June 23-25, 1999
Chicago, Illinois

Facilitated by the
National Center for
Photovoltaics (NCPV)
for the U.S. PV industry

Prepared by Energetics, Incorporated
Columbia, Maryland • September 1999

Report of the Photovoltaic (PV) Industry Roadmap Workshop

June 23-25, 1999
Chicago, Illinois

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Foreword

This report documents a workshop on the technology barriers and research needs of the photovoltaics (PV) industry. The workshop, which was held June 23-25, 1999, in Chicago, Illinois, brought together 44 technology and market experts from the PV industry, universities, and government research programs. It was facilitated by the National Center for Photovoltaics (NCPV) on behalf of the PV industry's effort to develop its technology roadmap for the future.

The PV Industry Roadmap is an industry-wide effort to create a blueprint of research, technology, and market priorities that are needed to accomplish long-term PV industry goals. These goals are articulated in the document *The Industry-Developed PV Roadmap: A Framework for U.S. Industry and Technology Leadership* (attached as Appendix A to this report). The roadmap workshop held in Chicago represents a major effort to identify research needs for the Roadmap. We welcome comments and suggestions regarding the completeness and accuracy of the workshop's findings.

This document must be viewed as evolutionary in nature. While it presents an impressive distillation of PV industry research needs, the workshop was necessarily limited in time, scope, and participation, and may not fully incorporate all viewpoints. Every effort was made to include a broad range of industry participants, but it is inevitable that valuable ideas may have been left out. Thus, this document should be considered as a "work in progress" to develop an industry consensus on PV research and market transformation needs that will evolve as additional information becomes available.

Contacts

For current versions of this document and updates about the PV Industry Roadmap, please see www.nrel.gov/ncpv. Please send any comments to pvsac@sandia.gov.

Executive Summary

The U.S. photovoltaics industry is the world leader in research, technology, manufacturing, and market share. In recent years, however, foreign governments have recognized the very large market oppor-tunities that PV systems present. World interest is being fueled by a number of key PV attributes, including its availability as a clean, emission-free, and renewable energy source, its reliability, consumer-friendliness, and ability to be deployed in a variety of applications, and its importance to our national energy security as a fuel-free, distributed energy source. This world interest is reflected in well-coordinated research and deployment programs in various countries, including Japan and Germany, among others, that is leading to establishment of very strong international competition in PV technology.

The U.S. PV industry has recognized that large market opportunities exist for photovoltaics, but understands as well the challenge of emerging international competition. To meet this challenge, and to realize the environmental, economic, and energy-security benefits of a large PV industry for the U.S., a committee has been convened to develop a strategic plan, or roadmap, for achieving full market potential of the U.S. PV industry. The Advisory Board for the National Center for Photovoltaics (NCPV) is currently serving as the PV Roadmap Steering Committee, and consists of representatives of major U.S. PV manufacturers, utilities, and universities (Exhibit 1). The NCPV is facilitating the development of the PV Industry Roadmap for the U.S. PV industry. The NCPV helps guide the U.S. PV R&D program for the U.S. Department of Energy and is a partnership between the National Renewable Energy Laboratory (NREL) in Golden, Colorado, and Sandia National Laboratories in Albuquerque, New Mexico. Together, these organizations and individuals are utilizing the expertise of industry, the

Exhibit 1. PV Roadmap Steering Committee

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

research community, and other interested parties to cooperatively develop a strategic plan that will raise the level of financial and technical investment in photovoltaic technologies.

The roadmap will guide U.S. photovoltaics research, technology, manufacturing, applications, markets, and policy through 2020. Early in 1999, the PV committee established the following vision as a first step in developing the PV industry roadmap:

> *"...to realize a thriving United States-based solar electric power industry, which provides competitive and environmentally friendly energy products and services that meet the needs and desires of the domestic electric-energy consumer."*

In support of this vision, the PV Roadmap Steering Committee identified an aggressive growth strategy for the PV industry (Exhibit 2) that would result in a large projection of cumulative installed PV capacity in the United States and the world (Exhibit 3). Additionally, four concepts for implementing the vision and these projections have been developed. They are as follows:

Exhibit 2. PV Growth Strategy 2000-2020

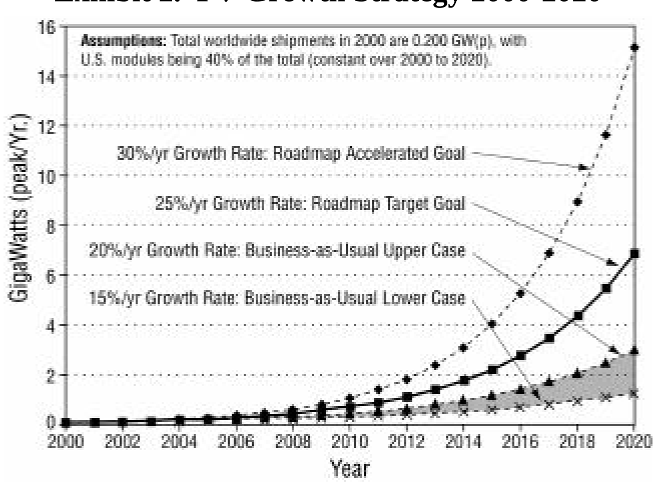
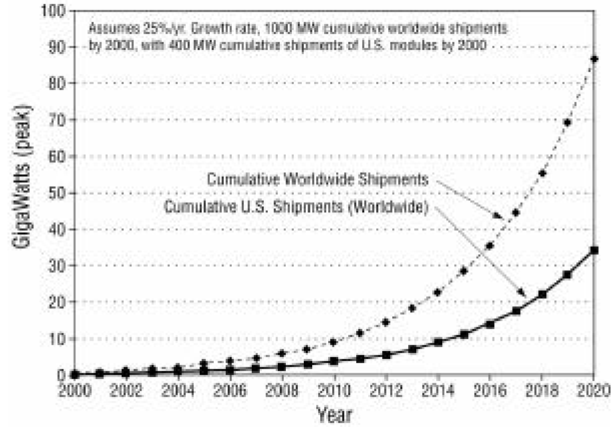


Exhibit 3. Cumulative PV Shipments for the U.S. and Worldwide



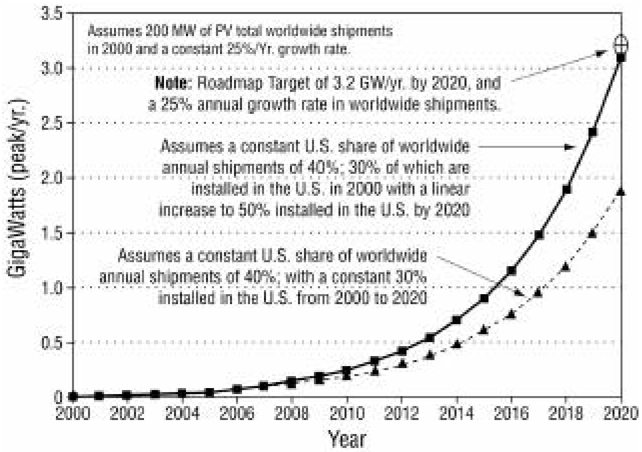
- *Maintain the U.S. industry's worldwide technological leadership*
- *Achieve economic competitiveness with conventional technologies*
- *Maintain a sustained market and PV production growth*
- *Make the PV industry profitable and attractive to investors*

The PV Industry Roadmap Steering Committee articulated a number of goals and targets to support the vision and four concepts. Addressing new electrical generating requirements, the PV Roadmap Steering Committee projected the following "endpoint" for 2020:

> *"For the domestic photovoltaic industry to provide up to 15% (about 3,200 MW) of new U.S. peak electricity generating capacity expected to be required in 2020. The U.S. cumulative PV shipments will be about 30 GWp at this time."*

Overall goals for the U.S. photovoltaics industry align with the 25% annual production growth rate displayed in Exhibit 4. Specific goals are categorized in two major industry target areas—installed volume and cost:

Exhibit 4. Projections of U.S. Manufactured PV Modules Installed in U.S. Domestic Applications



- Total installed volume of at least 6 GW for the U.S. industry in 2020, of which 3.2 GW is used in *domestic* installations. Expected application mix will be

  < 1/2 AC distributed generation
  < 1/3 DC and AC value applications
  < 1/6 AC grid (wholesale) generation

- Installed volume will continue to increase, exceeding 9 GW in 2030.

- *Cumulative* U.S. installed capacity in 2020 of about 15 GW, or about 20% of the 70 GW expected worldwide.

- End-user costs, including O&M, of $3 per watt AC in 2010, and approaching $1.50 per watt AC in 2020. Manufacturing costs are projected to be 60% of system costs.

- International markets are significant and will remain a substantial portion of sales for the U.S. PV industry. A strong domestic market for PV systems is necessary in order to keep the international competitiveness of the U.S. PV industry and to obtain the environmental and distributed energy benefits of PV energy for U.S. consumers.

To reach these goals, the PV industry and its partners identified four critical **Technology Development Areas,** around which the roadmap process was fashioned. These include:

- Markets and Applications
- PV Components, Systems, and Integration
- Manufacturing, Equipment, and Processes
- Fundamental and Applied Research

On June 23-25, 1999, the NCPV, on behalf of the PV Industry Roadmap Steering Committee, hosted 44 experts from the PV industry, as well as decision-makers from electric utilities, universities, research organizations, system integrators, and marketers, to develop the preliminary outlines for the PV Roadmap. The three-day workshop addressed technology and market barriers, and research, marketing, and technology transfer needs of the entire PV industry. The core of the workshop was four facilitated breakout sessions, in which participants explored the primary barriers and needs in the four technology development areas. These breakout sessions resulted in over 140 ideas, of which about 20 were considered priority. Exhibit 5 lists the top research and technology transfer needs for each breakout session.

Workshop participants took a further step in each of their breakout sessions to identify a progression of actions that should be taken to best address the barriers and needs related to each Technology Development Area, which included both linkages among the categories of needs as well as time frames for achieving success in carrying out the top priority needs and actions. Each group identified appropriate time frames in which research or market transformation would be expected to yield benefits. Research and technology transfer activities were assigned to one of three time frames: near-term (0-3 years), mid-term (3–10 years), and long-term (beyond 10 years). Participants also identified appropriate roles for industry, government, and educational institutions to support selected research or technology transfer activities. In some instances, industry was identified as the lead; in others, government was so identified. The results of these efforts are described in this report and will undoubtedly shape the compre-hensive roadmap for implementing PV technology goals.

In closing remarks, workshop participants supported continuation of the roadmapping effort for photovoltaics, suggesting that an actual roadmap, based on the stated vision and the results of this first workshop, be developed by the industry, with support from government and other interested partners. Participants pointed to major paradigm shifts in the energy supply and distribution system as a result of deregulation in the electricity marketplace. These shifts are driving consumer support for self-supply of energy in ever-increasing numbers. The PV industry should work through its trade association and allies to pursue collaborative research and technology transfer activities for both their own, and world-wide consumer benefit.

Exhibit 5. Selected High Priority Research and Technology Transfer Needs for the PV Industry

Markets and Applications	PV Components, Systems, and Integration	PV Manufacturing	Fundamental and Applied Research
Create an effective industry coalition by forming a traditional, professional, industry-funded trade association, that can lobby and market PV, conduct analysis of competing technologies, and develop alliances with other groups Conduct consumer education programs in cooperation with other organizations, such as DPCA and NAESCO Include photovoltaic technology education as a part of the science curriculum, so that it is a standard component of science learning Improve involvement with government, legislative, and regulatory decision-makers and clearly articulate the impacts of inaction Obtain long-term, low-interest financing for PV systems	Develop national and international standards for PV products and components, including ratings and verification tools for appropriate sized systems Provide wider, more effective public exposure to PV products and their value Design value-added building products using PV Improve reliability, cost-effectiveness, and ease of maintenance for PV products that may be used in buildings and building systems, and quantify externalities associated with these products Demonstrate examples of good building design, and integrated systems, using PV components	Develop manufacturing partnerships so manufacturers can work with suppliers to develop the next generation of PV equipment Develop on-line diagnostic tools and systems to enhance process control and development Conduct equipment demonstrations at high volume (10,000 cells), so that others involved in manufacturing can observe and analyze data Develop high volume, high throughput, high efficiency cell processes Design lower cost module packaging	Research, develop, and demonstrate new materials, such as thin glass, through chemical tempering, thin semi-conducting materials, new encapsulants, low temperature conducting epoxy, optimized transparent conducting oxides, and alternative substrates Improve cell efficiencies to reduce material costs Develop materials and devices with high efficiency and low cost through R&D with specific targets Address issues to increase throughput, including improved automation, process control and scale-up (for cells and module fabrication), high speed interconnect and encapsulation, strategies to improve industry wide throughput, and development of novel technologies such as rapid thermal processing (RTP) and high rate deposition (HRD) Address thin-film manufacturing issues, such as basic R&D, to develop process control needs, process models, in-situ diagnostics, reactor and equipment design, mixed process integration, and better intermediate in-line testing and diagnostics

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Plenary Session

BACKGROUND

The U.S. PV industry is the world leader in research, technology, manufacturing, and market share. In recent years, however, foreign governments have recognized that PV systems present a potentially large market opportunity for electrification of both urban and rural communities. World interest is being fueled by a number of PV attributes, including its availability as a clean, emission-free, and renewable energy source, its reliability, consumer-friendliness, and ability to be deployed in a variety of applications, and its importance to national security as a fuel-free, distributed energy source.

Industry leaders understand the challenge of emerging international competition. To meet this challenge, the industry began the development in January 1999, of a roadmap, or strategic plan, for achieving full market potential of photovoltaics, both in the U.S. and abroad. The PV Industry Roadmap Steering Committee has prepared a long-term vision of market, industry components, manufacturing, and research challenges in a document entitled, *The Industry-Developed PV Roadmap: A Framework for U.S. Industry and Technology Leadership.* This roadmap vision represents an important step toward defining a comprehensive research, development, and deployment strategy that will enable the photovoltaics industry to achieve its long-term goals.

The *Framework* document recognizes the importance of collaborative planning and R&D partnering to its future vitality, especially since no segment of the industry is currently large enough to guide the needs of the entire infrastructure on its own. By developing a roadmap to the year 2020, the U.S. PV industry hopes to address critical needs of photovoltaic technology and ensure continued U.S. industry leadership both here and abroad.

The photovoltaics industry roadmap process is being coordinated by the National Center for Photovoltaics (NCPV). The NCPV Advisory Board is currently serving as the roadmap's steering committee and guiding the overall roadmap process. With the *Industry-Developed PV Roadmap* as a basis for discussion, the NCPV planned and coordinated a PV Industry Technology Roadmapping Workshop on June 23-25, 1999, to address barriers and needs of the PV industry.

The Plenary Session of the workshop helped participants gain a common understanding of the vision for the U.S. PV industry, implications of the vision in terms of directions, goals, and targets, financing PV in relationship to competing technologies, and marketing PV to potential end users.

THE VISION FOR THE U.S. PV INDUSTRY

Allen Barnett, representing the PV Industry Roadmap Steering Committee, reviewed the vision as articulated in the *Industry-Developed PV Roadmap* document, *"...to realize a thriving United States-based solar electric power industry, which provides competitive and environmentally friendly energy products and services that meet the needs and desires of the domestic electric-energy consumer."*

He spoke about the need for the PV roadmap to serve all interests, including consumers, industry leaders, researchers, and manu-facturers. The roadmap can help them all to get PV costs into a competitive range, as compared with competing technologies, and to enhance profits, which, in turn, will improve the health of the industry.

IMPLICATIONS OF THE VISION: GOALS, TARGETS, AND ENDPOINTS

Roland Hulstrom, representing the NCPV, reviewed the Goals, Targets, and Endpoints articulated in the *Industry-Developed PV Roadmap* document. The roadmap focuses on maintaining and building the global leadership of the U.S. PV industry, in large part through growth in the domestic market. A projected growth figure is estimated to be 25% annually.

The "endpoints" projected for PV are for the domestic photovoltaic industry to provide up to 15% (about 3,200 MW) of new U.S. electricity generating capacity in 2020 and 25% in 2030. U.S. cumulative PV shipments will be about 30 GW at this time.

Specific goals stated in the roadmap document include total installed volume of at least 6 GW for U.S. industry in 2020, of which 3.2 GW will be used in domestic installations. The application mix is expected to be:

1/2 AC distributed generation
1/3 DC and AC value applications
1/6 AC grid (wholesale) generation.

Installed volume will continue to increase, exceeding 9 GW of domestic photovoltaics in 2030. In 2020, the cumulative installed U.S. capacity will be about 30 GW, or about 35% of the 86 GW capacity expected worldwide.

PV end-user cost goals (including O&M costs) are expected to be $3/watt AC in 2010, approaching $1.50/watt AC in 2020. Total manufacturing costs are projected to be 60% of the costs of the system.

Mr. Hulstrom discussed the implications of these goals and targets. For example:

- The level of annual shipments will have to double every 4.1 years to maintain a 25%/year growth rate. Manufacturing capacity will have to increase accordingly.
- The U.S. will ship as many MW (of modules) from 2000 to 2008, as they did from 1980 to 1998.
- To meet the 2020 goal (3.2 MW of PV systems in the U.S.), the percentage of U.S. modules shipped to domestic applications will have to increase from 30% in 2000 to 50% by 2020.
- Capital investment dollars will be needed to support rapidly increasing manufacturing capacity growth.

FINANCING PV—KEEPING IN MIND COMPETITIVE TECHNOLOGIES

Robert Shaw, President of Arete Corporation, discussed the availability of capital for the photovoltaic industry. Sources of capital for energy businesses are available from "angel" investors, venture capital funds, government grants and contracts, corporations, institutional investors, the public market, banks, international funding agencies, and foundations. Businesses in need of funds need to understand how to attract these investors and understand that a profitable return on investment is the one key element with which investors need to be comfortable.

Social and community value of PV may be of interest to an investor, but it does not sell the story. Mr. Shaw explained that investors want a unique, well protected product or technology; a large market opportunity; a strong management team; and a track record of "on-plan" performance. In his view, the PV market is huge and the "story" is compelling—the industry just needs to do a better job of selling their story.

MARKETING PV: MEETING THE NEEDS OF END USERS

A panel of PV experts then discussed marketing photovoltaic technology and systems to meet the needs of potential end users. The panel consisted of Bob Johnson, Strategies Unlimited; Allen Barnett, AstroPower; Roland Hulstrom, NCPV; Bob Shaw, Arete Corporation; Bill Roppenecker, Trace Engineering; and Mike Stern, UPG Golden Genesis. The session was moderated by James Gee, NCPV.

Mr. Johnson presented information on the market share of PV-generated electricity in remote industrial, housing, and consumer environments; in grid-connected situations; and supplied to indoor consumers. Exhibit 6 illustrates PV's percentage of market share in these applications. Exhibit 7 illustrates the growth of major PV applications during the years 1980–1998.

Panel members then discussed a number of issues with the assembled workshop participants, including the need to allow net metering when integrating PV systems into the electricity grid; the need for better marketing to illustrate the benefits of PV to potential end users; the need for solar education in our schools, so that students can educate not only themselves, but influence their parents and care-givers; the need to work cooperatively with architects, engineers, and builders, so they become more comfortable with incorporating PV systems in their buildings; and the need to conduct cost comparisons with competing technologies on the basis of life cycle costs, rather than first costs.

DISTRIBUTED GENERATION: PV'S ROLE

Joe Ianucci of Distributed Utility Associates discussed how distributed utility resources will play a role in future electricity generation and distribution, and specifically how photovoltaics can become a significant part of the distributed utility marketplace. Exhibit 8 illustrates distributed utility technologies, which are growing in significance. PV has value as a distributed resource, but faces competition from other electricity distributed generation methods, including standby diesel generation, reciprocating engines, small com-bustion turbines and microturbines, batteries and other electricity storage, fuel cells, and natural gas.

Mr. Ianucci explained that distributed generation is likely to be developed at a rapid pace, due to utility deregulation, and that such resources will meet between 5–40% of U.S. annual energy load growth. If utilities do not take the lead in developing these resources, individual customers will do so,

Exhibit 6. Photovoltaic Market Applications – 1999 Share – Conventional Competition

Category	Market Position
Remote Industrial	MWp share: 29% (1) Price/competition: 0.1-0.5x (2)
Remote Habitation & Consumer Power	MWp share: 37% (1) Price/competition: 0.2-0.8x (2)
Grid-Connected	MWp share: 31% (1) Price/competition: 2-5x (2)
Consumer (Indoor)	MWp share: 4% (1) Price/competition: N/A (2)

(1) 1998 – 134.8 MWp, $512 million in modules FOB mfg.,$1.5 billion in end user systems sales.
1999 Est. – 155 to 170 MWp, $570 to $630 million in modules FOB mfg., $1.7 to $1.9 billion in end user systems sales.
(2) Ratio of installed photovoltaic system cost to the cost of competing conventional power.

assisted by aggressive energy services companies. The challenge for PV manufacturers, distributors, and marketers is to design PV systems so that they can be purchased by large numbers of end-use customers, and installed, operated, and maintained safely and cost-efficiently.

Exhibit 7. Growth of Major Photovoltaic Applications (1980-1998)

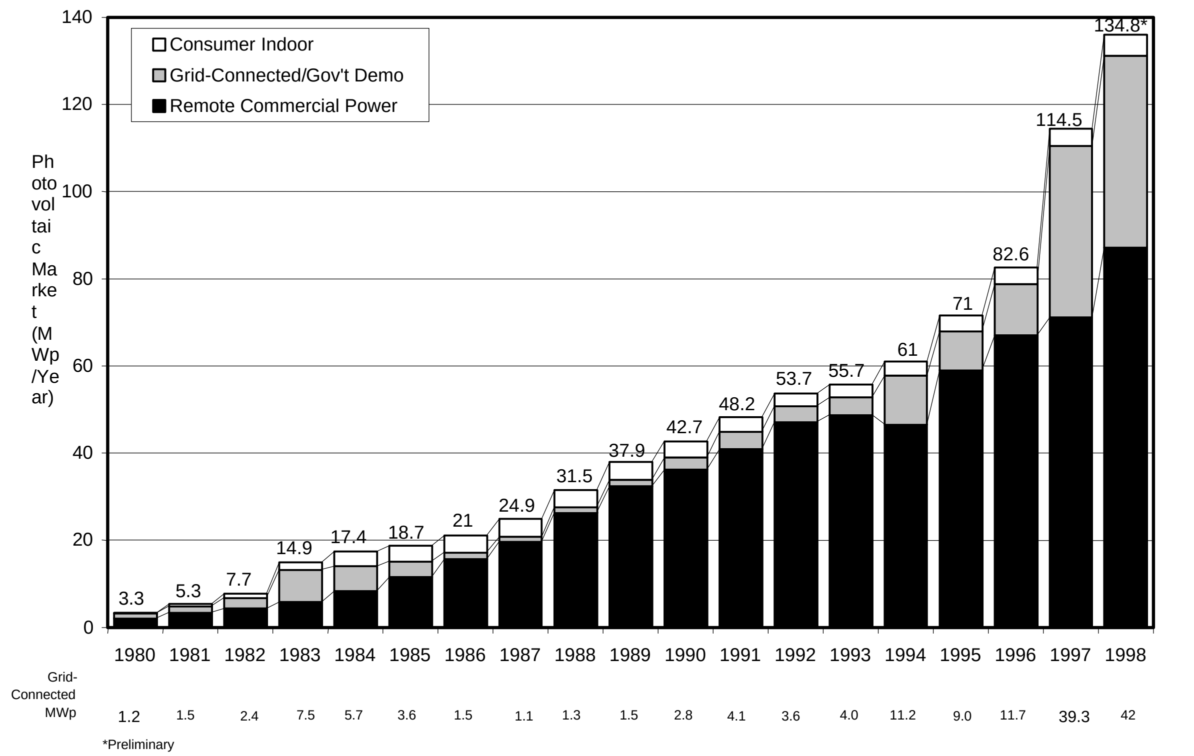


Exhibit 8. DU Technologies

- Distributed Generation
  - wind generation
  - photovoltaics
  - fuel cells
  - reciprocating engines
  - combustion turbines
  - thermal electric generators
  - Stirling engines (solar, natural gas hybrid, cogen)
- Distributed Storage
  - flywheels
  - SMES
  - batteries
  - supercapacitors
  - thermal
  - hydrogen
- Customer Energy Efficiency and DSM
- Enabling Technologies

WORKSHOP STRUCTURE

In closing the Plenary Session, Rich Scheer of Energetics, Incorporated, reviewed the agenda for the Roadmap Workshop and described the process that would be used. The core of the workshop agenda was a series of professionally facilitated breakout sessions, one for each Technology Development Area. Four parallel work groups of eight to ten people each met for 4 hours to analyze a specific set of issues related to achieving a strong PV industry in the future. The Technology Development Areas included 1) Markets and Applications, 2) PV Components, Systems, and Applications, 3) PV Manufacturing, and 4) Fundamental and Applied Research and Development. Mr. Scheer introduced the Energetics facilitators for each breakout group (Exhibit 9).

Mr. Scheer then reviewed the workshop process, including the purpose, scope, and structure for the breakout sessions (Exhibit 10). He emphasized that the results of the workshop would provide a major technical input to development of the Photovoltaics Industry Roadmap and that additional information, analysis, and inputs would be required to fully develop the Roadmap.

Exhibit 9. Breakout Session Facilitators

Markets and Applications	Jan Brinch
PV Components, Systems, and Applications	Rich Scheer
PV Manufacturing	Melissa Eichner
Fundamental and Applied Research and Development	Paula Taylor

Exhibit 10. Workshop Format and Process

Purpose

This workshop was part of an effort by the photovoltaics industry to develop a technology roadmap for achieving identified market, component, manufacturing, and research goals established by the NCPV Advisory Board. The purpose of the workshop was to

- identify critical system requirements and their targets;
- specify technology drivers and their targets;
- identify technology alternatives and their timelines; and
- recommend technology alternatives that should be pursued.

The results of the workshop will be used directly in the development of the PV Industry Roadmap. When completed, this roadmap will provide a complete picture of the near-, mid-, and long-term needs of the photovoltaics industry.

Format and Scope

The workshop was a 3-day facilitated meeting that brought together technical and marketing experts from the PV industry and related organizations to identify research, development, and marketing needs and priorities through interactive discussion.

- The scope of the workshop included both technology and market solutions.
- Participants considered research, development, and market solutions that address near- (0–3 years), mid- (3–10 years), and long-term (beyond 10 years) industry needs.
- The workshop did not result in recommendations for funding specific RD&D projects. Instead, it produced sets of RD&D options based on judgements of technical and market needs.

Workshop Structure

The workshop was a product-oriented meeting in which participants had active roles. The workshop consisted of three separate sessions spread over 3 days. Each session is described below:

Plenary Session: Representatives from the NCPV and from the PV industry provided an overview of the roadmap process and described the vision for the U.S. PV industry, as well as directions, goals and targets articulated in the *Industry-Developed PV Roadmap, A Framework for U.S. Industry and Technology Leadership*. Presentations were also given on financing and marketing PV, as well as the role of photovoltaics in the distributed generation marketplace. The session also included instructions for the breakout groups and a description of the workshop process.

Breakout Sessions: The participants were divided into four smaller groups that met separately to address technology and market issues related to the PV industry. These four groups, Markets and Applications, PV Components, Systems, and Integration, Manufacturing Equipment and Processes, and Fundamental and Applied Research, began their deliberations by discussing the vision and goals outlined in the Industry-Developed PV Roadmap. Each group then discussed the scientific, technical, institutional, and market barriers that stand in the way of reaching the vision and goals. Participants were then asked to discuss and rank possible initiatives that could overcome these barriers, and to segment these initiatives into an appropriate time frame, (near, medium, and long term). Following these discussions, the groups discussed anticipated roles for industry, government, and/or academic institutions in supporting selected activities, and the interrelationships among the activities.

Summary Session: All workshop participants convened to hear concise summaries of the results of each breakout group. After each presentation group members fielded questions and engaged in a discussion of the findings. At the conclusion of the presentations, each individual had an opportunity to provide concluding remarks and suggest next steps.

Markets and Applications

The purpose of this breakout session was to discuss barriers to successful markets for photovoltaics and actions that industry and other institutions and organizations should take to hasten the expansion of PV by the year 2020. Participants in the breakout group were asked to discuss key targets of opportunity for PV technology in building, industry, and institutional markets, technology barriers that stand in the way of reaching those markets, and research or other needs that could improve market implementation of PV.

Due to time limitations, the discussion in this group focused primarily on "marketing" PV, rather than on the specific markets or applications for PV technologies. Future study on the markets and applications for grid-tied systems (end-user opportunities, investment options), distributed generation, and DC and AC value-power, need to take place.

As shown in Exhibit 11, the participants in this breakout session represented a cross-section of industry interests with a stake in improving markets for PV technologies.

Exhibit 11
Participants
Markets and Applications
Breakout Session

PARTICIPANTS	ORGANIZATION
Clay Aldrich	Siemens Solar
Gerry Braun	BP Solarex
Tom Dinwoodie	PowerLight
Joe Iannucci	Distributed Utility
Chris Sherring	PVI Photovoltaics International
Mike Stern	UPG Golden Genesis
Jerry Ventre	Florida Solar Energy Center
Howard Wenger	AstroPower

FACILITATOR: Jan Brinch, Energetics, Incorporated
NOTE TAKER: Jen Ryan, Energetics, Incorporated
TECHNICAL ADVISORS: Larry Kazmerski, NCPV
Richard King, DOE

PV VISION AND GOALS

Focus Question 1: How do the vision and goals expressed in the PV Industry Framework document relate to markets and applications? Do the goals and targets need to be modified?

Members of the Markets and Applications Breakout Session discussed the stated vision and goals. The group determined that although they need additional validation and refinement by the PV Roadmap Steering Committee, which had earlier formulated them, further investment of time in discussing the vision and goals at this roadmap workshop would be unproductive. Thus the group decided to accept the vision and goals as presented.

The group did, however, make a number of important points for consideration by the NCPV Advisory Board and the PV Roadmap Steering Committee. The group expressed the opinion that the vision and goals are inconsistent; while the vision is directed expressly to U.S. markets, the goals speak to both U.S. and international markets. If a 50/50 U.S./international market split is going to be attained, the vision must address non-U.S. markets as well. Participants discussed the feasibility of attaining the cost goals as described in the Industry-Developed PV Roadmap and determined that the only way to accomplish these goals is with a more active government PV program.

The group discussed the reality of the $3/watt cost goal (end-user cost, including power conditioning and O&M) for the year 2010. Recognizing that the installed cost of

PV may need to be less than $3/watt, the group discussed market drivers for renewable energy at that or other price points. It still remains to be seen what customers will pay for renewable energy, although according to recent surveys, customers may be willing to pay more for "green" power.

The group recommended that the final report more clearly define the mix of PV applications; e.g., AC distributed generation for commercial/residential rooftop systems, AC grid generation for larger power systems, and DC and AC for off-grid systems.

BARRIERS TO MARKET ACCEPTANCE OF PV

Focus Question 2: What scientific/technical, institutional, and market barriers stand in the way of reaching the goals and targets of the Industry-Developed PV Roadmap Document?

The Markets and Applications Breakout Group discussed a number of barriers that stand in the way of reaching the goals and targets expressed in the vision document. Each barrier was grouped into one of five categories: Consumer Awareness and Education; Government/Legislative/ Regulatory; Industry; Technical; and Financial, as illustrated in Exhibit 12.

From a consumer perspective, the major barrier standing in the way of successful market penetration for PV systems is a lack of awareness and understanding of how PV benefits buyers' own self-interest, and how PV systems work, perform over time, and need to be maintained. The technology needs to be Asold@ like any other electrical product, so consumers can compare PV product options with other consumer products used for similar purposes.

Many government, legislative, and regulatory barriers stem from changes occurring in the electric utility industry. Deregulation in states across the country is creating concerns about stranded assets, standby charges, interconnection require-ments, and net metering. Individuals and organizations who install PV systems need to feel confident that they will not be financially Apunished@ with high standby and interconnection charges. They also need to feel confident that their distribution utility will work cooperatively with them to allow grid connections. Government policies need to be consistent throughout each political jurisdiction to minimize bureaucracy and standardize end-user incentives. In this way, government's past singular focus on R&D will broaden to include commercialization.

From an industry perspective, barriers include the lack of a profitable distribution infrastructure, as well as few wholesale and retail avenues for the purchase of PV systems. Breakout Group members discussed the need for a "Home Depot" approach to marketing PV. Consumers need to be able to purchase PV components and systems in much the same way they purchase other appliances.

The PV industry is too focused on technology as opposed to profitability. This must change. And while numerous states are encouraging and even providing incentives for consumers to purchase green energy, the process for doing so is relatively immature. As a result, brand name recognition and pricing are developing on a rather *ad hoc* basis in states across the country, causing confusion and sometimes irresponsible sales techniques.

Technical barriers are primarily cost related. The price of PV systems is still too high, compared with competing electricity generation and distribution methods. Other issues such as aesthetics, storage, and uneven quality standards are important, but pale in comparison to the need to bring down system costs. Financial barriers are intertwined with technical barriers, in that they relate to the high costs for PV systems. Financing PV, as compared with lower-cost alternatives, is a major financial barrier; until the cost of manufacturing, distributing, selling, and maintaining PV systems goes down, consumers will not purchase and use them.

Group members focused almost exclusively on barriers standing in the way of U.S. markets for PV; they did not focus much attention on international markets. However, members agreed that foreign governments that support PV technologies in other countries through "tied aid" provide a major disincentive to U.S. industries. U.S. PV companies that seek to market the technology in other countries are doing so without financial support from the U.S. government. Without increased attention to the non-U.S. market, the vision and goals of the PV Roadmap Document will not be met.

Exhibit 12. Barriers to PV Markets and Applications

♦ = Top Priority

Consumer Awareness and Education	Government/ Legislative/ Regulatory	Industry	Technical	Financial
Lack of consumer awareness and understanding of PV benefits and availability ♦♦♦♦♦♦♦ Current focus on selling technology, not commercialization ♦ Consumer fears related to performance, reliability, and environmental impacts Consumer skepticism based on past history and reputation of solar energy Product not "user-friendly" Constantly updated technology – consumers wait for next "better idea" Need for homeowner training Consumer reluctance to purchase non-standard systems	Barriers resulting from electric utility deregulation ♦♦♦♦♦ - Disincentives net against metering - Stranded assets - Standby charges Uncertain or negative interconnection standards ♦♦♦♦ Government policy barriers related to PV ♦♦♦♦ - Inconsistent - Bureaucratic - Lack of incentives - Needs to be coordinated with industry PV lacks political "strength/muscle" ♦♦ Subsidized non-solar options ♦♦ Negative tax policies ♦ Other governments' "tied aid" ♦ Unfocused use of U.S. government information to international markets ♦ Politics of funding in infancy period - Import/export duties - Unreasonable building code requirements - Lack of positive codes/covenants - Political barriers	Lack of profitable distribution infrastructure ♦♦♦ - Sales and service Lack of purchasing channels ♦♦♦ Immature/inconsistent green selling/marketing programs ♦♦ Immature sales chain ♦ Incomplete geographical coverage ♦ Uncertain availability of product supply/capacity Uneven quality standards	System costs ♦♦♦♦♦♦ Lack of solar resource knowledge ♦ Manufacturers not taking advantage of "enabling technologies" System aesthetics Equipment theft Lack of low cost storage Uneven quality standards	Lack of attractive financing for PV systems ♦♦♦ Lower cost electricity alternatives ♦♦♦ Mobility of home owners leading to high life-cycle costs Costs associated with re-roofing System transaction costs Foreign competition

KEY ACTIONS TO OVERCOME PV MARKET BARRIERS

Focus Question 3: What are the key research, development, and demonstration needs which should be taken to overcome these barriers? Which of these needs require attention in the short-term (0–3 years), mid-term (3–10 years), and long-term (>10 years)?

The Markets and Applications Breakout Group re-phrased this focus question to address key actions that need to be taken to overcome identified barriers. Action items were segmented into the same categories as barriers, as shown in Exhibit 13, and all were identified as having to take place in the 0–3 year range, although they will certainly continue throughout the next 10 years.

In the area of awareness and education, alliances with other groups are needed to sponsor education programs about PV technologies and applications for potential end users. Such groups as the Distributed Power Coalition of America (DPCA) and the National Association of Energy Services Companies (NAESCO) could be potentially useful partners in education, training, and technology application of photovoltaics in the residential, commercial, industrial, and institutional sectors.

The group also identified the need to make PV (as well as solar thermal) a part of educational curricula throughout the formalized educational system in this country. In much the same way as recycling has become popular in large part because of children's exposure to the need and process in schools, solar energy needs to be taught as part of an energy curriculum. Children will then pass on their knowledge and comfort with the technology to their parents, and become educated consumers as they grow to adulthood.

Other educational activities, including development of PV customer "success stories," conduct of public service and marketing campaigns, and other steps that raise PV awareness and understanding are necessary.

In the field of government, legislative, and regulatory activity, the Markets and Applications Group identified a number of key actions. At the top of the list is the need to clarify and publicize the results of inaction—what happens if government, legislative, and regulatory action is not taken to assist the PV market. Equal attention needs to be taken to adopt national interconnection standards; to remove disincentives, such as standby charges and customer retention fees; to provide consistent, multiple-year federal funding for research, development, and demonstration; and to develop a program that matches RD&D funding levels to these priorities. Discussion ensued on the industry's focus on consistent federal funding, while consistent sales goals did not appear to be of great concern. Industry needs to define the magnitude of federal funding and sales goals to reach the goals of the *PV Roadmap Document*.

Other actions were identified, including establishment of incentives for commercial PV use, such as a 25% state tax credit; federal matching of state incentives; renewable portfolio standards; development of effective competitive tools to counter "tied aid;" and adoption of national net metering legislation. Additional actions are shown in Exhibit 13.

In terms of industry actions, the Markets and Applications Group believes that the PV industry must take a lead role in achieving the transition to PV market acceptance. The group supports creation of a traditional, professional, industry-funded trade association, separate and apart from any existing industry association. Such a trade group should speak with a “common voice” on behalf of the PV industry. The group should be independent and bipartisan, perform lobbying activities, provide marketing services, conduct policy studies, and serve the PV industry’s interests. Breakout Group members agreed that a more extensive discussion needs to take place with other interest groups to determine the next steps toward forming such an industry association. One member drew a pinwheel diagram, symbolizing the need to start such a PV industry association, which would in turn lead to improved support for commercialization, which would lead to a growth in revenues, and a growth in industry dues, resulting in improved success for the association.

Other industry actions identified included spending more money on marketing, specifically “green marketing” in deregulated markets; developing ESCO alliances; developing “plug and play” technologies; developing national training and certification programs for system installers; and achieving quality control at all levels of product development, marketing, installation, and maintenance.

In the area of technical actions, the group agreed that a true market exists for PV but that the industry needs to look outside the U.S. and be able to sell complete solutions in order to expand abroad. Other action items include developing strategies for reducing non-hardware costs, such as installation and maintenance, and providing incentives for manufacturers to develop more reliable products.

Financial actions suggested included creation of long-term, low-interest financing for installation of PV in a variety of applications; establishment of price points geared to market segments; and 0% mortgage financing subsidized by a highway tax and linked to carbon emissions reductions.

The group discussed actions that need to be taken to address international market barriers. Mass deployments of small PV systems in a concentrated region, together with necessary infrastructure improvements, may be a cost-effective model for electrification in remote regions of the world. However, some group members believe that government should not play a role in such a deployment strategy; others believe that government should play a more active role, despite past problems with government-sponsored international activities. Respected government agencies can work in industry’s favor. Therefore, increased attention should be focused on the government’s role in international business development activities.

Exhibit 13. Key Actions to Overcome PV Market Barriers

♦ = Top Priority

Consumer Awareness and Education	Government/Legislative/ Regulatory	Industry	Technical	Financial
Develop alliances with other groups to sponsor consumer education programs ♦♦♦♦ - DPCA - NAESCO	Clarify and publicize results of inaction ♦♦♦♦	Create an effective industry coalition by forming a traditional, professional, industry-funded trade association ♦♦♦♦♦♦♦♦ - Bi-partisan - “Swat” team - Lobbying activities - PV marketing board - Policy writing - Technical analysis of competing and complementary electric generating systems	Sell complete service solutions ♦♦	Create long-term low-interest financing for PV ♦♦♦♦
Make solar a part of science curricular “standards of learning” ♦♦♦	Adopt national interconnection standards ♦♦	Spend more money on marketing ♦♦♦ - Green pricing	Develop strategies for reducing non-hardware costs ♦	Establish price points geared to market segments ♦
Evaluate PV from a customer viewpoint	Remove disincentives, e.g., standby charges, customer retention fees ♦♦	Develop ESCO alliances ♦♦	Strive for consistent success in implementing large numbers of roof top systems	Offer zero percent mortgage financing ♦ - Subsidized by highway tax - Linked to carbon emissions reductions
Develop PV customer “success stories”	Provide consistent multiple year federal funding ♦♦	Develop “plug and play” PV technologies ♦	Provide incentives to manufacturers to develop more reliable products	
Conduct intensive public service campaign	Develop a program plan that matches funding levels to these priorities ♦♦	Develop national training and certification program for system installers ♦		
Install PV public and institutional buildings to serve as demonstrations	Create incentives for commercial PV use, such as - 25% state tax credit - Federal matching of state incentive program - RPS - System Benefits Change	Achieve quality control at all levels ♦		
	Develop effective competitive tools to counter foreign-based “tied aid.” ♦	Develop task list for NREL to perform abroad ♦		
	Develop a clean slate for PV ♦	Achieve 100% product reliability		
	Adopt national net metering legislation ♦			
	Improve PV distribution infrastructure			
	Gather good solar data throughout the world			
	Intervene in state regulatory and legislative decision-making			
	Tie incentives and subsidies to emissions reductions			
	Provide state incentives for utilities to offer PV installations			
	Develop and communicate credible market scenarios to consumers			

PRIORITY ACTION ITEMS, PATHWAYS, AND TIMEFRAMES

Focus Question 4: How best should these research, development, and demonstration needs be addressed? What linkages exist among the needs identified by the Markets and Applications Group?

As illustrated in Exhibit 14, the Markets and Applications Group identified a progression of actions that should be taken to enhance photovoltaic technologies and applications into the 21st century. The PV industry must develop an organizational approach, become involved in regulatory activities, enhance the sale and marketing of PV components and systems, create and enhance international marketing opportunities, more actively commercialize the technology, and educate consumers about PV. Group members re-stated the action items identified in Exhibit 13, and identified performers (industry alone, government alone, industry-government partnership, and/or academia involvement). The progression of activities should take place within a 0–3-year timeframe, understanding that although there is an urgency to undertaking action, many of these activities will extend through the year 2010 and beyond.

Exhibit 14. Top Priority Action Items, Pathways, and Timeframes

(All 0-3 Year Timeframe)

Organizational Approach	Regulatory Actions	Sales and Marketing	International	Commercialization	Education
Develop traditional, professional, bi-partisan industry-funded trade association (I) Provide opportunity for industry to speak with a "common voice" - Fund "swat" teams - Write policy - Lobby for PV - Analyze complementary technologies - Establish PV marketing board - Conduct marketing campaign: "Got PV?" Develop alliances with other groups for consumer awareness and education (I) - NAESCO - DPCA Develop and communicate credible market scenarios (I) - Clarify how PV benefits buyers' self-interest and what happens if actions are not taken	Adopt national interconnection standards - Support IEEE Sec 21, etc. - Lobby states, EEI, and utilities to adopt IEEE standards Remove disincentives, e.g., standby charges, customer retention fees, etc. (I/G) - Lobby for PV exemption from standby, CTCs, up to a limited # of MW - Educate NARUC, and state regulatory commissions to enhance PV alternatives in new deregulated market	Increase sales and marketing budgets (I) - Market benefits of PV to potential end-users Sell complete service solutions (I) Identify targeted end-users for PV applications identified in Vision document (grid-tied systems, distributed generation, and DC/AC value applications) (I/G)	Develop effective competitive tools to counter "tied aid" (I/G) - Grow both national and international markets to reach vision and goals Develop task list for NREL to perform abroad (G) Develop PVGAP abroad (G)	Provide appropriate government subsidies for enhanced PV market (G) Improve commercialization strategy (I/G) - Establish effective RPS at both federal and state levels - Consider 25% federal/state tax credits - Offer financial incentives, e.g., SBC for PV R,D,&D (G) Encourage consistent multiple-year federal funding (G) Consider offering long-term low-interest financing for appropriate, easily integrated, reliable PV systems (G)	Make solar (thermal and PV) a part of science standards of learning (A/G) - Improve curriculum development - Develop teaching materials - Encourage adoption by state departments of education

I = Industry
G = Government
A = Academia
I/G = Industry-Government Partnership

PV Components, Systems and Integration

The purpose of the Components, Systems, and Integration breakout session was to discuss the fabrication, installation, and servicing of photovoltaic systems in retrofit applications and new construction. Included in the scope are both stand-alone and grid connected systems. The goals of the breakout session group were to:

- Discuss the draft vision and goals and obtain "customized" comments
- Identify top priority scientific, engineering, technical, and institutional barriers facing photovoltaic components, systems, and integration in achieving the vision and goals
- Identify top priority research, development, and demonstration (RD&D) needs in overcoming the barriers and achieving the goals
- Identify the time frames (near, mid, and long term) and performers (industry, government, industry-government partnerships) for the top priority RD&D needs.

Participants in this breakout session are listed in Exhibit 15.

Exhibit 15
Participants
Components, Systems, and Integration Breakout Session

PARTICIPANTS	ORGANIZATION
Hans Meyer	Omnion
Paul Wormser	Solar Design Associates
Chuck Whitaker	PVUSA
Steve Chalmers	PowerMark
Jito Coleman	Northern Power
John Wiles	SWTDI

FACILITATOR: Rich Scheer, Energetics, Incorporated
NOTE TAKER: Joseph Philip, Energetics, Incorporated
TECHNICAL ADVISOR: Chris Cameron, NCPV

VISION AND GOALS

Focus Question 1: How can the vision and goals expressed in the PV Industry Framework be "customized" to include the challenges and opportunities facing PV components, systems, and integration?

The group agreed that the vision statement does not define the kind of product and market the PV industry will be targeting in the year 2020. The vision needs to cover the future of PV systems in which they are likely to be sold as both "refrigerator-like" packaged systems for building owners and occupants and as power systems for grid connected applications.

In addition, members of the group felt that the vision needs to provide a "picture" of how PV systems will be incorporated into buildings and utility systems as if a home videotape were to be made in the year 2020. The vision needs to show PV systems installed on rooftops of new and existing buildings, incorporated into the designs of new buildings, providing services to remote and stand-alone applications, and interconnected to utility systems.

The group observed that the vision calls for moving the industry from installing 500 to 2 million units per year in the United States. Though this focus is on the United States market, the international market remains vital and should also be reflected in the vision. To increase the sales and use of PV, installation and operation and maintenance costs will be an issue, but the vision should include consumers who also value PV for the non-economic benefits. Seeking to achieve "lowest cost" systems should not be the only focus. Flexibility and service will be a key component to selling PV products on the market.

The vision should include "Green E" stickers displayed in home windows indicating that a portion of the home's electricity is supplied by solar energy. PV systems need to be widely understood and available to residential and commercial users, and serviced by contractors familiar with system installation and operations.

Participants in this group felt that the goals from the framework document should provide a benchmark for manufacturers. However, such goals may not reflect the needs of PV customers. For example, potential PV customers do not base their buying decisions on cost metrics such as \$3/W in 2010 and \$1.50/W in 2020, but rather value the non-economic benefits of PV systems. Nevertheless, the vision should include cost goals for electricity, such as 10 cents/kWh in 2010 and 5 cents/kWh in 2020.

Group members agreed that goals should be added that address the future market for PV systems and services. For example, goals to equip 10% of all new buildings and 1 million of existing buildings each year by 2020 with PV systems could be added. To achieve these goals, PV would have to be packaged as a "market-ready" product with the utility infrastructure capable of supporting "plug and play" applications. Systems will have to be designed so that building owners and occupants in the future will enjoy the architectural styles associated with PV systems and that they will be fully integrated into the future built environment. PV systems will be installed in homes and other types of buildings like plumbing, wiring, and other common building systems are routinely installed today. Architects and builders will need the skills and tools to incorporate PV into their designs.

BARRIERS

Focus Question 2: What scientific, engineering, technical, institutional, and market barriers stand in the way of reaching the vision and goals for PV components, systems, and integration?

A list of the ideas raised during the discussion of barriers may be found in Exhibit 16. While some barriers are technology-related, many involve customer and public policy issues. There is, for example, a lack of fundamental understanding of the optimal approaches for designing, fabricating, and installing PV components and systems. Existing systems experience some reliability problems and are not yet maintenance free, despite claims to the contrary. One of the highest priority barriers is the high cost of cell modules. Lower cost modules will reduce overall system costs, increasing potential market.

Exhibit 16
Barriers Facing PV Components, Systems, and Integration

♦ = Top Priority

Customers	Economics	Procurement	Codes & Standards	Public Policies	Technology	Standardiza-tion
Uninformed buyers ♦♦♦♦♦ - Too much talk of kW for Joneses' (gives them a headache) - Need to reduce technical jargon - Consumers have unrealized expectations - Absence of grade school education program Lack of early adopters ♦ - Lack of "Joneses" Unattractive, appearance not appealing to consumers ♦ Need to provide flexible components and systems, which can be easily maintained and serviced Incorrect perception that they are maintenance free Other solar systems didn't work	Lack of low interest capital ♦ High non-hardware transaction costs ♦♦ Competing technologies ♦ Lack of mortgage, tax deductions for PV ♦ Difficulty in moving from small to large industry O&M costs too high especially for small systems Insurance industry does not understand PV Absence of pollution credit for PV	Lack of local infrastructure (dealers, etc.) ♦♦♦ - No one local source for buying PV components and systems Most trades uniformed, e.g., inspectors/ permitters	Lack of technical standards for PV products ♦♦ No standard method to verify system performance Codes and standards difficult to set for varying PV systems and sizes	Difficult interconnection ♦ Utility policies and business practices ♦ Subdivision housing design does not consider PV ♦ Net metering not universally available ♦ Need to reach mass market through BIPV with architectural integration Restrictive covenants/ codes at subdivision level Lack of HUD acceptance for PV No subsidies	High cell/ module costs ♦♦♦♦♦ Systems not reliable enough now ♦♦ - Not maintenance free Lack of awareness of competing/ complementary technologies ♦♦ Lack of fundamental understanding of PV basic science ♦ Lack of display ("PV thermostat") ♦ Hard to install - Retrofit difficulties - Difficult roof mounts Low conversion efficiency Cost of magnetics Specific requirements for wire and connectors Lack of cheap, reliable energy storage - load and resource not designed together	Lack of standard products, packages, and service offerings ♦♦♦ - Each installation a special case - Need "plug & play" Not geared for mass production

RD&D NEEDS

Focus Question 3: What are the key research, development, and demonstration needs in PV components, systems, and integration that should be taken to overcome these barriers and achieve the vision and goals?

RD&D needs discussed by the group are illustrated in Exhibit 17.

The group agreed that manufacturers need to develop improved, reliable systems and components with lower installed costs, and that require less maintenance than units sold today. To address the new construction market, manufacturers will need to institute programs with architects and building designers so that packaged systems can be developed and marketed on a mass basis to potential residential and commercial users. This will require new research efforts to design PV systems and components that can be integrated into roof systems, walls, and other building features, and that may be interconnected to support local power system requirements.

Improvements in system reliability will enable PV to be more attractive to potential users. Another important near term RD&D need involves wiring systems for curtain wall applications. Additional needs include building products that use PV, such as roofing tiles, that are equal to or better than existing products. The development of large area thin-film modules will also assist architects, building designers, and owners. New and innovative methods for packaging cells for different applications will not only improve the potential for PV systems in building markets but will also help PV in other markets such as remote power and telecommunications applications.

New efforts to build a PV infrastructure are also needed. This infrastructure will make it easier for consumers to select, finance, monitor, and maintain PV systems, both for new construction and retrofit applications.

R&D is required to facilitate interconnection and operations. If “plug and play” modes are to become a reality, PV systems that provide AC power at lower cost than systems do today are needed. In addition, integrated units that include storage will have to be developed and marketed to users. For example, the integration of PV with storage systems (e.g. batteries, flywheels, and superconducting magnetic energy storage) and/or with grid back-up power supplies will enhance potential uses of the technology. Innovative magnetic/topology for power electronics will need to be conducted, and fault tolerant systems need to be developed.

PV installation technologies also need to be improved if they are to reach a wider market. For example, the development of module mounting systems would make it easier to install PV on rooftops. Leak-proof mounting systems that are reliable, easy to install, and lower in cost than today’s systems are needed to expand the PV market.

PV systems that involve lower transaction costs need to be developed. These systems would include "pre-approved" and standardized product packages that consumers would be able to purchase commercially from a variety of suppliers. These systems would be installed with a minimal amount of permitting and “hassle,” certainly much less than is currently required for the typical grid-connected PV installation.

Even with successful development of PV systems and components, an infrastructure will need to be in place for installing and servicing these systems. This infrastructure must make it easier for customers to buy and use PV. Efforts are needed to expose PV products to customers, installers, servicing companies, financiers, and others in the supply chain. Training for designers, installers, builders, architects, and approval authorities and inspectors is also necessary so that they know how to incorporate PV into their designs and buildings.

U.S. manufacturers need to continue to monitor market developments overseas. National and international PV standards need to be developed to make it easier for manufacturers, regulatory agencies, and consumers to design, permit, purchase, and install PV products. Interconnection standards need to be finalized to lower the cost of connecting PV systems to the grid.

Research on the integration of PV with other distributed generation and storage technologies is needed. New PV components and systems may also be needed in the design of hybrid systems that could involve fossil power systems and battery storage technologies. Such hybrid systems could expand potential markets for PV technologies.

Exhibit 17
PV Components, Systems, and Integration RD&D Needs

♦ = Top Priority

Standards	Education & Awareness	Government Action	BOS Issues	Demonstration and Testing	Studies & Analysis	Module Issues	System Issues
National & international standards for PV products and components ♦♦ - Ratings & verification tools for appropriate sizes Qualification tests for all components ♦ National interconnection standards ♦ Expedite listings	Wider public exposure to products and their value ♦♦♦ - Advertise PV Training for designers, installers, builders, architects ♦ Educate PV industry on system integration Increase experience of PV system engineers	Adequate funding for PV ♦ Consider PV for all government buildings Long-term commitment	Innovative magnetic/ topology power electronics ♦ Consumer value meter, feedback to customer visually PV BOS that looks like conventional electronic systems Silent inverters Better inverter that handles thin film and easier to fix	Demonstrate examples of good building integration ♦♦	Quantification of externalities ♦♦ Compare systems using module, string, or system inverters ♦ Enhance understanding of cell physics ♦ Focus on holistic view of DG ♦ - Understand competitive technology - Look for synergies and alliances with other technologies Understand competitors overseas ♦ Identify 20-30 year systems. What are the life-cycle costs? FCC regs specific to PV systems Review existing PV technology and develop new technologies for standardization Develop new markets, applications	Preferred value-added building products using PV ♦♦♦ - Enhanced PV products e.g., PV/thermal Large-area thin-film modules ♦ Innovative/ novel cell packaging ♦ Wiring systems for curtain wall applications ♦ Commercial building products flexible for architects ♦ - Colored cells New sources of silicon Flexible, high speed manufacturing Eliminate junction box Flexible sizing and interconnection of modules	Reliability ♦♦ Develop "AC Systems" ♦♦ Cost & ease of maintenance ♦♦ - PV products that accommodate building maintenance - Highly reliable zero-paid maintenance PV systems Fault tolerance systems ♦ Low transaction cost systems "preapproved" ♦ Utility interconnected systems with storage ♦ - Integrate PV with UPS systems - Low maintenance grid back-up Module mounting systems ♦ - Residential rooftop mounting & installation - Good, cheap, easy to install leakproof mounting systems Fire-awareness design Reduce costs of components & systems manufacturing Shade tolerance systems Standardize flexible designs Packaged PV powered applications

LINKAGES

Question 4: How best should these research, development, and demonstration needs be addressed? What linkages exist among the needs identified?

The discussion of linkages, timeframes, and performers emphasized that all efforts need to include participation from both industry and government. Major efforts are needed in infrastructure development, building integration, and systems research. The government will need to take the lead on developing an infrastructure favorable to PV with help from industry. Industry will be required to lead efforts in building integration; systems research will require an aggressive partnering relationship.

To develop an infrastructure requires the acceptance of PV by the public. This includes training the necessary trades to naturally integrate PV into buildings. Government agencies should take the lead to create national standards for interconnection of PV products and distributed generation. Government, with the help of industry, can remove obstacles to the integration of PV into the power market.

Industry must then develop marketable products that integrate easily into a developing infrastructure. Building integration of PV is one important example of the type of technology development that will add value to PV products. Giving architects and builders a number of flexible products to choose from will make it easier for the technology to be adopted. Innovative and novel use of PV will be a key in selling it.

However, PV technology will not survive if it doesn't prove itself in the field. PV systems will have to be extremely reliable. If system maintenance is costly and difficult, it is unlikely that the technology will be adopted. PV systems will not only have to be inexpensive and easy to install but also low maintenance. Industry will need to lead the development of better components and systems. But government can help in establishing qualification tests for all components that help ensure reliability of all PV systems.

Exhibit 18. Linkages, Timeframes and Performers
PV Components, Systems, and Integration

	< 3 years	3- 10 years	>10 years
Infrastructure	- Training for designers, installers, builders, architects. (G/I) - Wider public exposure to products & values (G/I) - Understand competitors overseas (I/G)	- National & international standards for PV products (G/I) - Focus on holistic view of DG (I/G) - National interconnect standards (G/I) - Quantification of externalities (G/I)	
Building Integration	- Wiring systems for curtain wall applications (I/G)	- Commercial building products flexible for architecture (I/G) - Examples of good building integration (G/I) - Preferred value-added building products using PV (I/G) - Innovative/novel cell packaging (I/G) - Large area thin-film modules (I/G)	
Systems	- Reliability (I/G) - Utility interconnected systems with storage (I/G) - Compare systems using module, string or system inverters (G/I) - Develop "AC systems" (I/G) - Module mounting systems (I/G) - Qualification tests for all components (G/I)	- Cost & ease of maintenance (I/G) - Innovative magnetic/topology for power electronics (I/G) - Low transaction cost systems "pre-approved" (I/G) - Fault tolerant systems (I/G)	- Enhance understanding of cell physics (G/I)

I/G = Industry/Government Collaboration (Industry-led)
G/I = Government/Industry Collaboration (Government-led)

PV Manufacturing

The purpose of this breakout session was to discuss manufacturing needs to achieve the PV vision. Participants in the PV Manufacturing Breakout Session, listed in Exhibit 19, represented manufacturers and researchers of various thin film and bulk PV materials, including cells, modules, arrays and systems, as well as manu-facturers of PV manufacturing equipment.

Exhibit 19
Participants
PV Manufacturing Breakout Session

PARTICIPANTS	ORGANIZATION
Bill Bottenberg	Photovoltaics International, Inc. (PVI)
Dave Carlson	BP Solarex
Maurice Covino	Spire
Ghazi Darkazalli	GT Solar
Erten Eser	IEC
Jim Galica	STR
Masat Izu	ECD
Terry Jester	Siemens Solar
Jim Rand	AstroPower

FACILITATOR: MELISSA EICHNER**,** Energetics, Incorporated
NOTE TAKER: KIM REICHART**,** Energetics, Incorporated
TECHNICAL ADVISORS: Roland Hulstrom and Tom Surek, NCPV

VISION AND GOALS FOR PV

Focus Question 1: How do the vision and goals expressed in the PV Industry Framework document relate to manufacturing? Do the goals and targets need to be modified?

Members of the group concluded that the ambitious vision and goals are a reasonable starting point for the purpose of identifying manufacturing barriers and manufacturing needs for PV. However, the vision statement should include international markets to reflect that the vision document contains international goals.

The group proposed an amendment to the vision to reflect the opportunity that will exist for communities who manufacture PV. This amendment is shown in Exhibit 20

Exhibit 20
Vision Amendment

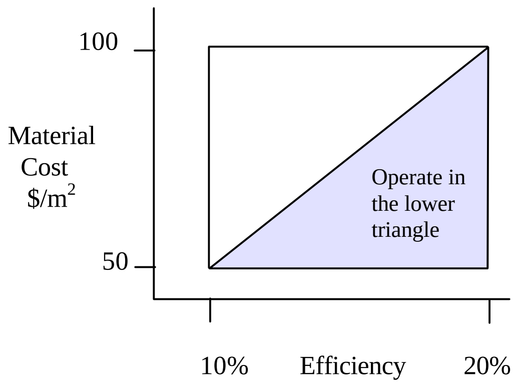
"PV module manufacturing plants will be sought after by every community in the U.S. for providing tens of thousands of jobs that are high-tech with a clean manufacturing environment."

To determine the impact of the PV vision and goals on manufacturing, the group estimated that significant achievements in output, productivity, and cost reduction are required. These estimates are shown in Exhibit 21. The requirements for material costs and efficiency are shown in Exhibit 22. There is concern that the required ramp-up rates do not provide time and incentives for collaboration. The assumed return on investment (e.g., EVA, capital cost, etc.) needs to be consistent across the goals.

Exhibit 21
Estimated Targets for Manufacturing Based on the Goals and Visions

- A 40-fold increase in PV module manufacturing is needed by 2020
- A 5-fold reduction in module manufacturing costs is needed by 2010, and a 10-fold reduction by 2020

Exhibit 22
Material Costs & Efficiency



BARRIERS TO PV MANUFACTURING

Focus Question 2: What scientific, technical, institutional and market barriers stand in the way of reaching the goal?

The group identified barriers in seven categories listed below and shown in Exhibit 23. Overcoming the barriers in the top two categories is considered most important to the success of PV manufacturing.

- Processes/Equipment Need Definition
- Process Controls and Scientific Understanding of Processes Involved
- Investment Needed for Scale-up
- Too Many Choices (Technology Diversity)
- Infrastructure of PV Industry and Use of Existing Infrastructure
- Standards Products/Testing
- Do Not Know What Marketing Process Will Look Like—Long Range Strategies

Overall, the highest priority barriers are the lack of support for advanced equipment development, and the lack of knowledge of high throughput process. Other barriers include the lack of advanced equipment and bottlenecks in manufacturing throughput.

Process Controls and Scientific Understanding of Processes Involved was concerned with the lack of basic science, especially scientific knowledge for in-line process control.

In Investment Needed for Scale-up, the barriers included lack of investment capital, slim profit margins, small customer base, and inadequate government understanding of the requirements to bring a technology on-line.

The existence of multiple technologies results in unfocused investment decisions. PV companies are too invested in their own technology, and rely too heavily on proprietary products. Manufacturers are concerned with the lack of dedicated suppliers, inadequate amounts of silicon, and an untrained regional labor force.

The PV industry infrastructure is weak. Duplicate R&D on equipment processes is conducted on different technologies. Products are not integrated into a whole building infrastructure process. Product standards are inadequate and poorly defined, leading to difficulties in making minor module changes.

There is no clear vision of what manufacturing facilities will look like in the 21st century. Many difficulties will have to be overcome to achieve the product and system manufacturing goals required to achieve the PV vision, including strengthening the infrastructure.

The PV industry needs to develop a model for high volume manufacturing. Will the PV manufacturing plant of the future look like a bottle manufacturing plant, a semiconductor manufacturing plant, or something else? The plants of today must be replaced by larger, more efficient plants with stock, not custom built, manufacturing equipment. Equipment manufacturers must also be ready to meet the demands of this larger, more robust industry.

Manufacturers must solve many problems to meet the production goals, including a steady flow of affordable silicon; a large trained workforce; new large plants capable of high output; quality assurance/quality control methods to quickly and accurately test products *in situ*; a planned distribution network; and enough profit to entice investors.

Exhibit 23. Barriers That Impede PV Manufacturing Processes

♦ = Top Priority Barrier ✪ = High Priority Category ★ = Priority Category

Processes/ Equipment Need Definition ✪✪✪✪★★★ ★	Process Controls, Scientific Understanding of Processes Involved ✪★★★★★	Investment Needed for Scale up ✪★	Too Many Choices, (Technology Diversity) ✪	Infrastructure of PV Industry and Use of Existing Infrastructure ✪	Standard Products/ Testing ✪	Do Not Know What Manufacturing Process Will Look Like—Long Range Strategies
Lack of support investment for advanced equipment development work ♦♦♦♦♦ Lack of knowledge of high throughput process ♦♦♦♦ Inadequate high throughput and high efficiency for specific applications ♦♦ Bottlenecks in manufacturing throughput ♦ Lack of specific manufacturing equipment for the industry - Now there is a lack of specific equipment - In the future, industry should have more generic equipment ♦	Lack of fundamental/ scientific knowledge for scale-up ♦♦ Inadequate (real-time) process controls - Development of diagnostics for in-line processes - Lack of QA/QC ♦♦ Lack of basic science for in-line process control ♦♦	Government's inadequate understanding of what it takes to bring technology on-line – impacts government investment ♦♦♦ Lack of customers to support equipment manufacturers - Transition from foreign to U.S. customers ♦♦ International competition (Japan putting high dollars in PV) ♦ Lack of up-front money (i.e., investment capital) - Cannot get investment capital without proprietary product ♦ Lack of profit Not enough government incentive to invest in technologies	Lack of conviction to a technology choice—having multiple technologies—investment decisions are not focused ♦♦♦ Industry wants to create everything themselves—proprietary products - Companies do not go outside their organizations for development (not-invented-here syndrome) - Lack of academic and company cooperation ♦♦ Struggle adopting new technologies ♦ Love technology too much—each company's mind set	Infrastructure is weak; duplicate R&D projects to develop equipment processes--cannot buy anything in industry ♦♦♦ Integration of whole building infrastructure process into products - Need business model to take advantage - Very product specific - Make PV products that meet a specific market that drives manufacturing ♦♦ Not enough raw material (silicon) to support 25% at price needed with today's technology No dedicated material suppliers Inadequate labor force (regional) Cheap, reliable inverters needed Large distribution system needed by 2020 - Shipment of materials needed—near manufacturing site and suppliers - Shipping costs could be significant	Inadequate product standardization--lack of product definition ♦♦ Difficulty in changing module configurations (minor changes) Lack of rapid screening of prototypes Each company wants specific material—product requirements insufficiently specified Only one qualification test; it's too rigid, too high, may not fit all applications (IEEE/Z&Z) Hierarchy between modules and finished systems - Take out a layer of module hierarchy to gain cost savings—need manufactur-ing technology strategies to do this	Scale problem—production now vs. what will be needed in 2020 ♦♦ Lack "picture" of factor in 2020 ♦ Inadequate cooperation by industry ♦ Lack of long range view in U.S. industry ♦ Not right players yet in manufacturing equipment—not in PV game yet Lack of manufacturing model--need to process large areas Environmental-ly conscious manufacturing, (e.g., meeting license requirements)

Actions/Solutions to Overcome the Barriers

Focus Question 3: What are the key manufacturing needs that should be taken to overcome these barriers? Which of these needs should be addressed in the near-term (less than 3 years), mid-term (3-10 years) and long-term (more than 10 years)? Which organizations (industry, government or universities, or some combination) should be responsible for confronting these issues? In the real world with limited resources, which of these needs would have the highest priority?

The group identified manufacturing needs to address the barriers in six categories listed below and shown in Exhibit 24. Addressing the needs in the top three categories is considered most important to the achieving the manufacturing goals.

- High Volume Throughput
- Process Control and Development
- Common Industry Objectives
- Low Cost, Reliable Module Testing and Packaging
- New Process Development
- Balance of Systems Research

The highest priority is the need for manufacturing partnerships to work with suppliers to develop the next generation of equipment. This equipment will not be proprietary but shared by all PV manufacturers. Development of common industry objectives was also identified as a key RD&D need.

Diagnostic tools, systems, and processes are needed for in-situ production optimization. Fundamental research is needed to improve throughput through process controls.

High-volume equipment demonstrations are needed to learn more about increasing throughput and cell processing efficiency, along with continuous processing.

Research is needed to lower the cost of module packaging, improve thin film packaging, develop a better understanding of fundamental failure mechanisms, and develop high-throughput module assembly processes.

Of the issues that must be confronted to meet the PV vision goals, the majority are related to developing equipment and processes for high-volume production or in-situ diagnostic processes, and reducing the costs of production. Exhibit 25 presents a proposal of who should perform the highest priority RD&D that is needed and the timeframe when results can be anticipated. Most of these issues can be addressed by industry, or industry partnerships with government and/or universities.

Almost all of the manufacturing needs will need to be addressed within a 0 to10 year timeframe to achieve the ambitious production goals of the PV vision. R&D consideration for the long-term needs to be made with guidance from the government, universities, and national laboratories.

Priority should be given to identifying manufacturing challenges that are common among companies and investing to solve these issues. A tactical plan is needed that is market specific, not company specific. To enhance market success, equipment and manufacturing commonalties need to emerge.

Exhibit 24. Manufacturing Needs

♦ = Top Priority Barrier ✪ = High Priority Category ★ = Priority Category

High Volume - High Throughput ✪✪✪★★★★	**Process Control and Development** ✪✪✪★	**Common Industry Objectives** ✪★★★★	**Low Cost, Reliable Module Testing and Packaging** ✪★	**New Process Development** ✪	**Balance of Systems Research**
Equipment demonstration at high volume - 10,000 cells - everyone sees data ♦♦♦♦ Need to develop high volume, high throughput, high efficiency cell processes ♦♦♦ Develop continuous process (not batch) ♦♦♦ Develop lowest cost processes per W ♦ High speed glass and thin sided film handling and transferring equipment for in/out processes ♦ Transferring equipment Maintenance to increase up time Automating and integrating processes Continued work on cell efficiency, basic research with manufacturing focus Develop funding sources to make this happen (investment support) Joint program with suppliers to improve quality and reduce costs Develop compatible processes for manufacturing lines among manufacturers (equipment)	Diagnostic tools, systems, and processes need to be developed, on-line and in situ ♦♦♦♦♦ Conduct targeted fundamental research to provide scientific understanding of manufacturing process—diagnostic tools and improved throughput ♦♦ Laser processes--basic scribing of thin films Continued process modeling development Intelligent process control (IPC) systems for manufacturing	Develop manufacturing partnerships so manufacturers work with suppliers to develop the next generation of equipment that can be shared (will not share processes) - Overarching organizing body ♦♦♦♦♦♦ Identify common equipment needs ♦♦ Make manufacturing equipment for full production—no room for developing - Need to prototype manufacturing—work with PV equipment manufacturers to develop prototype equipment ♦ Research on high material utilization—resulting in less wastes produced (design for environment) ♦ Make equipment that can be transferred to >1 manufacturer – not company specific - What does a 250 MW plant look like? ♦ Material recycling, gases, slurries, etc. Information dissemination—research on specific projects where collaboration is obtainable Foster competitive edge by obtaining governmental support of manufacturing processes	Lower cost module packaging ♦♦♦♦ Thin film packaging research ♦♦♦ Fundamental failures mechanisms ♦♦♦ Develop high throughput module assembly process ♦♦ Better methods/models for module lifetime expectations--excellent testing ♦ Standard interconnection between module Research to change fundamentals of module manufacture--new module manufacturing processing	Identify material substitutions for improved safety, lower costs ♦ Alternative low cost manufacturing processes, e.g., vacuum, throughputs ♦ Energy efficient manufacturing processes are needed—thermal vs. effusion furnaces Conduct R&D to develop manufacturing lines capable of producing a variety of products (flexible manufacturing)	Lower cost inverters--increase volume Research on codes and standards for integration into buildings Demonstration projects for building integrated projects for buildings—unique and integrated products

Exhibit 25. Linkages and Performers
PV Manufacturing RD&D Needs

(High Priority, *Priority*)

Performer	Timeframe		
	Near-Term 0-3 Years	**Mid-Term 3-10 Years**	**Long-Term >10 Years**
INDUSTRY	Equipment demonstration at high volume Identify common equipment needs Develop high throughput module assembly process *High speed glass and thin sided film handling and transferring equipment for in/out processes*	Thin-film packaging research Develop continual processes (not batch) *Make manufacturing equipment for full production—no room for developing—need to prototype—work with PV equipment manufacturers to develop prototype equipment* *Research on high material utilization resulting in less wastes produced*	
INDUSTRY-GOVERNMENT COLLABORATION	Develop manufacturing partnerships so manufacturers work with suppliers to develop the next generation of equipment that can be shared to decrease development costs (will not share processes)—use company manufacturing collaborative to guide activities at labs and university—plan research for the long-term (assume different technology in 10 years)	Lower cost module packaging[2,3] New module processing materials[1] Develop high volume, throughput, efficient cell processes-government funding role[5] *Identify material substitutions for improved safety, lower costs* *Make equipment that can be transferred to >1 manufacturer (now manufacturing is company specific)*	
INDUSTRY-UNIVERSITY	*Develop diagnostic processes (in situ, in-line)*[1,4] *Research on high material utilization resulting in less wastes produced*	*Research on high material utilization resulting in less wastes produced*	
INDUSTRY-GOVERNMENT-UNIVERSITY	Fundamental failure mechanisms[1]	*Develop diagnostic processes (in situ, in-line)*[1,4] Develop high-volume throughput, efficient cell processes-government funding role (publish research)[1,5]	Fundamental research understanding and modeling processes (ongoing)[1] *Alternative lower cost manufacturing processes, e.g., vacuum, throughputs* *Develop lowest material cost processes per watt*
GOVERNMENT-UNIVERSITY		*Develop better methods/models for module lifetime expectations—accelerate testing*	

Links to other breakout groups:
[1]R&D
[2]Component Integration
[3]Markets $

Manufacturing:
[4]Diagnostics
[5]High Volume

Fundamental and Applied Research and Development

The purpose of this breakout session was to discuss key barriers to, and needs of, photovoltaic research and development to achieve the goals identified by the NCPV advisory board. The participants in the Fundamental and Applied Research and Development Breakout Session, listed in Exhibit 26, represented researchers, developers, and manufacturers of various thin film and bulk PV materials, cells, modules, arrays and systems.

Exhibit 26
Participants
Fundamental and Applied Research and Development Breakout Session

PARTICIPANTS	ORGANIZATION
Alan Delahoy	EPV
Bulent Basol	ISET
Jeff Britt	Global Solar
Jack Hanoka	Evergreen Solar
Tim Anderson	University of Florida
Subhendu Guha	USSC
Juris Kalejs	ASE Americas
David Lillington	Spectrolab
Ajeet Rohatgi	GIT

FACILITATOR: Paula Taylor, Energetics, Incorporated
NOTE TAKER: Robyn McGuckin, Energetics, Incorporated
TECHNICAL ADVISORS: John Benner, and James Gee, NCPV

VISION AND GOALS FOR PV

Focus Question 1: How do the vision and goals expressed in the PV Industry Framework relate to fundamental and applied research? Do the goals and targets need to be modified?

Members of the Fundamental and Applied Research and Development Breakout Session discussed the vision and goals and reached consensus that those presented in the PV Industry Framework document were an acceptable starting point for the purpose of identifying barriers and R&D needs for PV. The discussion did, however, include comments for later consideration to strengthen the vision and goals. Members of the group agreed that the vision statement should be more brief and at least mention international markets in the context of developing the domestic market. The group also pointed out that the vision contained goals (e.g., "...to realize a thriving United States-based solar-electric power industry...") and that some of the existing goals were actually targets (e.g., 3.2 GW of the new domestic capacity in 2020 and end-user costs approaching $1.50 by 2020). The group did not invest a significant amount of time in reworking either the vision or goals, but did suggest that the NCPV advisory board include international markets and U.S.-based manufacturing in the vision statement. Furthermore, participants noted that a thriving U.S. PV industry would be the *outcome* of effectively pursuing a well-defined vision.

BARRIERS TO PV TECHNOLOGIES

Focus Question 2: What scientific/ technical, institutional and market barriers stand in the way of reaching the goals and targets of the Industry-Developed PV Roadmap Document?

The group identified barriers that fell into four broad categories, as shown in Exhibit 27: Evolutionary R&D Barriers; Leap-Frog R&D Barriers; Manufacturing Infrastructure R&D Barriers; and Institutional R&D Barriers.

Evolutionary R&D Barriers are those challenges that prevent incremental improvement to existing PV technology and market growth.

Leap-Frog R&D Barriers are those challenges that impede revolutionary changes to PV technology, manufacturing and market growth necessary to achieve the targets and goals cited in the Industry-Developed PV Roadmap Document.

Manufacturing Infrastructure R&D Barriers are the challenges to logistics, materials handling, production scale and yield, and product consistency that will be necessary to achieve the stated targets and goals.

Institutional R&D Barriers are challenges to achieving the goals for PV that are created by market perceptions, funding availability and public policy. Some of the barriers listed under Leap-Frog R&D Barriers, Manufacturing Infrastructure R&D Barriers, and Institutional R&D Barriers have bulleted sub-items that were important enough to list as part of a larger barrier.

Eight barriers emerged as having top priority for three or more of the group's members. The high cost of module materials and the high cost of encapsulation were the highest-ranking barriers in the Evolutionary R&D category. The two highest-ranking Leap-Frog Barriers were the lack of materials and devices to obtain high efficiency and low-cost systems, and insufficient R&D on manufacturing throughput. Increasing throughput and yield also ranked high in the Manufacturing Infrastructure and R&D category, along with issues facing thin-film manufacturability. High-ranking Institutional R&D Barriers included inadequate support from government for R&D and unclear selection criteria for resource allocation.

The participants discussed several times the "chicken and egg" nature of PV barriers. These discussions highlighted the importance of timing research and development activities in such a way that they cyclically advance materials availability, materials and manufacturing cost reductions, production machine availability, and cost reduction, and availability of suitably trained technical and marketing personnel. No single area can advance without parallel advancement of the other areas.

Exhibit 27. R&D Barriers to Vision, Goals, Targets

♦ = Votes for Top Priority

	Evolutionary R&D Barriers	Leap Frog R&D Barriers	Manufacturing Infrastructure R&D Barriers	Institutional R&D Barriers
High Priority	Cost of materials that go into module is too high ♦♦♦♦♦♦ Cost of encapsulation is too high ♦♦♦	Materials and devices to obtain high efficiency at low cost are not available ♦♦♦♦♦♦♦♦♦ - Low cost, high performance, thin silicon devices not available - Lack 20% cell structure with low temperature interconnect and contact material - Low cost, high performance for thin film not available - Low cost, lattice matched substrate for III-V not available Insufficient R&D to improve throughput (GW/factor) ♦♦♦♦♦	Issues of increasing the throughput and yield remain ♦♦♦♦♦♦ - Processing rate and yield are too low - Needed process controls do not exist - Automation is insufficient - Scale-up is still necessary - Insufficient R&D to improve throughput (to approximately 200 MW/factory) Thin film-manufacturing issues ♦♦♦♦♦ - Thin film, high efficiency semiconductor manufacturing equipment does not exist	Inadequate support from government ♦♦♦♦♦ - Support for small business is lacking - Support for high risk, high payoff is lacking Selection criteria for resource allocation is not clear ♦♦♦
Moderately High Priority	Availability of semi-conductor materials feedstock is insufficient ♦♦ Reliability data for emerging technology is insufficient ♦		Manufacturing equipment, capital costs are too high ♦♦ Limited availability of viable tandem junction modules in marketplace (other than amorphous silicon) ♦ Low cost tin oxide coated glass is not available Lack of manufacturing equipment vendors exists ♦ - Vendors of types of equipment do not exist/too few - An insufficient volume of equipment is available	Coordination and partnerships are lacking ♦♦ Poor public interface has created barriers ♦♦ - Have not sold consumers on value of PV - Misperception and stigma of PV impedes acceptance - Insufficient market conditioning Insufficient resources (private sector) ♦ - Technically trained persons - Lack of access to capital Poor means of rapid technology transfer from research to industry ♦
Moderate Priority	Environmental, health and safety issues and end-of-life disposal of modules have not been addressed		Lack of uniform credible cost models Material handling process is insufficient for 3,000 T/day volume - Inadequate materials scheduling - Inadequate materials transportation	Lack of focused regional research institutes, acting as an industry and research link (state funded) Lack of appreciation of fundamental nature of task: high technology, low value added, low cost – which affects funding decisions Insufficient industry analyses - Foreign competition - Other/related technologies – PV and non-PV technology – Ancillary technology

ACTIONS/SOLUTIONS TO OVERCOME THE BARRIERS

Focus Question 3: What are the key research, development, and demonstration needs that should be taken to overcome these barriers? Which of these needs could be addressed in the near-term (less than 3 years), mid-term (3-10 years) and long-term (more than 10 years) if resources were unlimited and work could start immediately? In the real world with limited resources, which of these needs would have the highest priority?

In a discussion of the above focus question, the members of the R&D breakout group identified specific R&D needs. The R&D needs, like the barriers, fell into four categories: Evolutionary R&D Needs; Leap-Frog R&D Needs; Manufacturing Infrastructure R&D Needs; and Institutional R&D Needs. Most of the R&D needs identified have bulleted sub-items that specific capture details important to achieving the goals cited in the Industry Developed PV Vision Document.

The members of the breakout group assigned priority ranking to the needs that they identified (only the main needs were eligible for priority ranking). Seven R&D needs shown in Exhibit 28 emerged as having top priority for three or more of the group's members. The high ranking Evolutionary R&D Needs included investigating new materials to reduce material cost, e.g., EVA, chemical tempering of glass, thin semiconductor materials, encapsulates, low-temperature conducting epoxy, optimized transparent conducting oxide and alternative substrates, and increasing the availability of semi-conductor feedstocks through development of high-volume, cost-effective silicon production process.

High-ranking Leap-Frog R&D Needs included developing materials and devices with high efficiency and low cost through targeted R&D for each technology[1] and conducting R&D high-rate deposition and processing to improve throughput.

The highest-ranking Manufacturing Infrastructure and R&D Need was to address throughput issues by conducting R&D on automation, process control, high-speed processes and scale-up. The group consensus was that the most beneficial throughput activities would be those that coordinate R&D on common needs across the industry, allowing technology-specific manufacturing R&D to independently build upon that foundation.

The second highest-ranking Manufacturing Infrastructure and R&D Need was to address thin-film manufacturing issues through basic R&D of process controls and diagnostics and designing reactors and equipment.

The highest-ranking Institutional R&D Need was to promote government support for R&D.

As shown in Exhibit 29, three R&D needs received priority votes from one or two members of the group, indicating moderately high priority. Only one R&D need, shown in Exhibit 30, received no priority votes. As discussed in the "Linkages Between R&D Needs" below, moderately-high priority (one or two votes) and moderate priority (no votes) R&D needs are related to high-priority activities and cannot be neglected. This interaction further highlights the "chicken and egg" nature of R&D needs for PV and the importance of timing research and development activities.

[1]The group identified specific R&D needs for thin silicon devices, silicon wafers, thin films, and III-V materials. The group also agreed that additional specific R&D areas should be identified through review of the *Basic Research Opportunities in Photovoltaics* (BROPV) document (the Executive Summary of this document appears as Appendix B to this Report).

Exhibit 28. High Priority R&D Needs to Overcome Barriers

♦ = Priority

Evolutionary R&D Needs	Leap Frog R&D Needs	Manufacturing Infrastructure R&D Needs	Institutional R&D Needs

Investigate new materials to reduce materials cost
♦♦♦♦♦♦
- EVA
- Thin glass through chemical tempering
- Encapsulates
- Low temperature conducting epoxy
- Optimized transparent conducting oxide
- Alternative substrates
 	
Improve cell efficiencies to reduce material cost
♦♦♦♦♦♦♦♦
- Form alliances with suppliers to reduce material cost
	Develop materials and devices with high efficiency and low cost through R&D with specific targets (draw more from BROPV document)
	♦♦♦♦♦♦♦
	– Thin Si devices
	  – 18-20% efficiency
	  – 10-100 µm thick
	  – 5-50 µs light time –
	  – Light trapping
	  – Surface with low
	
	– 20% cell structure with low-temperature interconnection and contact materials
	  – Back-contact interdigitated cell
	  – Thin - 100 µm Si wafer
	  – Low temperature conducting epoxy
	  – New interconnect technology
	
	– Low cost, high performance thin films
	  – Improve performance and lower cost of amorphous Si and alloys, CIGS and CdTe thin films to achieve a manufacturing cost of 75¢/w in 2010
	
	– III-V Materials
	  – Low cost concentrator modules (500x) with 40% efficiency
	  – New 1 eV materials
	  – Transparent conductor tunnel junctions
	  – Low cost, lattice- matched substrate
	  – New module design
	  – Reliability testing
	
	Conduct R&D focused on throughput
	♦♦♦♦♦♦
	- Develop new processes to achieve high-rate deposition and processing
		Address issues to increase throughput
		♦♦♦♦♦♦♦♦♦
		- Improve automation, process control and scale up (for cells and encapsulates)
		- Develop high speed interconnect and encapsulation
		- Develop a strategy to improve industry wide throughput (common themes across technologies)
		- Develop novel technologies such as rapid thermal processing (RTP) and high rate deposition (HRD)
		
		Address thin-film manufacturability issues
		♦♦♦♦♦♦♦♦
		- Conduct basic R&D to develop process control needs, process models, in situ diagnostics
		- Conduct reactor and equipment design
		- Develop mixed process integration
		- Develop better intermediate in line testing/diagnostics
			Promote support from government
			♦♦♦♦
			- Carry a unified flag (e.g., roadmap)
			- Develop a business-credible “story” for Congress

Exhibit 29. Moderately High Priority R&D Needs to Overcome Barriers

♦ = Priority

Evolutionary R&D Needs	Leap Frog R&D Needs	Manufacturing Infrastructure R&D Needs	Institutional R&D Needs
Increase availability of semiconductor feedstocks ♦♦ - Develop a process to produce Si at volume and cost to meet goals			**Improve coordination and develop partnerships** ♦♦ - Get people with diverse backgrounds together regularly to coordinate goals and planning (like this meeting) - Establish formal partnerships outside of PV – Fuel cell – Glass – Storage – Inverters – Carrier – End-user – ESCOs - Establish partnerships between government, industry and universities - Establish NREL partnerships with others outside of DOE for R&D funding - Establish formal partnerships between PV companies **Clarify selection criteria for resource allocation (government)** ♦ - Involve stakeholders in strategic planning - Align criteria with the plan (that is developed with stakeholder input) - Implement a regular review process to update criteria

Exhibit 30. Moderate Priority R&D Needs to Overcome Barriers

♦ = Priority

Evolutionary R&D Needs	Leap Frog R&D Needs	Manufacturing Infrastructure R&D Needs	Institutional R&D Needs
Reduce cost of encapsulation			

TIMEFRAME TO MEET R&D NEEDS

In a hypothetical situation posed in the breakout session, participants were asked to identify the amount of time needed to advance a particular R&D activity to “the next phase” of development if resources were unlimited and work could start immediately. Exhibit 31 presents the top ten PV R&D needs identified by this group in the categories of short-, mid- and long-term time frames and the organizations (industry, government and universities) that are most likely to be involved in each R&D area. (The organizations expected to participate in each area are listed in the bottom of the far left column in Exhibit 31. Where more than one organization is identified, the order in which they are listed indicates which entities should take a greater role.)

For the purpose of the discussion, the time frames were defined as less than 3 years, 3 to 10 years, and longer than 10 years. These time frames do not indicate a calendar date in which each body of work would be complete relative to the other R&D activities. Instead, these time frames reflect the soonest a viable product would emerge if work began immediately with no limitation on the resources for funding or qualified personnel. In this very hypothetical case, the group identified only two sets of actions that could be completed within three years from the day they begin: R&D of polycrystalline thin-film compounds, and establishing an input mechanism to government resource allocation. The group identified the remaining R&D areas as ongoing, iterative activities in which each improvement (in materials, devices, or process equipment/ methods) will precipitate subsequent work.

After the hypothetical exercise to estimate the amount of time required to accomplish each R&D need, the group abandoned the “unlimited resources” notion, and identified the R&D needs they would pursue if they had real-world constraints on funding and personnel. Exhibit 32 presents the priorities assigned by the members of the group as they considered limited-resource constraints on R&D. The priorities shown in this Exhibit will provide a basis for future PV roadmapping activities that identify the order and timing of R&D to achieve the vision and goals set out by the industry.

Exhibit 31. Timeframe for Top R&D Needs

(Milestones and Performers)

R&D Area and Performer	Timeframe – Earliest Emergence of a Viable Product* — Near-Term 0-3 Years	Mid-Term 3-10 Years	Long-Term >10 Years
DEVELOP MATERIALS AND DEVICES WITH HIGH EFFICIENCY AND LOW COST	Thin Si Devices Research and develop materials, process, and cell design to achieve 16% efficiency**	Thin Si Devices Develop pilot equipment at 18% efficiency device	Thin Si Scale up to large production at 20% efficiency
	Concentrators – Complete all 4 R&D items on previous board – Pilot production of modules with target efficiency >30%	Concentrators Prototype manufacturing of next generation 4-Junction modules with >35% efficiency	
	A-Si Thin Films and Alloy – Improve light trapping via tin oxide or back reflector – Develop high quality, low gap materials, like A-Si alloy or microcrystaline Si – Improve stability of A-Si alloy (ongoing)	A-Si Thin Films and Alloy Conduct technology-specific R&D (TBD) that achieves cost of $0.75/W by 2010	
	Polycrystalline Thin-film Compounds – R&D on lower cost substrates, encapsulants monolithic integration – R&D on improving module efficiency to 12-15% by low cost, large area process (ongoing)		
Performers: Universities, Government and Industry	III-V Materials – Develop module technology for concentrators – Develop materials and design device for concentrators	III-V - Materials Reduce costs in balance of system	III-V Materials High volume manufacture of concentrator modules at 50% efficiency

* This time frame does not indicate the calendar date that the work must be complete or the order in which the work should be done. Instead, this time frame reflects the soonest a viable product would emerge if work began immediately with no limitation on the resources for funding or qualified personnel.

* * Group members recommended using the *Basic Research Opportunities for Photovoltaics* document to expand this list. The Executive Summary for the document appears in Appendix B to this Report.

Exhibit 31. Timeframe for Top R&D Needs *(continued)*

(Milestones and Performers)

R&D Area and Performer	Timeframe*		
	Near-Term 0-3 Years	**Mid-Term 3-10 Years**	**Long-Term >10 Years**
ADDRESS ISSUES TO INCREASE THROUGHPUT Performers: Industry	- RTP and HRD developed - Develop industry-wide program to address automation, proc. control, interconnection, encapsulation (constant and ongoing) Throughput increases follow production curve	Manufacture HRD and RTP equipment Throughput follows production curves	HRD and RTP large scale production Throughput follows production curves
PERFORM R&D TO IMPROVE THROUGHPUT Performers: Universities, Government and Industry	Develop processes transfer to address thin film issues	Develop equipment transfer to address thin film issues	
ADDRESS THIN FILM MANUFACTURING ISSUES Performers: Industry, Government and Universities		New reactor equipment design and improvement of 25MW-50 MW systems	Develop reactors and equipment to produce 50 MW - >100 MW systems
INVESTIGATE NEW MATERIALS TO REDUCE MATERIAL COST Performers: Industry, Government and Universities	Ongoing iterative process		
IMPROVE COORDINATION AND DEVELOP PARTNERSHIPS Performers: Industry and Government		Look for additional and nurture existing C&P relationships	
INCREASE AVAILABILITY OF SEMICONDUCTOR FEEDSTOCK Performers: Government and Industry	Develop process to produce Si at volume and cost to meet goals	Identify a Si supplier	
REDUCE COST OF ENCAPSULATION Performers: Industry		Cost goal achieved for encapsulation	
PROMOTE SUPPORT FROM GOVERNMENT Performers: Industry, Government and Universities	Develop and deliver “flag” and story	Revisit “flag” and story	Revisit “flag” and story
CLARIFY SELECTION CRITERIA FOR RESOURCE ALLOCATION Performers: Industry, Government and Universities	Establish and maintain input mechanism		

* This time frame does not indicate the calendar date that the work must be complete or the order in which the work should be done. Instead, this time frame reflects the soonest a viable product would emerge if work began immediately with no limitation on the resources for funding or qualified personnel.

LINKAGES BETWEEN R&D NEEDS

Focus Question 4: How best should these research, development, and demonstration needs be addressed? What linkages exist among the needs and the four categories (Evolutionary R&D Needs, Leap-Frog R&D Needs, Manufacturing Infrastructure R&D Needs, and Institutional R&D Needs)?

Exhibit 32. Priorities for Short-, Mid- and Long-Term R&D Under Limited Resource Constraints

R&D Area	Priority
Develop High-Efficiency, Low-Cost Materials & Devices	I
Address Issues to Improve Throughput (in a manufacturing setting - highly related to area below)	II
Perform R&D to Improve Throughput (highly related to area above)	II
Address Thin Film Manufacturing Issues	II
Investigate New Materials to Reduce Materials Costs	III
Improve Coordination and Develop Partnerships	IV
Increase Availability of Semiconductor Feedstock	V
Promote Support from Government*	NA
Clarify Selection Criteria for Resource Allocation*	NA

* These items were considered "institutional" activities rather than activities involving R&D directly and were, therefore, not ranked.

As mentioned in the preceding sections on barriers and R&D needs, PV R&D embodies a "chicken and egg" problem in that nearly all facets of R&D impact others. In the process of identifying, categorizing, priority ranking, and estimating time frames for PV R&D needs, the members of the Fundamental and Applied Research and Development Breakout Session also identified some of the linkages between R&D areas. Exhibit 33 identifies the relationships that the group members identified during the breakout session. This list of linkages is not complete; additional discussion among PV experts will be necessary to develop a list that is complete and that has a sufficient level of detail to support development of technology and industry roadmaps for PV. Additional discussion among PV experts will be necessary to develop a list that is complete and that has a sufficient level of detail to support development of a technology and an industry roadmap for PV.

Exhibit 33. Linkages Between PV R&D Areas

R&D Area	Linkage
Develop High-efficiency, Low-Cost Materials & Devices	Should draw upon the *Basic Research Opportunities in Photovoltaics* document.*
	Should coordinate activities on thin silicon devices, concentrators, thin film, and III-V materials, focusing on common needs.
	Should include improving cell efficiency.
Address Issues to Improve Throughput (in a manufacturing setting)	These R&D areas are highly linked. R&D to improve throughput and actions in manufacturing to improve throughput must occur iteratively, with each step building on the last. These R&D areas also link to "Investigate New Materials to Reduce Materials Cost" and the specific activities related to reducing the cost of encapsulation.
Perform R&D to Improve Throughput +highly related to area above)	
Address Thin Film Manufacturing Issues	No linkage was explicitly identified.
Investigate New Materials to Reduce Materials Costs	Will impact all other areas as new materials emerge and precipitate development of new processes and equipment.
Improve Coordination and Develop Partnerships	In addition to the items detailed in Exhibit XY, this thrust should include efforts to develop alliances with suppliers and link to the R&D area of "Investigate New Materials to Reduce Materials Cost"
Increase Availability of Semiconductor Feedstock	No linkage was explicitly identified.
Promote Support from Government**	No linkage was explicitly identified.
Clarify Selection Criteria for Resource Allocation**	No linkage was explicitly identified.

* The Executive Summary of this document appears in Appendix B to this Report.
** These "institutional" issues do not directly involve R&D directly, but have significant linkage to all R&D

Summary Session

The Summary Session provided an opportunity for representatives from the four breakout session to present the results of their deliberations to all participants. Each group selected one of its members to present key findings and to summarize their discussions on the Roadmap Vision and Goals, technology and market barriers, research and market needs, and linkages among the four technology areas. Each presentation included a question and answer period followed by an open discussion. The findings and recommendations of each breakout session are described in full in the appropriate sections of this report.

Common Issues and Themes

An important objective of the Summary Session was to articulate the potential linkages and cross-cutting themes among research and market needs related to the photovoltaics industry. During the presentations, participants pointed out areas of similarities among the breakout groups and the linkages among research and market activities. For example, the PV Manufacturing breakout group recommended that lower cost module packaging be developed as an industry-government collaboration; this need was linked to better component integration and market enhancements.

Cross-cutting themes which were discussed at the workshop, and further addressed during a preliminary review of the breakout session reports are as follows:

- Potential PV end-users need to be identified, and alternative, high-value applications need to be delineated for each of them, particularly domestic, grid-tied applications.

- Alternative subsidy opportunities to enhance the grid-tied PV market need to be developed.

- Installed system prices must be significantly reduced.

- For grid-tied systems, customer expectations in terms of performance and reliability need to be met. This will require a higher level of oversight of the quality of installed systems.

- The value of photovoltaics must be readily apparent to potential end-users. This will require the collection of statistically significant component and system performance data, operations and maintenance data, and life-cycle cost information. This information will need to be compared with alternative electricity generation data.

- New building-integrated PV products that are attractive and easily integrated into new and existing building construction processes need to be developed.

- Grid-tied PV applications must be accepted by the electric utility industry.

Exhibit 34 provides a graphic representation of some of the cross-cutting research and market needs for the PV industry. Common needs, based on the above-listed cross-cutting themes, include improved consumer education and outreach on PV use and design; improved utility interconnections to

Exhibit 34. Common Needs of PV Industry

Needs	Markets and Applications	PV Components, Systems, and Integration	PV Manufacturing	Fundamental and Applied Research and Development
End-User Identification and Education	Sponsor education programs.	Wider public exposure for PV products. Training for designers, installers, builders, architects/ engineers.	Encourage partnerships with manufacturers and suppliers to develop better components/ systems	Develop high-efficiency, low-cost materials & devices.
Funding	Push for consistent Federal funding.	Promote adequate funding for PV component research.	Lower cost of module packaging, through research. Develop diagnostic tools, systems, processes.	Conduct R&D on new materials to reduce materials cost. Promote government funding.
Institutional/ Regulatory Enhancements	Promote grid-tied utility interconnections. Support net metering.	Promote utility interconnect with battery storage. Establish national/international standards for PV products and components.	Develop equipment and processes for high volume products.	Develop coordinated R&D programs; share research results.

encourage and improve grid-tied PV; consistent and enhanced federal funding for PV research; improved financial incentives for end-users to adopt PV technology; and development of partnerships with manufacturers, suppliers, researchers, and end-users to develop cost-effective equipment, systems, and building-integrated PV designs for enhanced markets. While there was a different focus for each sector of the industry, these common needs may be helpful as a basis for developing the PV Roadmap and for designing research and market transformation needs.

Concluding Remarks

The Summary Session concluded with brief remarks from each workshop participant including identification of additional issues, and suggestions for next steps. These comments are summarized below.

The workshop was overwhelmingly viewed as effective in bringing together the major figures in PV research, components, manufacturing, and marketing, and, perhaps for the first time, attempting to develop an effective vision and roadmap for the industry. Participants were very positive about the process used to convene participants and to develop consensus in the four breakout sessions. Although a number of participants felt that the workshop was not long enough to satisfactorily examine every issue or reach consensus on them, most participants were very pleased to have been invited and to have taken part in the workshop. They requested further input in development of the industry roadmap and suggested additional work be done on the industry vision and goals.

A number of participants spoke of the need to develop collaborative efforts with government, both federal and state, on PV technology improvements and market transformation. Companies must join together to share their knowledge, both technically and on market issues. Integration among manufacturers, sales personnel, installers, and distributors will help focus all of their attention on the end-user, the consumer.

Maintaining focus on the consumer was considered to be one of the most important needs for the PV industry. By designing, manufacturing, and selling products that consumers can and will use, and making it cost effective and easy for consumers to purchase, install, and maintain these products, the PV vision and goals established by the Roadmap Steering Committee will be met.

There was spirited discussion about the domestic market for PV versus the international market. A number of participants felt that the workshop's emphasis on the domestic market was short-sighted because PV opportunities in developing, non-electrified countries are very large. Others thought that in order to properly develop and remain competitive in international markets, the U.S. market must be better developed. Certainly this is an issue which will need more discussion in the Roadmap document itself.

Overall, a common message from workshop participants was the need to follow through with the results of the workshop as quickly as possible. This included preparing a draft report, circulating it to participants for their review and comments, and development of the final workshop report coincident with development of a process for designing the actual Roadmap. All of these activities were seen as important.

And finally, participants encouraged the workshop organizers to continue this dialogue among members of the PV industry. The roadmap process was seen as valuable and necessary for the industry's future success.

Appendix A. The Industry-Developed PV Roadmap: A Framework for U.S. Industry and Technology Leadership

The U.S. photovoltaics industry has the distinction of being the world's leader in research, technology, manufacturing, and markets. During the last several years, though, other foreign interests have recognized the critical importance of this technology and have accelerated their own strategic incentives toward securing dominant global positions. Three key attributes of this electricity source are fueling the intense world interest in photovoltaics:

- *Environment:* PV is truly a clean, emission-free renewable electrical generation technology, with substantial potential and competitiveness in the world's future energy mix.

- *Technology:* PV is elegant, reliable, manufacturable, consumer-friendly, and can be deployed in a wide range of applications.

- *National Interest:* PV is critical to our energy security, strategic technology, and long-term economic growth. As a "distributed" generation source, this technology acts as a network—not a grid—and is much less susceptible to large-scale outages caused by disasters of natural or human origin. It mitigates our dependence on foreign energy supplies, while providing distinct benefits to our domestic economy.

The PV industry recognizes the importance of collaborative planning and R&D partnering to its future vitality—especially because no segment of the industry is currently large enough to guide the entire infrastructure and competitive investments on its own. By developing a "roadmap," the U.S. PV industry will address the critical needs of photovoltaics technology and will ensure U.S. industry leadership over foreign competitors and growing investments by their governments. Our document is a framework that can serve to develop strategic plans for and investments in this technology and business—specifically as a U.S. strategic and national resource.

This "framework" roadmap will evolve into a full roadmap to guide U.S. photovoltaics research, technology, manufacturing, applications, markets, and policy through 2020.

The Vision

"The Vision is to realize *a thriving U.S-based solar-electric power industry, which provides competitive and environmentally friendly energy products and services that meet the needs and desires of the domestic electric-energy consumer.*"

In support of this vision, the industry and its partners have generated several key projections, which include annual module shipments strategies for the U.S. PV industry (Figure 1) and cumulative PV shipments for the United States and the world (Figure 2).

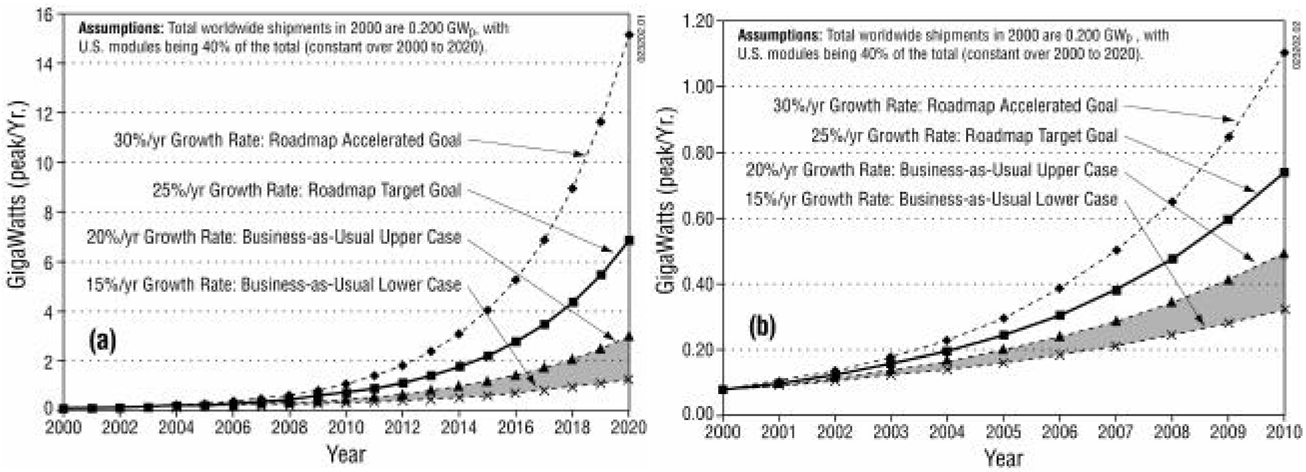


FIGURE 1a & 1b. Growth curves, showing shipments in GW_p as a function of time, for Roadmap annualized growth (25%), accelerated growth (30%), and business as usual (between 15% and 20%). Annualized growth characteristics are compared for the time periods of (a) 2000-2020 and (b) 2000-2010.

Four strategies are the focus for implementing the Vision:

Maintain the U.S. industry's worldwide technological leadership—*Photovoltaics is a technologically sophisticated product that is also evolving rapidly. Technological leadership is necessary both for economic competitiveness in PV markets and for PV to reach its potential within the national energy portfolio*.

Collaboration and cooperation of industry, government, and educational institutions is paramount to preserving and enhancing this leadership role. With mounting foreign investments and eroding U.S. market share, it is essential to strengthen and expand these relationships to secure our future. This will involve taking our core research, development, and other intellectual resources and integrating them with the U.S. industry's best interests. Furthermore, we must provide sound and well-conceived programs and *sustained* investments that clearly support and guide critical global U.S. industry leadership. Partnering of national laboratories and universities with the U.S. industry is essential.

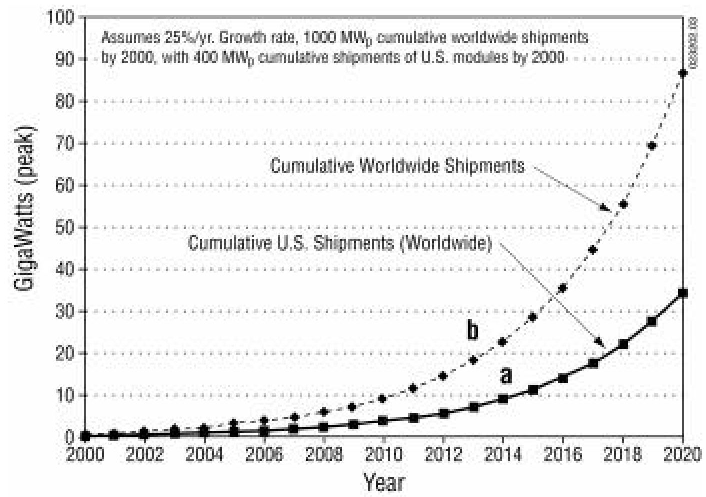


FIGURE 2. Cumulative PV shipments for the (a) United States, and (b) world.

Achieve economic competitiveness with conventional technologies—*During the past 25 years, the cost of photovoltaics has come down by several orders of magnitude. Concurrently, the industry has grown at annualized rates of 15%-20%—a growth rate comparable to that of the semiconductor and computer industries, which are in the "hundreds of billions of dollars" business category today. Based on the actual cost of electricity at the point of use, current PV systems are within a factor of 2-2.5 for distributed generation (e.g., residential* *rooftops). The advantages of PV cited above—environment, technology, and national interest—provide a unique competitive posture for this technology. Enormous markets will be established for PV as the cost of the technology approaches conventional technologies. This roadmap highlights the route to be taken in reaching peak-watt costs of under $3 in a timeframe that will ensure this competitive position.*

Maintain a sustained market and PV production growth. A sustained growth in PV production capacity and markets will establish PV solar energy as a significant contributor to the nation's energy portfolio. In the United States, peak electrical generation capacity in 1999 is about 800 GW_p.[1] With the projected U.S. PV industry growth in this roadmap (25%/year), about 10% of U.S. peak generation capacity[2] would be approached by PV by 2030 and would potentially be exceeded in 50 years. In reality, we expect U.S. demands for electricity to be met by a portfolio of alternatives. We also confidently anticipate that PV will be a major, pivotal part of that portfolio. PV will strongly impact AC distributed generation and DC value applications. It will provide a significant portion of the new U.S. electricity peak generating capacity between 2020 and 2030. In meeting the roadmap's cost goals, the industry will approach $10 billion per year, creating thousands of high-value jobs for the domestic markets alone and enormous environmental benefits within the timeframe of the roadmap.

Make the PV industry profitable and attractive to investors—*The aggressive growth in this roadmap will require considerable private investment. The PV industry must be profitable and attractive to investors to garner the levels of required investment. In attaining the market and technological goals of this roadmap, profitability and substantial investment can be realized. To grow into the predicted $10 billion-per-year U.S. business, we must establish strategic guidance and provide foundational funding now. With this roadmap, the industry will be profitable, the investments of the private-sector will be secured, and the nation will have an industry that clearly leads the world in production, deployment, technology, and domestic economic benefit.*

Beyond these four strategic thrusts, PV and this roadmap provide us with a path toward becoming better stewards of our environment. Photovoltaics is a viable option to improve the quality of life of our world citizens by deploying secure, reliable, and clean energy to power our homes, factories, and institutions.

Attention to this roadmap is crucial to ensure a long-term strategic vision. Attaining the goals is paramount to maintaining U.S. technical and manufacturing leadership.

DIRECTIONS, GOALS, AND TARGETS

This roadmap focuses on maintaining and building the global leadership of U.S. industry. A major target is the domestic markets. With a projected growth of 25% per year in the U.S. PV industry, the cumulative installed PV will increase substantially from its 1998 level of 60 MW_p. The U.S. generation capacity grows at

1%-3% per year, and this incremental capacity addition is expected to be about 21.5 GW in 2020.

Addressing the new (added) peak electrical generating requirements, the following "**endpoint**" is projected for PV in 2020:

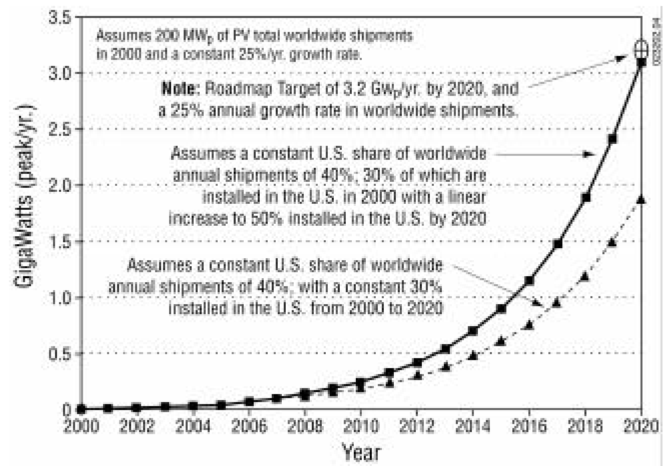
> *"For the domestic photovoltaic industry to provide up to 15% (about 3,200 MW_p) of new U.S. peak electricity generating capacity expected to be required in 2020. The U.S. cumulative PV shipments will be about 30 GW_p at this time."*

Non-domestic markets are significant and represent a substantial portion of the sales—especially in the near-term periods of this roadmap. In fact, when preparing the details, we will need to account for the influence of international and other high-value markets in the near-term expansion of the industry, in advance of large-scale domestic markets.

International markets are already being addressed and will continue to be a major part of the U.S. PV company portfolios. However, the importance of PV technology to the interests of the United States makes it imperative to develop a plan that clearly identifies our domestic markets as a major target for growth, sales, and consumer use.

Figure 3 projects U.S. manufactured PV modules installed in domestic applications as a function of time. If we do not focus on and develop U.S markets—that is, if the percentage of U.S. shipments between domestic and international remains at the current level—then the 3.2 MW_p goal in 2020 cannot be met, unless an unlikely total growth rate of 50% is attained. Without this focus on domestic markets, which complements the global marketplace, the United States will lose—to foreign competition—its opportunity to serve its citizens and own national interests.

The ***overall*** **goals** for the U.S. photovoltaics industry align with the 25% annual production growth rate. This rate, represented in Figure 1, is compared to an accelerated scenario of 30% and business-as-usual scenarios of 15%



and 20%.

FIGURE 3. Projections of U.S. manufactured PV modules installed in U.S. domestic applications, for a constant 30% U.S. market and a linear increase from 30% to 50% from 2000 until 2020.

The ***specific*** **goals** for the roadmap are categorized in two major industry target areas:

■ Total installed (annual) peak capacity**—**This will be at least **6 GW_p** installed worldwide by the U.S. industry during 2020, of which **3.2 GW_p** will be used in ***domestic*** installations. The industry expects the application mix to be:

1/2 AC distributed generation
1/3 DC and AC value applications
1/6 AC grid (wholesale) generation.

The installed volume will continue to increase, exceeding 25 GW_p of domestic photovoltaics during 2030. In 2020, the cumulative installed capacity in the United States will be about 15

GW_p, or about 20% of the 70 GW_p expected cumulative capacity worldwide.

■ Costs—The cost to the end-user (including O&M costs) will be $3 per watt AC in 2010 and will approach $1.50 per watt AC in 2020. The total manufacturing costs are projected to be 60% of the costs of the system.

To reach these goals, the PV industry and its partners have identified four critical ***Technology Development Areas***, around which the roadmap is fashioned. These areas are:

• Markets and Applications
• PV Components, Systems and Integration
• Manufacturing, Equipment, and Processes
• Fundamental and Applied Research

Coordinated Approach and the Road Ahead

The roadmapping process is now to build the details around this framework, specifying the short- and mid-term goals and objectives and the technology pathways to meet these long-term roadmap goals. The success in 2020 of achieving the vision and these goals will be a hundredfold growth—over 2000 levels—in domestic markets and the U.S. industry. The roadmap will set the stage for further ramping up of the use of this valuable renewable resource beyond 2020, providing significant portions of U.S. and world electricity generation by an environmentally clean, reliable, and competitive energy source.

Addressing the issues and achieving success with the roadmap goals is not a matter of choice. The U.S. industry and its partners must be ready to meet the ever-growing demand for consumer energy products and sources by making the right choices today, revisiting the technology guidance system frequently, and readjusting our direction in response to technology advancements and market needs. Research implemented today allows for choices in products and product availability tomorrow. Resources invested today provide the foundation for long-term success.

The Photovoltaic Industry Roadmap is a guide, and its success depends on the direction, resources, best scientific and technological approaches, use of the best and most advanced technologies, and continued efforts of the “best and brightest” among the industry, federal laboratory, and university partners. The framework roadmap sketched here provides a basis for more detailed planning and a picture of the needs and requirements for photovoltaics research, technology, manufacturing, applications, markets, and policy through 2020—developed by the U.S. industry as a guide for the efforts of the U.S. PV Program. We desire to meet the scientific challenges, fend off growing competition from foreign interests, and provide the nation with a technology that is critical to environmental and national interests. Therefore, we strongly urge support of these goals by their adoption in the technical direction of the U.S. PV Program and by the funding required to realize their success.

NOTES

1 *Annual Energy Outlook 1999*, DOE/EIA-0383(99), Energy Information Administration (Dec. 1998), p. 125, shows 776 GW_p "net summer capability" for year 2000.

2 Comparisons of the conventional U.S *peak* electrical generation capacities and the PV *peak* generation capacities refer to "summer capability" during peak summer-time conditions (mid-day, bright sunshine), when PV modules can produce electrical power according to their peak (e.g., GW_p) ratings.

This framework PV Industry Roadmap is respectfully submitted by the following representatives of the U.S. photovoltaics industry and strategic partners:

Allen Barnett
President,
AstroPower

Larry Crowley
President,
Idaho Power

Chester A. Farris
President and CEO,
Siemens Solar Industries

Harvey Forest
Past President and CEO,
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Lionel Kimerling
Thomas Lord Professor of Materials Science and
Engineering, and Director, Materials Processing Center,
Massachusetts Institute of Technology

Roger Little
President,
Spire Corporation

William Roppenecker
President,
Trace Engineering

Richard Schwartz
Dean, Schools of Engineering,
Purdue University

Appendix B. Basic Research Opportunities in Photovoltaics

EXECUTIVE Summary

Photovoltaic (PV) technology for conversion of sunlight to electricity is the most cost-effective method for meeting the electric power needs of many consumers around the world today. This is due in large part to more than 25 years of research and development supported by nations throughout the world with the vision to provide a clean, renewable source of energy. The U.S. PV research program was by far the largest during the first decade of development. U.S. based manufacturers today hold the major market share of this successful, rapidly growing worldwide business that generated nearly a billion dollars in sales during 1998. Most of the product serves applications some distance from the utility power grid or in installations that compete with retail prices for electricity. Consistent with the time horizon needed for any major change in national infrastructure, another 25 years of sustained, aggressive growth will be required for PV to displace a significant fraction of conventional energy generation sources. This growth will rely on con-tinuous introduction of new technology, underpinned by sound fundamental research. As we enter this phase, unfortunately, U.S. programs lag fundamental research efforts in Europe and Japan in both scope and funding.

As we embark on this phase of development, both the National PV Program within the DOE Office of Energy Efficiency and Renewable Energy and Basic Energy Science within the Office of Science are focusing increasing attention on the basic research issues that must be addressed to maintain the PV growth rates as well as on opportunities to accelerate this pace. *The Basic Research Opportunities in Photovoltaics Workshop*, held May 3, 1999 in Seattle, Washington, brought together experts in PV and related fields to offer guidance for initiatives on high payoff research programs.

The expediency of a one-day meeting was made possible by a number of factors. First, this workshop built on the findings of a prior meeting. A Research Assistance Task Force, chaired by Alex Zunger, met during July 27-29, 1992, to discuss *Research Opportunities in Photovoltaic Semi-conductors*. These extended interactions were documented in a special issue of the *Journal of Electronic Materials* (Volume 22, number 1, January 1993). Second, the 195th Meeting of the Electrochemical Society, which included a special Symposium focused on photovoltaics, provided a venue which attracted many workshop participants for whom the cost and inconvenience of travel could be minimized. Finally, and most importantly, workshop participants carried out extensive dialogue by phone, fax, and e-mail prior to arriving on May 3 and after the meeting as they identified key research issues and prepared the final manuscripts.

The workshop was structured into eight topics. Each topic area opened with a presentation in which the participants were asked to address the following areas:

- A brief introduction of the area of research

- Key research issues that were identified in the previous workshop of July 1992
- What fundamental research has been done since then or is currently being done to address those issues
- What are the research issues that are still relevant in light of advances made since the first workshop
- Identification of new fundamental research opportunities that will lead to important advances and innovations
- Identification of significant commonalties and common research issues that have a cross-cutting impact such as logically exist in silicon-based thin films, II-VI and related materials.

Participants in each topic area broke out into separate discussion groups to develop a concise set of issues and opportunities in light of their own views along with input from questions and comments from the other workshop participants that followed the presentation. Many of the attendees roved between groups to share in discussion of several topics. Results of the discussions were captured on flipcharts for presentation to the entire workshop.

After the meeting, participants in each working topic continued discussions by electronic means, completing journal articles that are to be published as a separate section in the ECS *Proceedings of the "PV for the 21st Century Symposium."*

For executive review, the key issues and opportunities identified by the topic area are highlighted below. They are not in priority order, unless specifically noted as such.

Amorphous and Micro-Crystalline Silicon (in priority order)

- Understand and control Si and alloy film structure, with increasing emphasis on high deposition rate as the structural order increases
- Understand the role of H in establishing nanostructure, in alloying and doping, in metastability, and as a structural modifier during solar cell operation
- Understand and control the gas phase chemistry, the reactions on the growing surface, and their effects on device properties

Crystalline Silicon

- Fundamentals of impurities and defects
- Interface and passivation issues for screen-printed contacts
- Impurity separation technology
- Thin-layer crystalline silicon of high quality, deposited at high growth rate using either low-temperature processing or a low-cost substrate compatible with high temperature processing
- Control of light - texturing, light trapping, and optical modeling

Cadmium Telluride

- Understand the basic nature of poly-crystalline CdTe needed for truly predictive models, alternative process pathways, and meaningful process monitors and control
- Measurements on samples prepared with systematic variation of process variables and incorporation of extrinsic dopants to elucidate the role of impurity atoms (Cl, O, Cu) and defects on bulk CdTc pro-perties and nanoscale variations of the polycrystalline material and its related alloys
- CdS/CdTc junction modeling and analysis with controlled degree of interdiffusion and other process variables
- Transparent conducting oxide front layers and their impact on subsequent depositions

- Understand the role of Cu in back contacts and exploration of Cu-free contact

Copper Indium Diselenide

- Development of an integrated predictive understanding of CIGSS materials and devices
- Development of novel deposition techniques and characterization of mechanisms of growth in existing and novel processes
- Novel materials, especially with wide energy gaps (>1.7 eV) other than CIGSS alloys
- Develop real-time material characterization for process control
- Alternative front and rear contact materials

III-V Materials

- Investigation of the influence of InGaAsN growth conditions on materials properties such as background impurity incorporation, carrier trap density and energies, and minority carrier properties
- Fundamental properties of 1 eV semiconductors for high efficiency, multiple junction devices
- Detailed transport studies in compensated InGaAsN to determine if electron localization is intrinsic in InGaAsN
- Development of technology capable of measuring I-V performance of multiple junction device

Novel Materials and Energy Conversion Approaches

- Nano/molecular composites - hierarchical structures
- Organic semiconductors
- Hot carrier devices

Semiconducting Oxides

- Synthesis, characterization, and understanding of new compositions and phases of TCOs
- Investigate scattering mechanisms to guide development of TCOs with higher electron mobilities
- Investigate the role of impurities and defects
- All oxide devices

Characterization

- Atomic and nanoscale characterization of impurity, native defects, extended defects, and interfaces - higher spatial resolution and trace impurities
- Performance characterization of developing technologies - high flux operation, multijunction, lower bandgap
- In-situ probes for diagnostics and process control - immediate response, integrated to ensure relevance

Appendix C. Workshop Agenda

PV Industry Technology Roadmapping Workshop

Chicago Radisson O'Hare Hotel
Facilitated for the U.S. PV Industry by the National Center for Photovoltaics

June 23-25, 1999

Wednesday, June 23, 1999

12:00 – 1:00	Registration – Grand North Ballroom	
1:00 – 1:30	Welcome – Grand North Ballroom – Workshop Overview	Larry Kazmerski, Director, NCPV
	Purpose, Process, and Expected Results	Richard Scheer, Energetics
1:30 – 2:00	The Vision for the U.S. PV Industry	Allen Barnett, AstroPower
2:00 – 2:30	Implications of the PV Vision: Directions, Goals and Targets	Roland Hulstrom, NCPV
2:30 – 3:00	Break	
3:00 – 3:45	Financing PV – Keeping in Mind Competitive Technologies	Bob Shaw, Arete Ventures
3:45 – 4:45	Marketing PV: Meeting the Needs of the End Users	Panel Discussion
	Bob Johnson, Strategies Unlimited	James Gee, NCPV, Moderator
	Allen Barnett, AstroPower	
	Roland Hulstrom, NCPV	
	Bob Shaw, Arete Ventures	
	Bill Roppenecker, Trace Engineering	
	Mike Stern, UPG Golden Genesis	
5:30 – 7:30	Reception – Heathrow Room	
	No-Host Bar and *Hors D'oeuves*	

Thursday, June 24

7:30 – 8:30	Continental Breakfast – Grand North Ballroom	
8:30 – 9:30	Distributed Generation: PV's Role	Joe Iannucci, Distributed Utility Associates
9:30 – 9:35	Introduction to the Breakout Sessions	Richard Scheer, Energetics
9:45 – 10:30	Breakout Sessions	
	Grand North Ballroom – *Markets and Applications*	
	St. Lawrence Room – *Fundamental and Applied Research*	
	Superior Room – *Manufacturing, Equipment, and Processes*	
	Ontario Room – *PV Components, Systems, and Integration*	
10:30 – 10:45	Break – Grand North Ballroom	
10:45 – 12:00	Breakout Sessions Continue	
12:00 – 1:00	Catered Lunch – Grand Central Room	

1:00 – 2:30	Breakout Sessions Grand North Ballroom – *Markets and Applications* St. Lawrence Room – *Fundamental and Applied Research* Superior Room – *Manufacturing, Equipment, and Processes* Ontario Room – *PV Components, Systems, and Integration*	
2:30 – 2:45	Break – Grand North Ballroom	
2:45 – 4:15	Breakout Sessions Continue	
12:00 – 1:00	Adjourn for the day	
	Dinner on Your Own – *See Packet for Some Area Restaurants and Activities in the Windy City*	

Friday, June 25

7:30 – 8:30	Continental Breakfast – Grand North Ballroom	
8:30 – 9:30	Reports from Breakout Groups	
9:30 – 11:00	Facilitated Discussion of Linkages and Sequencing Issues Among Four Groups	Richard Scheer, Energetics
11:00 – 11:30	Concluding Remarks—Adjourn	Larry Kazmerski, Director, NCPV

Thank you in advance you in advance for completing the Workshop Evaluation, which you will find in your packet. Please leave this at the Workshop registration table outside the Grand North Ballroom.

Appendix D. Workshop Participants

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