win a seat on the House Appropriations Committee. Since elected, she has risen in seniority and is now the senior Democratic woman on Appropriations. She has secured subcommittees on Agriculture, the leading industry in her state, Transportation/Housing and Urban Development (HUD), and Defense. She is the first Democratic woman to serve on the House Defense Appropriations Subcommittee. In her legislative career, she has also served on the Budget; Banking, Finance and Urban Affairs; Veterans

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* Biographies as of April 2009, distributed at symposium.

Affairs committees, and on Veterans Affairs-Housing and Urban Development and Independent Agencies (Environmental Protection, Veterans, and NASA and the National Science Foundation), Foreign Operations, and Military Construction Appropriations subcommittees, which have allowed her to pursue her strong interests in economic growth and new technology, community rebuilding, and veterans. Congresswoman Kaptur was also appointed by party leadership to serve on the prestigious House Budget Committee for the 110th Congress.

Congresswoman Kaptur has focused strong efforts on rebuilding the economic might of her district, such as improvements in bridge, road, rail and port facilities, including the New Maumee River Crossing—the largest bridge project in Ohio's history; expansion of Toledo's Farmers' Market; development of the Maumee River Heritage Corridor between Ohio and Indiana, which includes passage of legislation and funds to acquire Fallen Timbers as a national affiliate of the U.S. Park Service; clean-up of the waterways adjacent to Lake Erie; development of initiatives to enhance the earnings potential of Northwest Ohio crops; shipping of federal cargos on the Great Lakes; acquisition of wildlife refuges and shoreline recreation; and expansion of university-related research.

Congresswoman Kaptur directed federal support to acquire Quarry Pond as the centerpiece for a new conservation and lands legacy endowment for northwest Ohio. Lucas County-based 180th Tactical Fighter Squadron underwent an F-16 modernization attributable to her efforts. Current and former Defense Department and other private-sector workers who were exposed to and suffer from beryllium were the beneficiaries of a major piece of legislation she guided to passage. She was awarded the Veterans of Foreign Wars Americanism Award, in part for introducing the legislation authorizing the National World War II Memorial in Washington in 1987, as well as for her longstanding commitment to America's veterans. She also received the Prisoner of War "Barbed Wire" Award for her commitment to veterans' affairs.

Dedicated to the principle that fiscal responsibility begins in "one's own backyard," Congresswoman Kaptur has consistently returned money to the federal treasury. She refuses to accept congressional pay raises and donates them to offset the federal deficit and charitable causes in her home community.

Marcy Kaptur is a lifelong resident of Toledo, Ohio, a member of Little Flower Roman Catholic Church, and a graduate of St. Ursula Academy. In 1968, Kaptur earned a bachelor of arts degree in history from the University of Wisconsin. She received her master's degree in urban planning from the University of Michigan. In 1993, Congresswoman Kaptur was awarded an Honorary Doctor of Laws degree by the University of Toledo in recognition of her "effective representation of the community," of the university and of northwest Ohio. St. Ursula Academy named Kaptur Alumna of the Year in 1995. Last year, the University of Michigan honored Congresswoman Kaptur with the Taubman

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College Distinguished Alumna award. Congresswoman Kaptur is the first woman so recognized and the first graduate of the Urban and Regional Planning Program to receive this award.

Congresswoman Kaptur recently received the Director's Award from the Edmund A. Walsh School of Foreign Service at Georgetown University for her commitment to increased understanding and appreciation of the peoples and cultures of Eurasia, Russia, and eastern Europe.

She was named the National Mental Health Association's "Legislator of the Year" for her championing mental health and received the 2002 Ellis Island Medal of Honor.

Congresswoman Kaptur is also the author of a book, *Women in Congress*, which was published by Congressional Quarterly.

JOHN E. KELLY III

Dr. John E. Kelly III is IBM senior vice president and director of research. In this job he directs the worldwide operations of IBM Research, with 3,200 technical employees at eight laboratories in six countries around the world, and helps guide IBM's overall technical strategy.

Dr. Kelly's top priority as head of IBM Research is to stimulate innovation in key areas and quickly bring those innovations into the marketplace to sustain and grow IBM's existing business, and to create the new businesses of IBM's future. IBM applies these innovations to help our clients succeed.

Dr. Kelly also leads IBM's worldwide intellectual property business as well as the company's open-source and open-standards strategies and practices.

Prior to beginning his current assignment in July of 2007, Dr. Kelly was senior vice president of technology and intellectual property, responsible for IBM's technical and innovation strategies.

In 2000, Dr. Kelly was group executive for IBM's Technology Group, where he was responsible for developing, manufacturing and marketing IBM's microelectronics technologies, products and services.

Dr. Kelly joined IBM in 1980. Between 1980 and 1990, he held numerous management and technical positions related to the development and manufacturing of IBM's advanced semiconductor technologies. In 1990, he was named director of IBM's Semiconductor Research and Development Center. In 1994, he was appointed vice president of business process reengineering for the Microelectronics Division.

In 1995, he was named vice president of systems, technology and science for the IBM Research Division. In this role, Dr. Kelly was responsible for the company's most advanced research activities. The following year, he was named vice president of strategy, technology, and operations for the Microelectronics

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Division. In 1997, he was appointed vice president of server development (from work stations to supercomputers) for IBM. In January of 1999, he was appointed general manager of IBM's Microelectronics Division, a position he held until August 2000.

Dr. Kelly received a Bachelor of Science degree in physics from Union College in 1976. He received a Master of Science degree in physics from the Rensselaer Polytechnic Institute in 1978 and his doctorate in materials engineering from RPI in 1980. In 2004, he received an Honorary Doctorate of Science from The Graduate School at Union College.

Dr. Kelly is on the board of governors of The IBM Academy of Technology; a board member and former chairman of the Semiconductor Industry Association; a fellow of the Institute of Electrical and Electronics Engineers, and on the board of trustees of Union College.

ERIC K. LIN

Eric Lin is chief of the Polymers Division in the Materials Science and Engineering Laboratory at the National Institute of Standards and Technology (NIST). He received a B.S.E. from Princeton University in 1991 (summa cum laude) and master's and Ph.D. degrees from Stanford in 1992 and 1996, respectively, all in chemical engineering.

Dr. Lin joined the NIST Polymers Division as an NRC-NIST postdoctoral associate in 1996, and joined the permanent staff in 1998. In 2002, he became the leader of the Electronics Group, where he established world-class research programs in semiconductor electronics processing, nanoscale materials, and organic electronics. His honors include the NIST Bronze and Silver Medals, the NIST Slichter Awards twice, the Presidential Early Career Award for Scientists and Engineers (PECASE), and participation in the National Academy of Science Kavli Frontiers of Science program. He is active in activities of several professional organizations, including the American Institute of Chemical Engineers, the American Physical Society, and the Materials Research Society.

ROBERT M. MARGOLIS

Robert M. Margolis is a senior analyst in the Washington, D.C., office of the National Renewable Energy Laboratory (NREL). Since joining NREL in 2003, Dr. Margolis has served as the lead analyst for the Solar Energy Technologies Program. In this role he has helped to define and carry out a broad analytical agenda focused on examining the potential for and challenges related to widespread adoption of solar energy. He has worked on issues such as; energy-economic-environmental modeling, including national and global-scale models; economic and

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market analysis of renewable energy technologies; R&D planning and evaluation; and long-term scenario development. Prior to working at NREL, Dr. Margolis was a member of the research faculty in the Department of Engineering and Public Policy at Carnegie Mellon University and a research fellow at the Belfer Center for Science and International Affairs at Harvard University. Dr. Margolis earned a B.S. in electrical engineering from the University of Rochester, an M.S. in technology and policy from the Massachusetts Institute of Technology, and a Ph.D. in science, technology, and environmental policy from Princeton University.

W. CLARK MCFADDEN II

W. Clark McFadden II represents corporate clients in international trade, encompassing work in litigation, regulation, and legislation. He also specializes in international corporate transactions, especially the formation of joint ventures and consortia, and international investigations and enforcement proceedings.

Mr. McFadden has a broad background in foreign affairs and international trade, having experience with congressional committees, the U.S. Department of Defense, and the National Security Council.

In 1986, he was appointed general counsel, President's Special Review Board ("Tower Commission"), to investigate the National Security Council system and the Iran-Contra Affair.

In 1979, Mr. McFadden served as special counsel to the Senate Foreign Relations Committee on the Strategic Arms Limitations Treaty (SALT II). Previously, from 1973-1976, he was general counsel, Senate Armed Services Committee, and was responsible to the committee for all legislative, investigatory and oversight activities.

Mr. McFadden is the secretary to the board of directors of the Semiconductor Industry Association, the Optoelectronics Industry Development Association, and the Semiconductor Research Corporation.

MARK PINTO

Dr. Mark R. Pinto is the chief technology officer, senior vice president, and general manager of the Energy and Environmental Solutions (EES) business at Applied Materials. Appointed corporate CTO in 2004, Dr. Pinto is responsible for the company's overall technology direction, its advanced R&D programs, and developing new business opportunities while also serving as chairman of Applied's Venture Investment Committee. In addition, Dr. Pinto leads the recently formed EES business which grew out of efforts to expand Applied's nanomanufacturing technology competencies into new markets, including cost effective solutions for solar photovoltaic module production.

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Previously, Dr. Pinto spent 19 years with the research division of Bell Laboratories and the Lucent Microelectronics Group, later spun off as Agere Systems. He was named a Bell Labs Fellow, the company's highest technical honor, for his contributions to semiconductor devices and simulation.

Dr. Pinto received bachelor's degrees from Rensselear Polytechnic Institute and a master's degree and Ph.D. in electrical engineering from Stanford University. As part of his doctoral work, he developed the device simulator PISCES-II, which was a standard tool in the industry for many years. Dr. Pinto has authored or co-authored more than 150 papers and has nine patents. He has been active in industry consortia including serving on the board of directors of Semiconductor Research Corporation and the Technology Strategy Committee of the Semiconductor Industry Association. He is also a fellow of the IEEE and served as an adjunct professor at Yale University.

STEVE O'ROURKE

Steve O'Rourke, managing director, joined Deutsche Bank in June of 2004 as a senior analyst covering Semiconductor Capital Equipment and materials, and expanded coverage to include the Solar PV Energy space since in 2006. Previously, he had held similar roles at Piper Jaffray and Robertson Stephens. Prior to working on Wall Street, O'Rourke spent more than eight years at Applied Materials, where he assumed numerous roles of increasing responsibility in engineering, sales and marketing, operations, product management, and strategic marketing. Then, for two years, he worked at an early-stage start-up company, Everdream Corp., in general management roles. O'Rourke earned his B.S. in electrical engineering from the U.S. Naval Academy, did graduate work in nuclear engineering with the U.S. Navy, and served three years as a submarine officer.

JIM RYAN

Dr. Ryan attended Rensselaer Polytechnic Institute in Troy, New York, where he received his B.S., M.S., and Ph.D. degrees in chemistry and an M.S. degree in biomedical engineering. Dr. Ryan is the founding dean of the Joint School of Nanoscience and Nanoengineering of North Carolina A&T State University and the University of North Carolina at Greensboro. His responsibilities include academic and administrative leadership of JSNN as well as the development of strategic partnerships with industry and government organizations. Dr. Ryan's research interests include thin-film deposition; interconnect technology, semiconductor manufacturing technology, and radiation-hardened nanoelectronics.

Dr. Ryan joined JSNN after working at the College of Nanoscale Science and Engineering (CNSE) of the University at Albany as associate vice president of

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technology and professor of nanoscience from 2005 to 2008. At CNSE, he managed the cleanrooms and numerous consortia involving CNSE and its industrial partners, such as IBM, TEL, AMAT, ASML, and others.

Dr. Ryan joined CNSE after a 25-year career with IBM. From 2003 to 2005, he was a distinguished engineer and director of advanced materials and process technology development and served as the site executive for IBM at Albany Nanotech. Prior to that assignment Dr. Ryan managed interconnect technology groups in research, development and manufacturing engineering areas at IBM. He is the author of over 100 publications and presentations, has 47 U.S. patents, and is the recipient of numerous awards, including 17 IBM invention plateaus, an IBM Corporate Patent Portfolio award, an IBM Division Patent Portfolio Award, IBM Outstanding Technical Achievement Awards for Dual Damascene and for Copper technologies, and the 1999 SRC Mahboob Khan Mentor Award.

BOB STREET

Bob Street is a Senior Research Fellow at the Palo Alto Research Center in California. His research interests are in large-area electronic materials and devices, including amorphous silicon, flat-panel x-ray image sensors, printed organic semiconductors, and flexible displays.

DICK SWANSON

Dr. Richard Swanson co-founded SunPower in 1985. He has served as president and chief technical officer since June 2003 and has been a member of the board of directors since 1985. Prior to his current position, Dr. Swanson served as chief executive officer and president from 1991 to June 2003 and vice president and director of technology from 1990 to 1991. From 1976 to 1991, Dr. Swanson served as a professor of electrical engineering at Stanford University. He holds a Ph.D. from Stanford University and both bachelor's and master's degrees in electrical engineering from Ohio State University.

JOHAN VAN HELLEPUTTE

Johan Van Helleputte is IMEC senior vice president, Strategic Development Unit, in charge of

- IMEC's corporate business plan;
- Negotiation of the protocol agreements with the Flemish Government;
- Start-up of new, strategically important projects;

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- Development of new strategic initiatives to support local and international hi-tech companies, such as the Microelectronics Training Center (established in 1999); and
- Corporate communication towards the local government organizations and other local stakeholders.

CHARLES WESSNER

Charles Wessner is a National Academy Scholar and director of the Program on Technology, Innovation, and Entrepreneurship. He is recognized nationally and internationally for his expertise on innovation policy, including public-private partnerships, entrepreneurship, early-stage financing for new firms, and the special needs and benefits of high-technology industry. He testifies to the U.S. Congress and major national commissions, advises agencies of the U.S. government and international organizations, and lectures at major universities in the United States and abroad. Reflecting the strong global interest in innovation, he is frequently asked to address issues of shared policy interest with foreign governments, universities, research institutes, and international organizations, often briefing government ministers and senior officials. He has a strong commitment to international cooperation, reflected in his work with a wide variety of countries around the world.

Dr. Wessner's work addresses the linkages between science-based economic growth, entrepreneurship, new technology development, university-industry clusters, regional development, small-firm finance and public-private partnerships. His program at the National Academies also addresses policy issues associated with international technology cooperation, investment, and trade in high-technology industries.

Currently, he directs a series of studies centered on government measures to encourage entrepreneurship and support the development of new technologies and the cooperation between industry, universities, laboratories, and government to capitalize on a nation's investment in research. Foremost among these is a congressionally mandated study of the Small Business Innovation Research (SBIR) Program, reviewing the operation and achievements of this $2.3 billion award program for small companies and start-ups. He is also directing a major study on best practice in global innovation programs, entitled *Comparative Innovation Policy: Best Practice for the 21st Century*. Today's meeting on "The Future of Photovoltaic Manufacturing in the United States" forms part of a complementary analysis entitled *Competing in the 21st Century: Best Practice in State & Regional Innovation Initiatives*. The overarching goal of Dr. Wessner's work is to develop a better understanding of how we can bring new technologies forward to address global challenges in health, climate, energy, water, infrastructure, and security.

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KEN ZWEIBEL

Ken Zweibel has almost 30 years experience in solar photovoltaics. He was at the National Renewable Energy Laboratory (Golden, CO) much of that time and the program leader for the Thin Film PV Partnership Program until 2006. The Thin Film Partnership worked with most U.S. participants in thin film PV (companies, universities, scientists) and is often credited with being important to the success of thin-film PV in the United States. Corporate participants in the Partnership included First Solar, UniSolar, Global Solar, Shell Solar, BP Solar, and numerous others.

Dr. Zweibel subsequently co-founded and became president of a thin-film CdTe PV start-up, PrimeStar Solar, a majority share of which was purchased by General Electric. Dr. Zweibel became the founding director of the Institute for Analysis of Solar Energy at George Washington University at its formation in 2008.

Dr. Zweibel is frequently published and known worldwide in solar energy. He has written two books on PV and co-authored a *Scientific American* article (January 2008) on solar energy as a solution to climate change and energy problems.

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George Washington University

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Appendix B

July 29, 2009, Symposium
State and Regional Innovation Initiatives—Partnering for Photovoltaics Manufacturing in the United States

Biographies of Speakers*

CAROL BATTERSHELL

Carol Battershell is the senior advisor for commercialization and deployment in the U.S. Department of Energy's office of Energy Efficiency and Renewable Energy. Ms. Battershell joined the Department of Energy in 2008 after 25 years in the energy industry with BP and Standard Oil. As senior advisor for commercialization and deployment, she is responsible for identifying and implementing opportunities to accelerate the commercialization of efficiency and renewable energy technologies in the United States.

Ms. Battershell's most recent roles at BP included:

- Vice president, policy and strategy for BP Alternative Energy, where she was instrumental in developing the strategy and business case for an 8 billion dollar investment to launch and grow the new BP Alternative Energy division, and
- Vice president, renewables and alternative fuels, where she directed BP's global activities in hydrogen and wind, as well as managed BP's "green energy" marketing and consulting company.

Additional energy industry positions have included operations and strategy roles in retail fuels marketing, strategy and financial roles in business-to-business fuels marketing, as well a corporate role in environmental policy and a development role as chief of staff to one of BP's most senior executives. She began her career as a refinery engineer in Ohio.

Ms. Battershell has a B.S. in engineering from Purdue University where

* Biographies as of July 2009, distributed at symposium.

she specialized in environmental engineering and an MBA from Case Western Reserve University.

Ms. Battershell has worked in a variety of locations in the United States and has spent 10 years living and working in Europe.

RICHARD BENDIS

Mr. Bendis currently serves as the founding president and CEO of Innovation America (IA), a national 501(c)3 not-for-profit, private/public partnership focused on accelerating the growth of the entrepreneurial innovation economy in America.

Mr. Bendis has distinguished himself as a successful entrepreneur, corporate executive, venture capitalist, investment banker, innovation and technology-based economic development leader, international speaker and consultant in the technology and health care industries.

Mr. Bendis has been engaged in and appointed to selected national innovation related organizations and committees that include the White House U.S. Innovation Partnership (USIP) Advisory Task Force and co-chair of the Small Business Innovation Research Committee, the National Governor's Association (NGA) Science and Technology Council of the State's Executive Committee, the State Federal Technology Task Force, the National Academies (NAS) Committee on *Competing in the 21st Century: Best Practice in State and Regional Innovation Initiatives*; National Academies Review of the SBIR Program; National Institute of Standards and Technology Manufacturing Extension Partnership (MEP) National Advisory Board; U.S. Small Business Administration's Angel Capital Electronic Network (ACENET) Board of Directors; American Academy for the Advancement of Science (AAAS) Nominating Committee and the American Association Research Competitiveness Program Advisory Committee; Council on Competitiveness—Clusters of Innovation Committee.

Mr. Bendis has also served as a board member and representative to the following organizations: National Association of State Venture Funds (NASVF) Founding Board member and Executive Committee member; American Society of Mechanical Engineers (ASME) Strategic Innovations and Initiatives Committee; State Science and Technology Institute (SSTI) founding board member and Executive Committee member; Eisenhower Fellowships Nominating Committee and the Ernst and Young Entrepreneurial Institute as national/regional judge.

Mr. Bendis has or continues to provide global consulting services to several international organizations including the International Science Parks and Innovation Expert Group, the United Nations, NATO, UK Trade and Industry, European Commission, French Embassy, the German Marshall Fund, and others global ventures.

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Mr. Bendis founded the Bendis Investment Group LLC, (BIG), a financial intermediary and consulting firm which has a joint venture with the Fortress Investment Group (NYSE, FIG) and is responsible for the origination of debt and equity investments located in BIG's network. Mr. Bendis, also recently provided interim CEO consulting services to the National Association of Seed and Venture Funds (NASVF) and strategic growth and repositioning services to the Pennsylvania Biotechnology Center.

Previously, Mr. Bendis served as president, and CEO of True Product ID, Inc.; a global publicly traded anticounterfeiting technology company (NASDAQ, TPID), which he relocated to Beijing, China. Mr. Bendis also founded and served as the founding president and CEO of Innovation Philadelphia (IP), a three-state regional public/private partnership dedicated to growing the wealth and workforce of the Greater Philadelphia Region. IP managed a portfolio of programs in four distinct areas: Direct Equity Investment/Financing Assistance; Technology Commercialization; Global/Regional Economic and Workforce Development; and Market Research and Branding. Mr. Bendis is on the IP Board of Directors.

Previously, Mr. Bendis successfully leveraged a career in the private sector (with Quaker Oats, Polaroid, Texas Instruments, Marion Laboratories, and Kimberly Services) and the venture capital industry (RAB Ventures) to lead the Kansas Technology Enterprise Corporation (KTEC). As its president and CEO, he developed KTEC into a globally recognized model for technology-based economic development. Mr. Bendis also successfully built an Inc. 500 health care software company, Continental Healthcare Systems, Inc., which he took public on NASDAQ and later sold to an international conglomerate. In addition, Mr. Bendis manages his own angel investment fund.

Mr. Bendis is a frequent consultant and speaker to the United Nations, NATO, the European Commission, METI, AKEA, national and international technology-based economic development organizations, as well as over 20 states, several U.S. cities and regions, and 16 countries. Mr. Bendis serves on several regional and national not-for-profit boards and committees including the National Association of Seed and Venture Funds (NASVF) and the State Science and Technology Institute (SSTI), both of which he was a founding board member. He was a nominee for the 2005 Ernst and Young National Entrepreneur Supporter of the Year Award (EOY) and was the 1996 recipient of the Regional Ernst and Young Entrepreneur of the Year Award; he currently serves as an EOY judge. He also serves on the board of FlagshipPDG (NASDAQ, PDGE).

NOLAN BROWNE

Nolan Browne was appointed managing director of the MIT-Fraunhofer Center for Sustainable Energy Systems in February 2008. He previously worked for

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Massachusetts-based Evergreen Solar, where he was responsible for developing business relationships around Evergreen's advanced module and expansion efforts. In this capacity, he successfully sourced three major polysilicon deals and played an instrumental role in sitting Evergreen's largest integrated solar module factory in North America. Prior to this, Browne served as a senior associate at Cambridge Energy Research Associates, where he started up CERA's Clean Energy Study. As a student at MIT's Sloan School of Management, he founded the MIT Energy Conference and was involved with a number of MIT energy start-ups, including GreenFuel Technologies. As an entrepreneur, Browne has founded two successful for-profit companies to date. He holds an M.A. and B.A. in International Economics from Johns Hopkins University School of Advanced International Studies (SAIS) and an MBA from the Massachusetts Institute of Technology.

DAVID EAGLESHAM

David Eaglesham is VP technology at First Solar. He has a Ph.D. in physics from the University of Bristol and achieved tenure as a lecturer at Liverpool University before joining Bell Labs in 1988. At Bell Labs he worked on semiconductor deposition techniques and doping and became director of electronic device research. He worked at Lawrence Livermore as chief technologist and at Applied Materials as director of advanced technologies before joining First Solar in 2006. He is a fellow of the American Physical Society, was named Outstanding Young Investigator by the Materials Research Society in 1994, and was MRS president in 2005.

STEPHEN EMPEDOCLES

Dr. Stephen Empedocles is director of business development for SVTC Solar, a solar development foundry that enables companies to transition new photovoltaic technologies into fully qualified, manufacturable products, ready for volume production. As a serial entrepreneur in the CleanTech and Advanced Materials space, Dr. Empedocles has founded and grown businesses in photovoltaics, solid state lighting, fuel cells, catalysis, and displays. He has a Ph.D. in physical chemistry from MIT and has been published in leading journals, including *Science*, *Nature*, *Physical Review Letters*, and *Forbes*, on topics ranging from fundamental nanoscience to the evolving trends in advanced materials business. He holds over 25 patents (issued and pending), and was selected as one of the world's top 100 young innovators by MIT Technology Review.

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PETE ENGARDIO

Pete Engardio is a senior writer for *BusinessWeek*. Engardio joined *BusinessWeek* in 1985 as a correspondent in Atlanta. In 1987, he moved to Miami as bureau manager. In 1990, he became a correspondent in Hong Kong. In 1996, he moved to New York and was editor of the Asian edition from 1998 to 2001. In 2003, Engardio received George Polk, Loeb, and Sigma Delta Chi awards. He was part of a team that won a 1998 Overseas Press Club Award. He is co-author of *Meltdown: Asia's Boom, Bust, and Beyond*. In 2004, Engardio was a Reuters Journalism Fellow at Oxford.

CHARLIE GAY

Dr. Charlie Gay was named president, Applied Solar, and chairman of the Applied Solar Council in 2009. As President of Applied Solar, Dr. Gay is responsible for positioning Applied and its solar efforts with important stakeholders in the industry, technical community and particularly governments around the world. As chairman of the Applied Solar Council, Dr. Gay leads a cross-company forum to assure cohesiveness on solar-related initiatives and strategy related to technology, and market development. An industry veteran with over 30 years of experience in the solar industry, Dr. Gay joined Applied Materials in 2006 as corporate vice president, general manager of the Solar Business Group.

Dr. Gay is also a co-founder of the Greenstar Foundation, an organization that delivers solar power and Internet access for health, education and microenterprise projects to small villages in the developing world. Greenstar has been recognized for its innovation by the World Bank, the Stockholm Challenge, the Technology Empowerment Network and the Tech Museum Awards.

Dr. Gay began his career in 1975, designing solar power system components for communications satellites at Spectrolab, Inc. and later joined ARCO Solar, where he established the research and development program and led the commercialization of single crystal silicon and thin film technologies. In 1990, Dr. Gay became president and chief operating officer of Siemens Solar Industries, and from 1994 to 1997, he served as director of the U.S. Department of Energy's National Renewable Energy Laboratory, the world's leading laboratory for energy efficiency and renewable energy research and technology. In 1997, Dr. Gay served as president and chief executive officer of ASE Americas, Inc., and in 2001 became chairman of the advisory board at SunPower Corporation.

Dr. Gay has a doctorate in physical chemistry from the University of California, Riverside. He holds numerous patents for solar cell and module construction and is the recipient of the Gold Medal for Achievement from the World Renewable Energy Congress.

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GABRIELLE GIFFORDS

Gabrielle Giffords is the U.S. Representative for the Eighth District of Arizona, a diverse area that covers 9,000 square miles including a 114-mile border with Mexico.

Congresswoman Giffords serves on the House Armed Services Committee and the Subcommittees on Air and Land Forces and Military Readiness where she fights for our military men and women and their families and the installations she represents at Fort Huachuca and Davis-Monthan Air Force Base. On the House Science and Technology Committee and the Subcommittee on Energy and the Environment, Cong. Giffords promotes an agenda of energy independence and solar initiatives in an effort to make Southern Arizona the "Solar-con Valley" of the nation. On the House Foreign Affairs Committee and the Subcommittee on the Western Hemisphere, she monitors our country's positions abroad, especially relationships in the Western Hemisphere and their impact on comprehensive immigration reform in the United States.

A third generation Arizonan and the youngest woman ever elected to the Arizona State Senate, Cong. Giffords represented her hometown of Tucson in the Arizona Legislature from 2000 to 2005. During her service in both the House of Representatives and the Senate, Cong. Giffords worked on legislation to expand health care coverage for Arizona families; to create and attract high-wage jobs to Arizona; and to protect Arizona's environment and open spaces. She served on the Appropriations, Commerce and Economic Development and Finance Committees.

As former president and chief executive officer of El Campo Tire, Inc., Cong. Giffords was able to utilize her experience as a small businesswoman with a broad background in national and international economic development. A 1996 graduate of Cornell University with a master's degree in regional planning, she is also a graduate of Scripps College where she was awarded a William Fulbright Scholarship to study for a year in Chihuahua, Mexico. Between her undergraduate work and her masters she worked as a researcher in San Diego studying the effects of Operation Gatekeeper II on the San Ysidro Port of Entry.

Experienced in international relations, Cong. Giffords served as president of the Atlantic Association of Young Political Leaders, represented the National Committee on China-U.S. Relations as a Young Leader's Forum Fellow and was a German Marshall Fund Manfred-Worner Fellow. In 2005 Cong. Giffords was selected for the inaugural two-year class of the Aspen-Rodel Fellowships in Public Leadership.

For combining her strong business background with a powerful commitment to public service, Cong. Giffords was named Woman of the Year by Tucson Business Edge in 2005; the YWCA named her Woman on the Move the same year. For her commitment to protecting the environment, she was named Legislator of the

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Year by the Arizona Planning Association and Most Valuable Player by the Sierra Club. She was awarded the Top 10 Technology Legislator of the Year award by the Arizona Technology Council for three straight years - 2003, 2004, 2005. She was named the Legislator of the Year in 2004 by the Mental Health Association of Arizona. She was also recently named one of America's Eight Young Leaders Worth Watching by Gannett News Service.

Congresswoman Giffords' commitment to her community has not been limited to her service in the Legislature. She has devoted her time as a member of over a dozen boards including 162nd Air National Guard Fighter Wing Minuteman Committee, the Metropolitan YMCA, the Anti-Defamation League, the Breast Cancer Boot Camp and the Tohono Chul Park. She is also a member of Congregation Chaverim.

With her family living in southern Arizona, Cong. Giffords has strong ties to Tucson and Sierra Vista. Her father served on the school board in Tanque Verde District and her mother is an art conservator. Her grandparents lived in southeastern Arizona and are buried in Ft. Huachuca. Cong. Giffords and her husband Mark Kelly enjoy hiking and spending time in the canyons and desert of Arizona.

JOHN GLOEKLER

John Gloekler is CEO of Apogee Solar. Previously John was CEO of G2 Microsystems, an IC company that developed the world's lowest power Wi-Fi chips. Prior to working at G2, he was a partner at Ernst & Young LLP and a leader of the supply chain practice. At E&Y, Mr. Gloekler led the Supply Chain Strategy practice and worked with IBM, Apple, HP, Seagate, Cisco, Microsoft, and others developing their supply chain strategies. He also held positions as vice president of manufacturing for Austek Microsystems and engineering roles at National Semiconductor and Texas Instruments. Mr. Gloekler has a B.S. in electrical engineering from the University of Cincinnati and an M.S. in business from Stanford University.

SUBHENDU GUHA

Subhendu Guha is the Chairman of United Solar Ovonic, the world's largest manufacturer of flexible solar laminates. Dr. Guha is an international authority in the science and technology of amorphous silicon alloy solar cells. His work has received recognition from the U.S. Department of Energy (Bright Light Award), *Popular Science* magazine (Best of What's New), and *Discover* magazine (Best Invention in the Environment Category). He was also the recipient of a World Technology Award in the Energy category in 2005 and a PVSEC Award in 2009.

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KEVIN HUTCHINGS

Kevin J. Hutchings is vice president of alliances, IBM Technology and Intellectual Property. He is responsible for IBM's Microelectronics technology development and manufacturing business alliances and licensing. In this and his prior role, Mr. Hutchings has been a lead contributor in the growth of IBM's successful semiconductor development alliances.

Prior to assuming his current role in June of 2007, Mr. Hutchings was director of IBM's System and Technology Group alliances, which develops, manufacturers and markets IBM's server, storage and microelectronics technologies, products and services.

Mr. Hutchings joined IBM in 1979; during his career at IBM he has held numerous management and technical positions related to the development, manufacturing and sales of IBM's advanced semiconductor technologies and services. In 2004, he was named director of alliances.

Mr. Hutchings received an Associate in Applied Science degree in electronics in 1979, a Bachelor of Science degree in electrical engineering from Rensselaer Polytechnic Institute in 1984, and a Masters of Business Administration degree from the Zicklin School of Business in New York City in 1998.

ALICIA JACKSON

Alicia Jackson currently serves as professional staff for the U.S. Senate Committee on Energy and Natural Resources, under the Chairmanship of Senator Jeff Bingaman. Dr. Jackson's portfolio on the committee includes smart grid, manufacturing and industrial competitiveness, federal energy R&D, and advanced energy storage technologies. Dr. Jackson's interests lie at the intersection of science and policy. She was an energy scholar in the Program on Science in the Public Interest at Georgetown University and founded a science policy course for science and engineering graduate students at the Massachusetts Institute of Technology. Prior to joining the committee, Dr. Jackson served as a policy fellow at the National Academies of Science and as an AAAS Congressional Science Fellow with the Senate Energy Committee. Dr. Jackson earned her Ph.D. in materials science and engineering from MIT in 2007, where she discovered a new class of nanomaterials known as nanostructured nanoparticles.

KRISTINA JOHNSON

Kristina M. Johnson is the Under Secretary of the U.S. Department of Energy. She was previously the provost and senior vice president for academic affairs of Johns Hopkins University. Prior to that, Dr. Johnson served as the Dean of

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Duke University's Pratt School of Engineering from 1999-2007 where she helped to set up interdisciplinary efforts in photonics, bioengineering and biologically inspired materials, and energy and the environment. Before that she was on the faculty of the University of Colorado, Boulder, from 1985-1999, where she led an NSF Engineering Research Center and involved engineers, mathematicians, physicists, chemists and psychologists in working to make computers faster and better connected. Dr. Johnson is an electrical engineer with more than 129 U.S. and foreign patents or patents pending.

JOHN LUSHETSKY

John Lushetsky is Acting Deputy Assistant Secretary for Energy Efficiency in the U.S. Department of Energy's (DoE's) Office of Energy Efficiency and Renewable Energy (EERE). Mr. Lushetsky is responsible for EERE's efforts to develop clean and energy-efficient technologies for vehicles, buildings, and industries and manages activities to implement energy efficiency and renewable energy technologies within the federal government. As part of EERE's senior leadership, Mr. Lushetsky helps to oversee $16.8 billion in American Recovery and Reinvestment Act funding, including state, city, and community programs for energy efficiency, as well as other energy efficiency programs focused on buildings, industrial technologies, and advanced vehicles.

Prior to this position, Mr. Lushetsky served as program manager of DoE's Solar Energy Technology Program (SETP) with responsibility for all activities under the Solar America Initiative. He directed the program's $170 million budget through solar technology research and development agreements with universities, venture capital funded start-ups, and established companies and oversaw solar research and development through the National Renewable Energy Laboratory (NREL) and other national labs. In this role, Mr. Lushetsky led key solar market transformation programs in collaboration with legislators, industry groups, utilities, city governments, and other key stakeholders.

Prior to his public service at the Department of Energy, Mr. Lushetsky's career included more than 20 years experience in technology development and commercialization roles with both start-up and Fortune 500 companies. Most recently, he was with Corning, Inc., where he held a number of senior positions with responsibility for strategic marketing and business development activities and assessed new opportunities for the company in a number of new technology and market areas. He also previously managed acquisitions, collaborations, and minority equity investments which expanded the company's access to new technologies.

Prior to working at Corning, Mr. Lushetsky was with Electrosource, Inc., an advanced battery technology start-up for electric and hybrid vehicles. At

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Electrosource, he forged groundbreaking international partnerships in India, China, and Taiwan managing marketing, business development, and company financing. Before Electrosource, Mr. Lushetsky consulted to the Department of Defense's Strategic Defense Initiative Organization developing new strategies for systems engineering, procurement, and development of tactical and strategic missile defense systems.

Mr. Lushetsky holds an MBA in international business from George Washington University and an M.S. and B.S. with high honors in engineering science from the University of Florida. He previously has done research and development in advanced optical systems.

W. CLARK MCFADDEN II

W. Clark McFadden II is a partner at Dewey & LeBoeuf, LLP. He represents corporate clients in international trade, encompassing work in litigation, regulation, and legislation. He also specializes in international corporate transactions, especially the formation of joint ventures and consortia, and international investigations and enforcement proceedings.

Mr. McFadden has a broad background in foreign affairs and international trade, having experience with congressional committees, the U.S. Department of Defense, and the National Security Council.

In 1986, he was appointed general counsel, President's Special Review Board ("Tower Commission"), to investigate the National Security Council system and the Iran-Contra Affair.

In 1979, Mr. McFadden served as special counsel to the Senate Foreign Relations Committee on the Strategic Arms Limitations Treaty (SALT II). Previously, from 1973-1976, he was general counsel, Senate Armed Services Committee, and was responsible to the committee for all legislative, investigatory, and oversight activities.

Mr. McFadden is the secretary to the board of directors of the Semiconductor Industry Association, the Optoelectronics Industry Development Association, and the Semiconductor Research Corporation.

JAMES MORELAND

James Moreland is the vice president of technology for SolarWorld Industries America. He is responsible for research and development, quality and for coordinating development tasks with SolarWorld Innovations, Freiberg.

Prior experience—35 years in the semiconductor industry, primarily in the silicon materials part of the supply chain. Dr. Moreland's posts have included the director of technology at Komatsu Silicon America, vice president for strategic

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technology development for Siltronic Corp., vice president of research and development for Siltronic AG, and director of quality for Siltronic Corp., and he has participated for many years in the development of ITRS and SEMI Standards.

MICHAEL POLCARI

Michael R. Polcari has served as SEMATECH's president and CEO since 2003. He is responsible for leading the consortium's advanced technology R&D programs in lithography, front end processes, interconnect, and metrology. Dr. Polcari has also overseen the launch of two SEMATECH subsidiaries—ATDF, as a leading R&D processing and prototyping center, and the International SEMATECH Manufacturing Initiative (ISMI), which has added seven members during his tenure.

Previously, Dr. Polcari was vice president of procurement engineering for IBM Global Procurement in Somers, NY, and was responsible for IBM's engineering effort in procurement including supplier quality management. During his nearly 30 years of working for IBM, Dr. Polcari also held positions as research director—Silicon Technology and director of the Advanced Semiconductor Technology Laboratory at the IBM T. J. Watson Research Center, and Lithography Systems Manager for the IBM Semiconductor Research and Development Center.

Dr. Polcari earned a Ph.D. and Master of Science in solid-state physics from the Stevens Institute of Technology. He conducted additional graduate work in physics at the University of Maryland, and earned a Bachelor of Science in physics from the University of Notre Dame.

Polcari has served as chairman of the board of directors of the Semiconductor Research Corporation (SRC) and as a member of several industry and university advisory boards. He is a member of the American Physical Society, the Electrochemical Society, the Society of Photo-Optical Instrumentation Engineers, and the Institute of Electrical and Electronics Engineers.

KENT ROCHFORD

Kent Rochford is the acting director of NIST Boulder Laboratories. He is also serving as the chief technical representative for the NIST Boulder Laboratories and acting director of the Electronics and Electrical Engineering Laboratory (EEEL). Dr. Rochford holds a Ph.D. in optical science from the University of Arizona and has broad experience in optoelectronics metrology. He joined NIST in 1992 as a postdoctoral research associate, and he conducted and led research on measurements and standards for sensing and communications until 2000. After two years of managing an engineering department in a start-up optical communications company working on components for high-performance communication

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systems, he returned to NIST in 2002. He was chief of the EEEL Optoelectronics Division from 2003 to 2008.

DOUG ROSE

Doug Rose joined SunPower in 2002 and currently holds the position of senior director, technology strategy. Previous roles at SunPower include product engineering manager of the company's cell pilot line, director of module research and development, and technology development director. His career spans more than 20 years of manufacturing technology development, thin-film PV research, silicon cell and module development, and technology assessment at GTE, the National Renewable Energy Laboratory, First Solar, and SunPower Corporation. Dr. Rose has degrees in mechanical engineering from Iowa State and Stanford University, and a Ph.D. in electrical engineering from the University of Colorado. He has 58 publications and patents in the field of solar energy.

JAMES SITES

Jim Sites is the associate dean for research and professor in the Colorado State University College of Natural Sciences. From 1981 to 1987, Prof. Sites was coordinator for the undergraduate physics laboratories, and during 1989-1990, he was associate department chair with responsibilities for course scheduling, teaching assignments, and space utilization. In 1994-1995, he was part of the university's Academic Change and Reform Committee, which initiated several university-wide structural changes.

From 1990 through 2000, Prof. Sites served as department chair with direct responsibility for the success of a 20-faculty-member department. That success included a tripling of external funding, establishment of a nationally recognized high-energy physics program, development of a highly popular outreach program for precollege students, expansion of the department's support staff, and completion of a major building addition.

Prof. Sites is currently serving in his sixth year as associate dean for research for the College of Natural Sciences. He has responsibility for major research and building projects, and he was instrumental in the establishment of the university's clean-energy supercluster. He also coordinates with other Colorado universities, provides oversight for several centers and institutes, and serves on the Council of Research Associate Deans, which advises the vice president for research.

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LARRY SUMNEY

Larry W. Sumney is president and chief executive officer of the Semiconductor Research Corporation (SRC). The SRC executes a global cooperative research effort in universities that is supported by leading integrated circuit manufacturers and suppliers worldwide. He received his B.A. from Washington and Jefferson College in 1962 with honors in physics; his master's in engineering administration (MEA) from George Washington University (GWU) and completed his course work toward the D.Sc. degree in systems engineering and mathematics, also at GWU.

Mr. Sumney began his career as a research physicist at the Naval Research Laboratory in 1962, later serving as research director of the Naval Electronics Systems Command where he defined broad basic research initiatives to support advanced systems needs of the Command. Following that assignment, Mr. Sumney was named the director of the Tri-Service Charge Coupled Device (CCD) Technology Development Program by the Office of the Under Secretary of Defense. He next joined the Office of the Undersecretary of Defense Research and Engineering where he had overall responsibility for the creation, implementation and management of the Very High Speed Integrated Circuits (VHSIC) Program, the largest (~ $1B) technology development program in the Department of Defense. He was named a "VHSIC Pioneer" in 1987.

In 1982, the Semiconductor Industry Association selected Mr. Sumney to head up the industry's new research consortium, the Semiconductor Research Corporation. He was named president and CEO in 1984 and a member of SRC board of directors several years later. In 1997, he became chairman of board, MARCO, a wholly owned subsidiary of SRC, which manages the Focus Center Research Program. In 2005, he became chairman of the board, NERC, another wholly owned subsidiary of SRC, which manages the Nanoelectronics Research Initiative. Since the SRC Education Alliance was established, he has held the position of board chairman. The SRC Education Alliance which is also a wholly owned subsidiary of SRC.

Mr. Sumney has served on the EECS Department Advisory Board of the University of California, Berkeley, on the University of Illinois, College of Engineering Advisory Board and the North Carolina State University Engineering Advisory Board. He is chairman of the SIA University Research Award Selection Committee. He is a participant in the SIA's Focus Center Research Program Governing Council. He has served on the Director's Advisory Board of the National Security Agency.

He is an ex-officio member of the Board of Directors for SEMATECH and the Semiconductor Industry Association (SIA). He is a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and was awarded, together with

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William C. Holton and Robert M. Burger, the 1998 IEEE Frederik Philips Medal. He is a fellow of the American Association for the Advancement of Science (AAAS), a member of the New York Academy of Sciences and is a University-Industry Forum Member (as a University Partner) of the National Academies' (NAS, NAE, and NIH) Government, University, and Industry Research Roundtable (GUIRR). He served as a member of the IEEE Robert N. Noyce Medal Committee from 1999 to 2002. He also served on the IEEE Frederik Philips Award Committee from 2000 to 2004. Mr. Sumney was named a member of ASTRA's (The Alliance for Science & Technology Research in America) Board of Directors' in June 2004. In January 2006, Mr. Sumney began serving on the Sun Trust Board of Advisors and was named a member of the University of Albany, Board of Visitors in January 2006.

SRC was the recipient of the National Medal of Technology in 2007; the year 2007 marks the 25th anniversary of SRC. Mr. Sumney has provided the overall leadership for SRC since its inception in 1982.

MARK UDALL

Mark Udall was elected to the U.S. Senate by the people of Colorado on November 4, 2008, after representing the state's second congressional district for five terms (from 1999 to 2008). Prior to that, Udall served in the Colorado State Legislature as a Member of the General Assembly for one term (1997-1999), representing the 13th district, which encompassed the community of Longmont and parts of southern Boulder County.

In the Senate, Mr. Udall serves on three committees and is one of a few freshman Senators chosen to lead a subcommittee. These committees include Armed Services, Energy and Natural Resources, and the Special Committee on Aging. Reinforcing his priority of protecting our western lands, Senator Udall chairs the National Parks Subcommittee. His committee assignments give him a platform to address many issues important to Colorado, including national security, energy, the economy, 'green jobs,' and natural resources.

Senator Udall is known for reaching across party lines to solve problems and for his willingness to work with people, including those with whom he has philosophical differences. His inclusive and bipartisan approach has led to a number of legislative achievements, including legislation to reduce wildfire risk and bark-beetle infestation, promoting the development of Colorado's aerospace industry, the high technology sector and energy resources, with particular focus on renewable energy and the so-called "Green Energy Economy." Senator Udall also led efforts to successfully pass the James Peak Wilderness Bill and legislation transforming the Rocky Flats Nuclear Weapons facility into a wildlife refuge. He's also championed

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health care for workers and retirees from the nation's nuclear weapons complex and consumer protection against abusive and predatory credit card companies.

Regarded as a national leader on renewable energy, Senator Udall worked to put Colorado at the forefront of sustainable energy development. In 2004, he successfully co-chaired the Amendment 37 campaign to pass Colorado's first Renewable Electricity Standard (RES), which requires power companies to use more alternative energy sources. In 2007, the House of Representatives twice passed a national renewable electricity standard championed by Senator Udall. He continues his work in the Senate to enact a national RES.

Senator Udall is also known for his efforts to develop a tough and smart national security strategy, leading legislative action to expand and strengthen the U.S Army. Moreover, Senator Udall has consistently fought for programs to benefit our nation's veterans.

The *Denver Post* notes that Senator Udall has a proven track record of bi-partisan accomplishments. The *Rocky Mountain News* says, "time and again he's reached across the political aisle to craft a compromise solution to some sticky political problem." The *Grand Junction Daily Sentinel* calls Senator Udall "conscientious," "highly capable" and "energetic."

Senator Udall was born on July 18, 1950, in Tucson, Arizona, but has spent his entire adult life in Colorado. After graduating from Williams College in 1972, he moved to Colorado's western slope and began a long and successful career with the Colorado Outward Bound School, as a course director and educator from 1975 to 1985 and as the organization's executive director from 1985 to 1995. Senator Udall is an avid mountaineer and has climbed or attempted some of the world's most challenging peaks, including Mt. Everest.

Senator Udall's family is no stranger to public service. His father, Morris "Mo" Udall, served in the U.S. House of Representatives for 30 years and ran for the Democratic nomination for President in 1976. His uncle, Stewart, is widely revered for his accomplishments while serving as Secretary of the Interior under U.S. presidents Kennedy and Johnson. In 2008, Udall's cousin, Tom Udall, was elected to the Senate from New Mexico.

Senator Udall and his wife, prominent attorney and conservationist Maggie Fox, have two children: a son Jed and a daughter Tess. They live near Eldorado Springs in Boulder County.

BETTINA WEISS

Bettina Weiss is the senior director of photovoltaics for SEMI's PV Group. She has been working in the semiconductor and related industries for almost 20 years. She joined the SEMI organization in January 1996 in the SEMI Europe office in Brussels, Belgium, as standards coordinator. In spring of 1997, she

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transferred to SEMI Global Headquarters in San Jose, California, as standards development specialist and, in 2000, became manager, program development, where she was responsible for the expansion of the SEMI International Standards Program into new technologies and new regions. From November 2003 to March 2008, she served as director, international standards, as chief staff of the SEMI International Standards Program. In April 2008, she accepted the position of senior director, photovoltaics, managing all aspects of SEMI's PV Group initiatives globally. Ms. Weiss works with industry stakeholders, academia, and governments worldwide, as well as the SEMI International board of directors to drive PV Group's global strategic mission in public policy, standardization, manufacturing supply chain support, market research and other initiatives.

Prior to joining SEMI, Ms. Weiss worked in marketing and sales positions at Metron Technology and Varian Semiconductors in Munich, Germany. She holds a B.A. degree in English from the Ludwig-Maximilian-University of Munich and is a certified translator (English) for Anglo-American Law and Economics. She lives with her husband Don in San Jose, California.

CHARLES WESSNER

Charles Wessner is a National Academy Scholar and director of the Program on Technology, Innovation, and Entrepreneurship. He is recognized nationally and internationally for his expertise on innovation policy, including public-private partnerships, entrepreneurship, early-stage financing for new firms, and the special needs and benefits of high-technology industry. He testifies to the U.S. Congress and major national commissions, advises agencies of the U.S. government and international organizations, and lectures at major universities in the United States and abroad. Reflecting the strong global interest in innovation, he is frequently asked to address issues of shared policy interest with foreign governments, universities, research institutes, and international organizations, often briefing government ministers and senior officials. He has a strong commitment to international cooperation, reflected in his work with a wide variety of countries around the world.

Dr. Wessner's work addresses the linkages between science-based economic growth, entrepreneurship, new technology development, university-industry clusters, regional development, small-firm finance and public-private partnerships. His program at the National Academies also addresses policy issues associated with international technology cooperation, investment, and trade in high-technology industries.

Currently, he directs a series of studies centered on government measures to encourage entrepreneurship and support the development of new technologies and the cooperation between industry, universities, laboratories, and government

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to capitalize on a nation's investment in research. Foremost among these is a congressionally mandated study of the Small Business Innovation Research (SBIR) Program, reviewing the operation and achievements of this $2.3 billion award program for small companies and start-ups. He is also directing a major study on best practice in global innovation programs, entitled *Comparative Innovation Policy: Best Practice for the 21st Century*. Today's meeting on "Partnering for Photovoltaic Manufacturing in the United States" forms part of a complementary analysis entitled *Competing in the 21st Century: Best Practice in State & Regional Innovation Initiatives*. The overarching goal of Dr. Wessner's work is to develop a better understanding of how we can bring new technologies forward to address global challenges in health, climate, energy, water, infrastructure, and security.

KEN ZWEIBEL

Ken Zweibel is the founding director of the George Washington University Solar Institute. He has almost 30 years experience in solar photovoltaics. He was the program leader for the Thin Film PV Partnership Program at the National Renewable Energy Lab until 2006. The Thin Film Partnership worked with most participants in thin-film PV (companies, universities, scientists) and is often credited with being crucial to the development of thin film PV in the United States. Corporate graduates of the Partnership include First Solar, Unisolar, Global Solar and numerous others. Dr. Zweibel subsequently co-founded and became president and chairman of a thin-film CdTe PV start-up, PrimeStar Solar. PrimeStar was subsequently purchased by General Electric and is now the feature company in their solar portfolio. In 2008 he became founding director of The George Washington University Solar Institute.

Dr. Zweibel is well known worldwide in solar energy. Recently, he co-authored a *Scientific American* article (January 2008) on solar PV and concentrating solar power as solutions to climate change and energy problems. He has also written two books and numerous articles on solar PV. He is participating on the DoE "Solar Vision" activity, which is defining a pathway for solar to be deployed on an energy significant scale in the United States. Dr. Zweibel is a graduate of the University of Chicago in physics.

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