Solar Electric POWER

The U.S. Photovoltaic Industry Roadmap

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- National Center for Photovoltaics: Workshop on PV Program Strategic Direction, July 14-15, 1997 (Golden, Colorado)
- U.S. Photovoltaics Industry PV Technology Roadmap Workshop, June 23-25, 1999 (Chicago, Illinois)
- PV Roadmap Conference, December 13-14, 2000 (Dallas, Texas)

SOLAR-ELECTRIC POWER

THE U.S. PHOTOVOLTAIC INDUSTRY ROADMAP

"…providing the electricity consumer with competitive and environmentally friendly energy products and services from a thriving United States-based solar-electric power industry."

Reprinted January 2003

Table of Contents

Executive Summary

Make no mistake! Photovoltaic solar electricity *can* deliver and *is* delivering clean, reliable, on-demand power in current markets worldwide. And it has been a "power of choice" for consumers during our own domestic needs for critical electrical service. Yes, it is a significant player in the United States and in the world's *long-term* energy portfolio. But solar electricity delivers electrical power *now* . . . and it can provide many more benefits.

Our challenge is to rapidly expand the U.S.-based photovoltaic (PV) industry's manufacturing capacity to meet growing demands. At the same time, we must significantly expand the domestic market to retain U.S.-based manufacturing plants and jobs.

To meet this challenge, we — the U.S.-based PV industry — have developed this roadmap as a guide for building our domestic industry, ensuring U.S. technology ownership, and implementing a sound commercialization strategy that will yield significant benefits at minimal cost. Putting the roadmap into action will call for reasonable and consistent co-investment by our industry and government in research and technology development. The energy security, environmental, and direct economic benefits will far exceed the investment. The benefits are immense, in both the near and long term, and are consistent with our nation developing a sound, secure energy strategy.

We emphasize that it is *not* our industry promise that photovoltaic technology will provide *all* our domestic electricity within the coming 20 to 30 years. However, PV *will* be a significant contributor within a portfolio of energy sources, with this roadmap laying out a course to meet those electricity needs when and where it makes economic and technical sense.

On the domestic front, our industry's goal is to meet 10% of U.S. peak generation capacity by 2030 — the energy equivalent of some 180 million barrels of oil in that year. By 2020, solar-electric power will be providing a significant share of *new*, added U.S. peak electricity generating capacity.

But why does this picture of the future make sense?

Generation of solar electricity coincides with the normal peak demand of customers. Additionally, photovoltaic energy does not pollute, uses a free and abundant fuel source, is controlled by the customer, can be located near the point of use, frees utility investment in distribution systems, slows the depletion of fossil fuels, and provides energy security and control.

Currently, solar electricity is not cost competitive with bulk, baseload power — but it does not *have* to be. Instead, it provides electricity when and where energy is most limited and most expensive — a highly valuable and tremendously strategic contribution. It does not simply *replace* some fraction of generation; rather, solar-electric power *displaces* the *right* portion of the load. Solar electricity mitigates the risk of fuel-price volatility and improves grid reliability, thus guaranteeing a more stable energy economy.

Electricity from PV technologies allows consumers to spend their own money on energy, giving them control over their own investment. It is a free-market commodity, involving a mix of both large and many small businesses — with customer choice underpinning success and growth.

What must be done by the shareholders — by us, the industry, and by our government partners — in this venture? This roadmap defines these roles . . .

In the near term

During the next 3 years, the *solar-electric industry* will deliver quality products and services into the marketplace at fair prices. The industry will emerge during this period. We will continue to build our manufacturing capacities to meet growing demands both in the United States and in the rest of the world. And we will continue to provide economic value — building toward our expectation of a $15 billion industry in 2020. Within 25 years, the industry expects to employ more than 150,000 Americans in high-value, high-tech jobs, which is about the size of the current glass industry.

To support these efforts, the *government* — at both the state and federal levels — needs to ensure a level playing field on which our solar-electric power industry may compete with other power players. It should also lower the barriers that hinder photovoltaics from being developed and deployed — something that can be done at little cost.

Government oversight and implementation is all that is required to bring about national net metering (equity in selling PV electricity to the grid at the utility retail rate), moderate residential tax credits at both the state and federal level, and manufacturing incentives (equity with other energy-product producers). We must work with the government to establish standards, codes, and certification, which are essential for consumer protection and acceptance. Government can also invest in delivering solar-electric power to its own facilities when and where it makes economic and technical sense — for example, in the areas of energy security, premium power, uninterruptible power sources, emergency shelters, and off-grid power systems.

In the mid term

During the period from 4 to 10 years, the major demands will fall on us, the *industry*, and on our partners in the *private and public sectors*. We will develop the needed technical products — whether for residential and commercial distributed generation or for architectural and building-integrated PV applications. Shares of our profits will be reinvested to ensure vitality and market growth. We will continue to grow our manufacturing capacities and the range of our product to meet consumer needs. Our impact on the supply of new electrical power in the United States will be significant, and this period will firmly establish PV technologies and the solar-electric industry.

Activities/Roles of the Solar-Electric Industry and the Government

	Near-Term (1-3 Years)	Mid-Term (4-10 Years)	Long-Term (11-20 Years)
Research and Development (Technical Issues)			
Industry Role	• Develop advanced PV production equipment • Improve throughput of products in manufacturing processes • Enhance investment capital • Integrate R&D activities • Create manufacturing partnerships • Garner industry consensus and framework for Manufacturing Center of Excellence, and initiate operations • Develop prepackaged PV systems for reduced cost and improved reliability	• Develop model for high-volume manufacturing • Ensure steady flow of available silicon • Agree on common equipment standards • Research thin-film packaging • Develop technology (e.g., building-integrated PV, architectural glass) • Develop small-scale, standardized PV products for easy installation suitable for do-it-yourselfer market • Standardize PV systems for utility installation on utility grids • Complete fully operational Manufacturing Center of Excellence	• Create new materials and devices with high efficiency and low cost • Develop quality assurance/quality control methods to test products on site • Expand operation of Manufacturing Center of Excellence in response to technology directions
Government Role	• Increase R&D emphasis on manufacturing improvements • Expand the use of PV in government facilities where it makes economical/technical sense • Continue PV R&D activities • Support Manufacturing Center of Excellence	• Sponsor R&D to improve lifetime of PV modules and systems • Continue PV R&D activities • Continue support for Manufacturing Center of Excellence	• Support basic research on materials for the next generations of solar-electric PV systems • Continue support for Manufacturing Center of Excellence
Market Opportunities (Market Issues)			
Industry Role	• Increase sales and marketing budgets • Invest in manufacturing capabilities to meet demand in USA and abroad • Support an independent, proactive industry association	• Obtain long-term, low interest financing for PV • Build manufacturing capabilities • Develop business models, rules, and products for utility and power generator use of PV as peak shaving alternative	• Foster robust domestic and international market for PV
Government Role	• Establish moderate residential tax credits (state and federal) • Create manufacturing incentives (equity with other energy-product producers) • Invest in PV for facilities owned and operated by government • Support retail competition, as well as customer options under traditional regulation, as opportunities for customer acquisition of PV	• Invest in retail infrastructure distribution network • Continue outreach, training, and public awareness projects	• Fully develop outreach, training, and public awareness program • Lobby for utility regulatory policies and practices that provide open and competitive market for PV
Policy and Institutional Initiatives (Institutional Issues)			
Industry Role	• Increase understanding and public awareness for business executives, federal and state policy makers, and consumers about solar electricity • Lobby for fair and equitable utility practices that allow solar electricity to compete on a level playing field • Support retail competition, as well as customer options under traditional regulation, as opportunities for customer acquisition of PV	• Invest in retail infrastructure distribution network • Continue outreach, training, and public awareness projects	• Fully develop outreach, training, and public awareness training • Lobby for utility regulatory policies and practices that provide open and competitive market for PV
Government Role	• Adopt net metering in all 50 states • Adopt uniform interconnection standards in all 50 states • Establish fair and equitable utility business practices for PV, e.g., standby charges, customer retention fees • Support broad outreach aimed at business executives, state and federal policy makers, and consumers regarding solar electricity • Give credit for PV in "urban airshed" programs for offsetting emissions	• Support national and international standards for PV products and components (e.g., ratings, verification tools) • Support PV infrastructure development (codes, standards, certification) • Establish environmental regulations that explicitly value clean energy solutions such as PV	• Continue to develop regulatory and policy framework that supports PV • Support tax incentive structure that encourages development of clean energy

Over the long term

During the 20 years of this roadmap, we must work together with government to maintain, in some areas — or regain, in others — our technical and research leadership of solar-electric technologies, from the semiconductor devices themselves to the electronics that control and ensure the quality of electricity produced.

The *industry* will invest in R&D to make manufacturing lines more effective, improve production throughput, and bring manufacturing to a position of world leadership. The *government* is asked to continue a reasonable investment in the nation's intellectual and research resource at national laboratories, universities, and other research organizations. This investment will guarantee needed improvement in existing technologies and the development of new and better technologies. These next-generation photovoltaic devices and products are vital for meeting future energy needs and maintaining U.S. leadership.

Our roadmap will guide U.S. photovoltaic research, technology, manufacturing, applications, markets, and policy through 2020. However, its ultimate success — the significant growth of solar electricity — depends on the investments, guidance, and attention given to it now. Photovoltaic solar power can be a significant part of our electrical energy economy in the future. How significant it is — and who owns it — depends on setting our sights in the right direction — on the right road — *today.*

CHAPTER 1

INTRODUCING THE PHOTOVOLTAIC INDUSTRY ROADMAP... FULL SPEED AHEAD

"As we meet tonight, many citizens are struggling with the high cost of energy. We have a serious energy problem that demands a national energy policy….The [western United States] is confronting a major energy shortage that has resulted in high prices and uncertainty. I have asked federal agencies to work with California officials to help speed construction of new energy sources. And I have directed [the] Vice President, Commerce Secretary, Energy Secretary, and other senior members of my administration to develop a national energy policy….Our energy demand outstrips our supply. We can produce more energy at home while protecting our environment, and we must. We can produce more electricity to meet demand, and we must. We can promote alternative energy sources and conservation, and we must. America must become more energy independent, and we will."

— President George W. Bush[1]

The 21st century brings numerous challenges and opportunities that will affect our nation's energy, economic, and environmental security. Global economic and population growth. Technological advances. Utility restructuring. Greater demand for power quality and reliability. Environmental sensitivities. Global warming. These major driving forces underlie the need — and the opportunity — for improving our nation's systems for generating and delivering energy.

Some of these forces have already affected our nation's energy supply and security. For example, the prices of natural gas and oil have increased dramatically and have exhibited considerable volatility. Electricity restructuring in California has caused enormous increases in electricity prices recently, while during the summer of 1999, stress on the transmission and distribution system caused widespread power outages that affected millions of people and thousands of businesses. Meanwhile, our nation is increasingly reliant on imported fossil fuels.

A comprehensive national energy strategy is required to meet these challenges. Renewable energy will be an important element of an energy portfolio that improves our energy security, preserves our environment, and supports economic prosperity. A portfolio of renewable energy technologies could provide a significant fraction of the nation's electricity generation requirements and, in concert with other generation sources, provide more reliable power.

Significant among the renewable technology options is solar-electric power — specifically photovoltaics (PV), which is a semiconductor technology that converts sunlight *directly* into electricity. The "photovoltaic effect" produces direct-current (DC) electricity, while using no moving parts, consuming no fuel, and creating no pollution.

[1] President George W. Bush, February 27, 2001.

Solar-electric power is ideally suited to be a major contributor to an emerging national energy portfolio. The U.S. electrical grid will increasingly rely on distributed energy resources in a competitive market to improve reliability and moderate distribution and transmission costs and on-peak price levels. Distributed power also allows greater customer choice — for example, some consumers place great value on power reliability or clean power, as well as on low energy cost. In addition, many regions of the United States are becoming limited by transmission capacity and local emission controls. Solar-electric power addresses these issues because it is easily sited at the point of use with no environmental impact. Moreover, because sunlight is widely available, the United States can build a solar-electric infrastructure that is geographically diverse and less vulnerable to international energy politics and volatile markets based on fossil fuels.

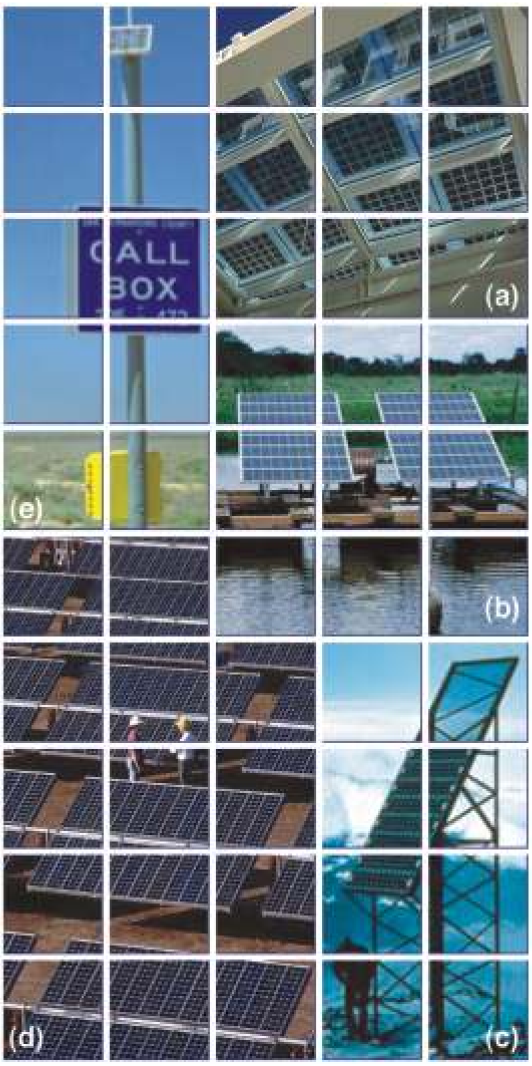


Figure 1 - Solar electricity from photovoltaics can be used in a wide variety of applications, which include: (a) building-integrated PV, (b) water pumping, (c) communications, (d) large-scale utility power, and (e) roadside emergency phones.

The International Energy Agency (IEA) projects that 3000 GW of new capacity will be required globally by 2020, valued at around $3 trillion; IEA also projects that the fastest-growing sources of energy will be supplied by renewables.[2] Much of this new capacity will be installed in developing nations where solar-electric power is already competitive. Clearly, the nation that can capture a leadership position has the potential for substantial economic returns.

The United States has long been the world's leader in photovoltaic research, technology, manufacturing, and sales. But other countries have awakened to the potential of photovoltaics and its rapidly growing markets. These countries are accelerating their own efforts to secure dominant technologies and global market share. Consequently, over the past few years, the United States has lost its dominant market share and now risks losing its lead in developing and commercializing technology. If we do not rise to the challenge of reestablishing a leadership position, then our domestic PV industry — which includes U.S.-based manufacturers, distributors, and installers — will continue to lose technology leadership, market share, jobs,[3] and revenues. We will be importing PV products to meet domestic demands for electricity — a position similar to the one we are in regarding petroleum.

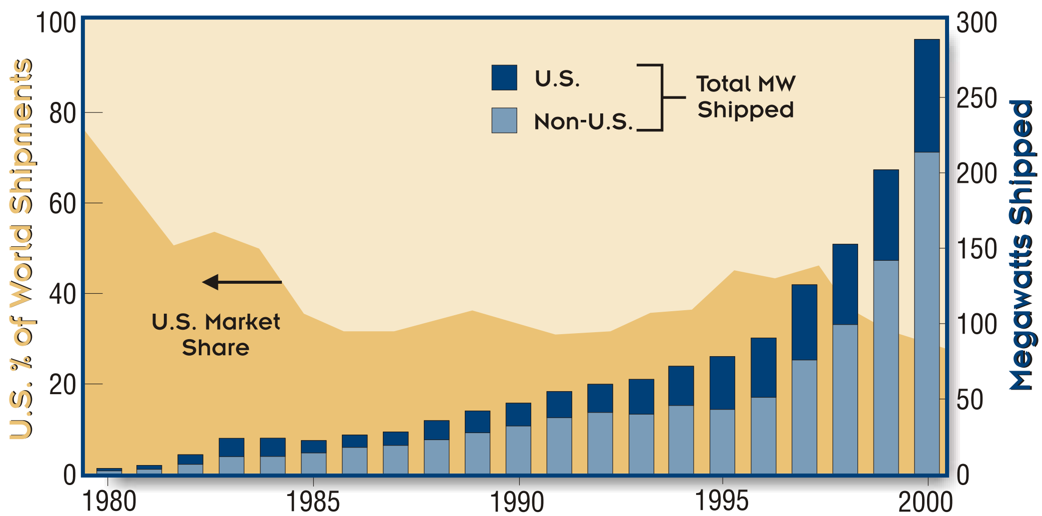
[2] IEA's *World Energy Outlook 2001, Executive Summary* (See www.eia.doe.gov/oiaf/aeo).

[3] Currently, our expanding U.S. PV industry directly employs some 20,000 people and indirectly supports more than 100,000 jobs. See M. Renner, "Energy Alternatives and Jobs," *Renewable Energy World,* November-December 2000, 27-32; Solar Electric Industries Association, *Solar Jobs for Today & Tomorrow* (See http://www.seia.org/sf/sfjobs.html).

We in the U.S.-based PV industry are working hard to meet growing market demand, confront increasing foreign competition, and build a stronger leadership position, because we realize the environmental, economic, and energy security benefits of a large and profitable PV industry within the United States. To do so, we have devised a unified industry roadmap with a vision and long-term strategies, goals, and targets through 2020. We have held two high-level meetings — the first in Chicago and the second in Dallas — in the past year to collectively develop this strategy.

Export markets —for example, village power in remote areas of the world — are significant and represent a substantial portion of current sales for our industry. These markets will *continue* to be a major part of the sales and marketing strategies of our PV industry. But because of the importance of solar-electric technology to the interests of the United States and the domestic consumer, it is imperative to develop a plan that clearly identifies our *domestic* markets as a major target for growth, sales, and consumer use.

Our roadmap will help to guide U.S. photovoltaic research, technology, manufacturing, applications, market development, and policy through 2020. Its success will depend on the direction, resources, scientific and technological approaches, and continued efforts of the "best and the brightest" among industry, the federal government, research organizations, and our educational institutions.



Source: PV News, PV Insider's Report, Feb. 2001

Figure 2 - Annual world PV shipments showing U.S. and non-U.S. production (in MW). Percent of U.S. market share is shown in light brown in the background.

CHAPTER 2

PV'S VALUE TO CUSTOMERS AND THE NATION ... WHY TRAVEL THE ROAD?

> *"Sooner or later we shall have to go directly to the sun for our major supply of power. This problem of the direct conversion from sunlight into power will occupy more and more of our attention as time goes on, for eventually it must be solved."*
>
> — Edison Pettit, Wilson Observatory, 1932

Americans are clear about their preferred energy future — plentiful and reliable sources of clean energy at reasonable prices. At the same time, a number of drivers, trends, and issues make meeting these preferences difficult. Global economic and population growth, technological advances, power quality and reliability problems, environmental challenges, and utility restructuring underscore the need and opportunity for re-engineering the nation's energy generation and delivery systems in the coming years. So, although photovoltaics is not the entire solution to these challenges, this renewable-energy option can be an important contributor to the energy picture of the United States and the world.

Photovoltaics has a variety of attributes that will make it an important component of our nation's energy future. PV is a versatile electricity technology that can be used for many applications, from the very small to the very large. It is a modular technology that enables electric generating systems to be built incrementally to match growing demands. PV is easy to install, maintain, and use. It is a convenient technology that can be used anywhere there is sunshine and that can be mounted on almost any surface. PV can also be integrated into building structures to maximize aesthetics and multifunctional value. These positive attributes allow PV to address the following market drivers for energy in the United States.

Reliable power and power quality. The cost of power interruptions is very large, and some customers — for example, those with vital Web servers or critical hospital or industrial needs — cannot tolerate power interruptions or poor-quality power. Each year, U.S. businesses spend some $2 billion for industrial uninterruptible power supplies while consumers purchase another 200,000 small generators (about 3 kilowatts) because of concerns regarding power quality and reliability. Furthermore, losses incurred by businesses due to power quality and reliability problems account for more than $30 billion each year.[4]

Dispersed-generation sources, such as PV, can improve grid reliability by reducing stresses on transmission and distribution systems. Photovoltaic technologies, in particular, provide ultimate power reliability with on-site generation. The reliability of photovoltaics is underscored, for

[4] Imre Gyuk, EESAT2000 Conference Paper, *Electrical Energy Storage Systems, Applications and Technologies*, Orlando, Florida, September 18-20, 2000; Venture Development Corporation. "The Global Markets for Uninterruptible Power Supplies, Volume 1: North America 5.0 KVA and Under," March 1999 (http://www.vdc-corp.com/news/news99/pr99-13-frames.html); Venture Development Corporation, "The Global Markets for Uninterruptible Power Supplies, Volume 2: North America Over 5.0 KVA," April 1999 (http://www.vdc-corp.com/news/news99/pr99-14-frames.html).

example, by San Francisco's recently announced plan to install photovoltaic-powered traffic stoplights that have backup battery power at 100 key intersections. The City will rely on PV to prevent dangerous traffic snarls during potential rolling blackouts due to a strain on conventional power generation.[5] As noted, in this stand alone application of PV, a battery backup ensures that power is available even at night or when the sun isn't shining. For a grid-connected application, the grid uses the generated solar electricity "while the sun shines," saving the use of conventional fuel. In effect, this unspent fuel acts as the storage (backup) for electricity needed at other times (e.g., at night).

Plentiful power where you need it. Solar-electric power systems provide a domestic source of energy that is plentiful, sustainable, and available throughout the United States. As an example, one utility — Sacramento Municipal Utility District — estimates that sufficient commercial and residential roof space, parking lots, and transmission corridors exist with south-to-west orientation for solar-electric power to provide 15% of its peak power needs. To grasp the potential of solar-generated power, the total electricity demand for the United States today could be supplied by PV systems covering only 0.4% of the nation in a high-sunlight area such as the Desert Southwest — an area about 100 miles by 100 miles. In reality, though, this power generation will be distributed across the United States, bringing generation sources close to the consumer point of use.

Customer choice. Increasingly, electricity customers want to choose their energy supplier, for both greater control of their power and to illustrate other personal values, such as concern for the environment. Photovoltaic solar-electric power increases customers' choice over the type of energy resource desired. Customers can have PV panels mounted on their homes and businesses. Business and industry owners can generate power for industrial processes and to heat and air-condition multi-family residential and commercial buildings and facilities. Businesses can also use PV to meet their critical power needs during power outages and shortages. In a competitive marketplace, customer choice will rely on interconnection and net-metering standards that fairly compensate grid-connected PV users for the energy they generate and that provide safe, secure interconnections with the power grid.

High value and appropriate applications. Customers — whether residential, commercial, or industrial — recognize that many factors besides price affect the value of energy: for example, power reliability, power quality, freedom from price volatility, or preference for environmentally clean technologies. Utility companies that invest in PV for their customers will be more competitive in the future. As the utility market deregulates, customers will choose their electricity providers based, in part, on the offered price and on desired preferences. As customers learn more about the benefits of PV, solar-electric power will become the power of choice for a larger number of customers and in increasingly diverse applications.

[5] "February 2001, Miscellaneous," *San Francisco Chronicle*, 2/1/01, Article posted on NCPV Hotline, (http://www.nrel.gov/ncpv/hotline_feb2001.html).

As an example of this situation in another country, Japanese homeowners exhibit a willingness to buy PV — even at about twice the cost of conventional grid-supplied power. Having few domestic sources of conventional energy, Japanese consumers place high value on personal control over their energy future. In the United States, citizens typically have no perception of a power shortage; historically, power has been relatively inexpensive. But in the long term, energy will become more expensive on a national and global basis, and consumers need to prepare for the bump if local electricity rates begin to climb.

Environmental quality. Solar-electric photovoltaic systems, which produce no atmospheric emissions or greenhouse gases, make environmental sense for our nation. Compared to fossil-generated electricity, each kilowatt of solar photovoltaics could prevent substantial emissions that endanger our environment and personal health. Typically, on an annual "per kilowatt" basis, PV offsets or saves up to 16 kilograms of nitrous oxides (NOx), 9 kilograms of sulfurous oxides (SOx), and 0.6 kilogram of other particulates. In addition, one kilowatt of PV typically offsets between 600 and 2300 kilograms of carbon dioxide (CO_2) per year.[6] These savings, of course, vary with regional fossil fuel mix and solar insolation.

Building a PV infrastructure provides insurance against the threat of global warming and climate change. For example, a 2.5-kilowatt system covers less than 400 square feet of rooftop area and supplies the necessary electricity for a typical U.S. home. The annual amount of carbon dioxide saved by the system is about equal to that emitted by a typical family car during the same year.

Environmental and power-transmission limitations increasingly constrain our nation's population from increasing or even meeting their power needs. Little room exists to build intra-urban power plants, and public tolerance is low for new transmission lines. As a long-term strategy, distributed PV brings generation to the point of customer use to meet moderate peak loads — electricity when and where it is most needed.

PV's value to customers is straightforward — it is about choice. Choice of supply, generation, and use. We can see our preferred future, where solar electricity meets a significant portion of customer demand. PV is truly the power of choice.

[6] EPA, "Demonstrating Pollution Reduction Capability of Photovoltaics" (See 199.223.18.230/epa/rew.nsf/soloar/index.html for solar calculator); P.D. Moskowitz, "Photovoltaics: Environmental, Safety and Health Issues and Perspectives," *Progress in Photovoltaics, Millennium Issue*, **8**, 27-38, 2000.

Chapter 3

Photovoltaic Industry Profile ... Travelers on the Road

"Photovoltaics is a significant part of our current business and is growing as the solar-electric industry expands in response to the demands for its products and services. This is especially true with the impacts of the building-integrated PV and architectural glass markets that are just beginning."

— Chris Cording, 2001, AFG Glass, Inc.

The photovoltaics industry directly impacts diverse parts of U.S. commerce. We contribute technology, research, manufacturing, training, installation, and clean electric power. Worldwide in 2001, the photovoltaic solar-electric business is about $2 billion and growing. We currently employ some 20,000 of America's most skilled and experienced workers in high-value, high-tech jobs. And by 2020, we fully expect to grow toward a workforce of 150,000[7] — about the size of the current glass industry — as this roadmap is implemented. Several years beyond 2020, we will be double this employment level — with jobs at the same level currently supported by General Motors or the U.S. steel industry.

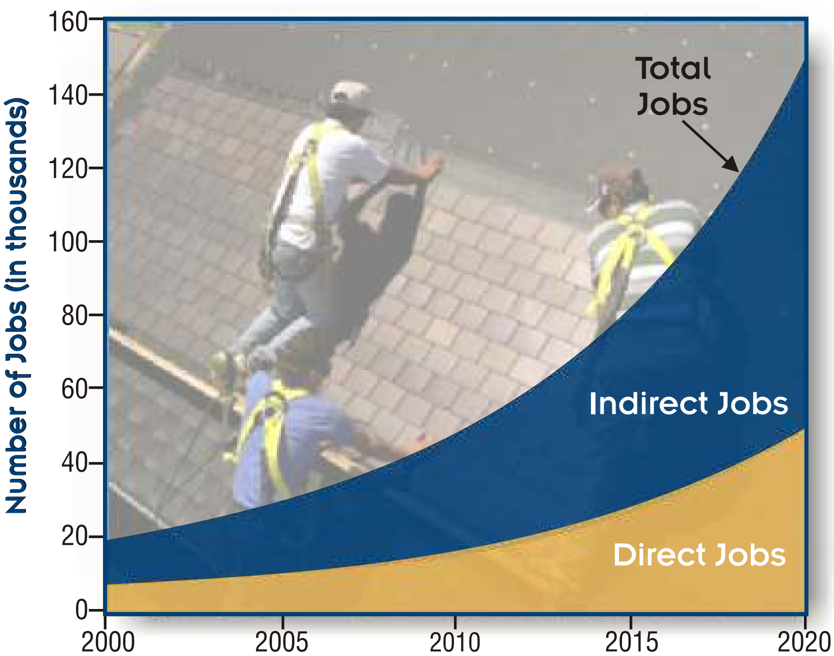


Figure 3 - Direct and indirect jobs over the 20 years of this roadmap.

We are engineers, scientists, managers, architects, builders, planners, educators, sales people, entrepreneurs, skilled laborers, financiers, designers, and investors — with a common goal of bringing *electricity consumers competitive and environmentally friendly energy products and services* that will benefit them, the United States, our

[7] Estimates based on *Directory of the U.S. Photovoltaics Industry*, Solar Energy Industries Association, Washington, D.C., 1996; "Energy Alternatives and Jobs," *Renewable Energy World*, v.3, n.6, Nov/Dec 2000, pp. 26-32.

Automated teller machines (ATMs), cellular telephones, pagers, global positioning systems for transportation, microwave transmissions, communication repeaters, direct TV — all these products already depend on photovoltaic power for their information transfer. Emergency warning systems, telephones and telecommunications, uninterruptible power supplies (UPS), premium power, highway, information, and construction signs, and numerous consumer products have selected PV for reliable and best-option power in our everyday living. The demand is growing for residential and commercial distributed generation, because solar electricity *can* and *is* helping to solve the critical power delivery problems spreading throughout our nation. We are U.S. industry, U.S. jobs, U.S. technology — united to be a positive and significant contributor to U.S. electricity security and its energy portfolio.

Who We Are — the People and Organizations Bringing You Solar Electricity — and What We Do

We are the semiconductor ***solar cell and module manufacturers and vendors*** who provide the building blocks for the solar-electric power system. We represent some two dozen companies with three dozen manufacturing sites in this country alone. In 2000, we shipped about one-third of the world's module products — some 75 megawatts. Our manufacturing capacity has doubled in the past 5 years, and we expect another doubling within the next 3 years, with an arsenal of technologies that includes crystalline, thin-film, and concentrator products. Our business has exceeded $500 million per year, and we contribute positively to the nation's balance of payments with an aggressive export market.

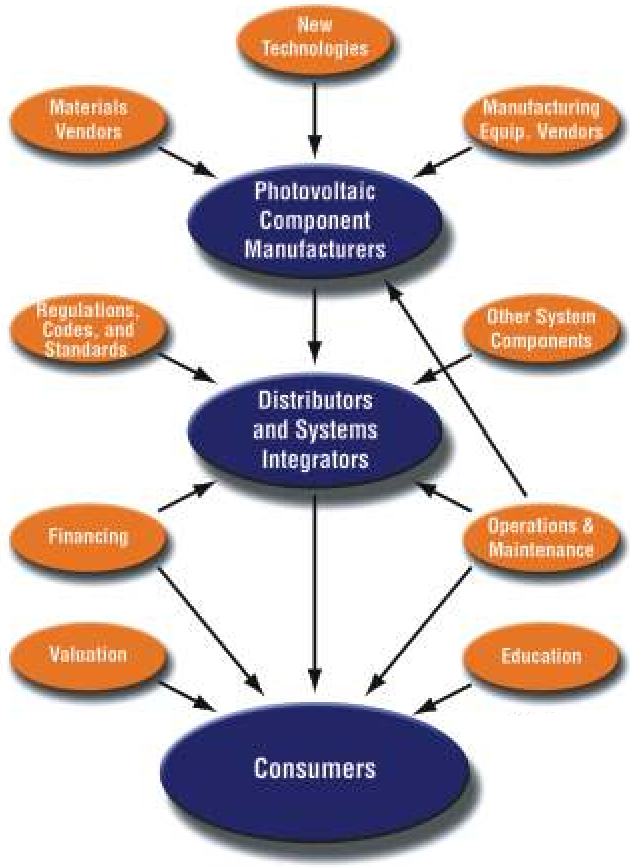


Figure 4 - A wide variety of manufacturers, businesses, regulatory boards, and educational organizations help bring high-quality solar-electric power to consumers.

We are ***PV equipment manufacturers***, designing and supplying the equipment needed to fabricate devices, assemble modules, and test products. We are the lifeline for the industry, challenged to anticipate evolving technology and to be ready with required fabrication and measurement systems when those products are set for production. Because of the nature of PV products, much of the equipment is specialized, with some equipment adaptable from the semiconductor electronics industry. Therefore, we serve more than 50 companies, including both solar-cell and module manufacturers who maintain relationships with PV-dedicated businesses and semiconductor industry equipment suppliers.

We are ***balance-of-systems (BOS) manufacturers and suppliers*** who make and market electronic components, and any necessary storage elements, that complete the solar-electric system. Currently, we are the 25 companies that design, develop, and fabricate equipment, electronics, and devices to monitor, control, ensure quality, store, and provide a utility interface to the electrical power produced by photovoltaic modules. Together with solar-cell and module manufacturers, we provide clean, reliable power appropriately sized to the application.

We are ***system integrators, packagers, and installers***. We are the hands and minds that bring solar-electric power to consumers. We work with individuals on their residences, with groups for microgrids and power parks, and with utilities for central-station and distributed-generation applications. We employ skilled labor to mount, monitor, and maintain these systems. We also work with builders and architects to meet local codes, standards, and regulations, and to design aesthetically pleasing buildings that enhance owner investment. Our directory includes some 170 primary businesses in the United States alone.

We are ***research and academic institutions*** — the life support system for this expanding industry. We are responsible for preparing the leaders and high-tech work force for the solar-electric industry. We educate and train the scientists, engineers, technicians, and support staff to meet labor needs. Most importantly, we are the underlying force in providing critical R&D, both to improve *current* technology and to develop the *next-generation* technologies of solar electricity necessary to maintain U.S. leadership and ownership. We are the 70 universities and three national laboratories directly partnered in photovoltaic R&D. We work with industry to invent, discover, and own the intellectual property that ensures U.S. technology, U.S. economy, U.S. jobs, and U.S. industry leadership.

We are many ***industries and organizations that benefit from and contribute to the solar-electric power business*** — the indirect partners. We are architects and builders who integrate photovoltaics into commercial structures, residences, and subdivisions. We are skilled laborers — the roofers, electrical and metal workers, machinists, transportation engineers — who provide support structures, deliver the product, and install it for the end-user. We are the commodity suppliers — the glass industry, electronic device manufacturers, plastics and polymer industries, equipment suppliers, wire and cable makers, and steel, aluminum, and other metal industries. These industries employ the labor force to meet growing needs in direct PV manufacturing and deployment operations. The photovoltaics industry benefits other professions with millions of *indirect* jobs, with estimates of 5 to 15 such positions for each person *directly* employed in producing PV systems.

We are also ***energy partners*** with photovoltaics solar electricity in the generation arena. Other energy sources — *wind, fuel cells, hydrogen, bioenergy, diesel, nuclear, natural gas, and hydroelectric* — combine forces with photovoltaics in hybrid and/or complementary energy delivery systems to deliver power to consumers. We maximize the best of each of our technologies for the region and the application, leading to competitive, reliable, and safer energy supplies. We are collaborators for a secure U.S. energy future.

Our U.S. photovoltaics industry is important for the nation. We offer energy security, a competitive edge in the world's economy, modularity and versatility, quality power, and reliability — with a distinct advantage for clean power generation and clean manufacturing among the current alternatives. We have a presence in the current electrical-supply market. We are a growing *power of choice* for environmental and electricity-demand reasons. And we are a factor in the future energy mix and economy for the United States and the world.

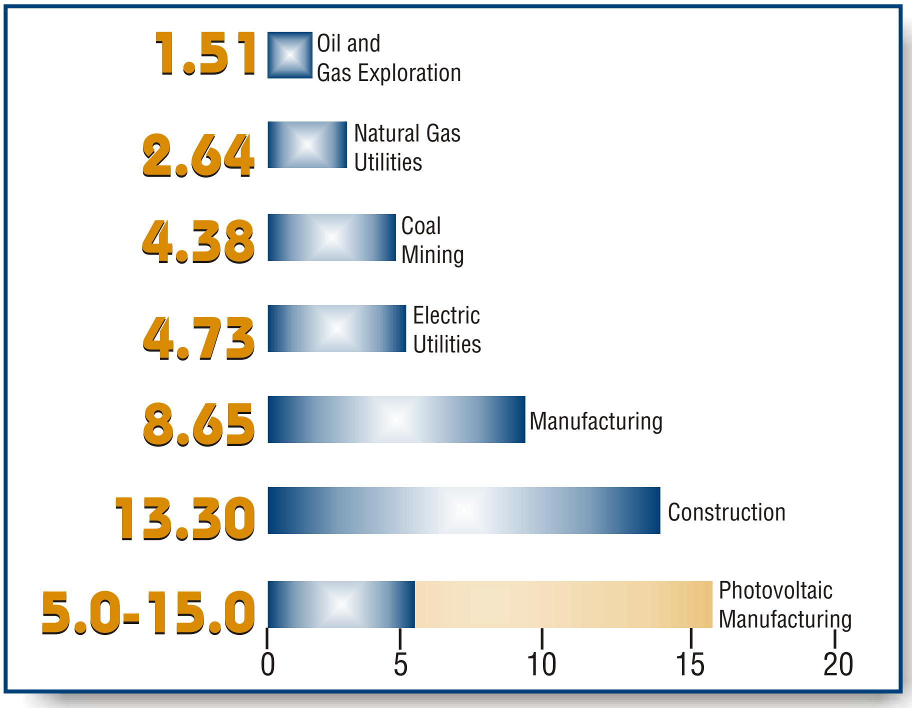


Figure 5 - U.S. direct jobs per million dollars of annual investment in PV activities (e.g., materials, manufacturing, labor). These investments are compared to investments in oil and gas exploration and other sectors.

Chapter 4

Solar-Electric Vision, Goals, and Targets ... Our Destination

"Our vision is to provide the electricity consumer with competitive and environmentally friendly energy products and services from a thriving United States-based solar-electric power industry."

Our Vision and Mission

Our Vision recognizes that a sustainable market-based approach will be required to achieve the Mission — to bring the energy security, environmental, and economic benefits of solar-electric power to the United States — by providing attractive products from a profitable industry. Coupled with an aggressive market transformation strategy, our goal is to make solar-electric power a significant component of the nation's energy portfolio within the next two decades.

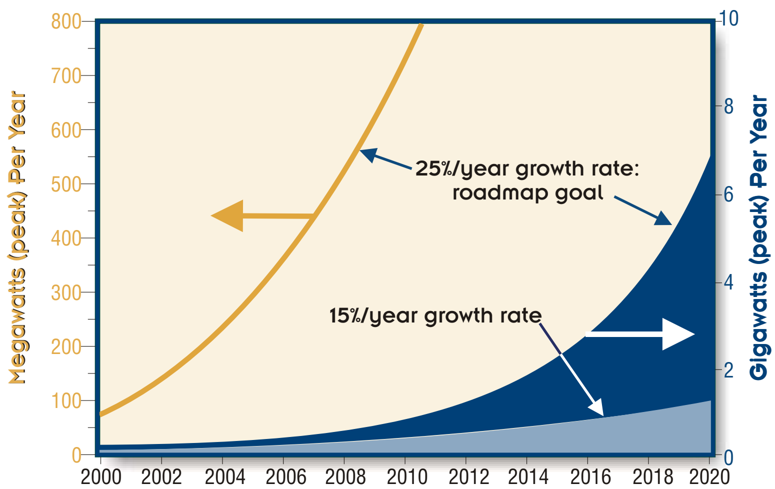


Figure 6 - Growth curves, showing annual U.S. industry shipments (into domestic and non-domestic markets) in GWp as a function of time, annualized at both 25% and 15% growth. The U.S. shipments are also shown on an expanded scale (left-hand axis) by light brown curve.

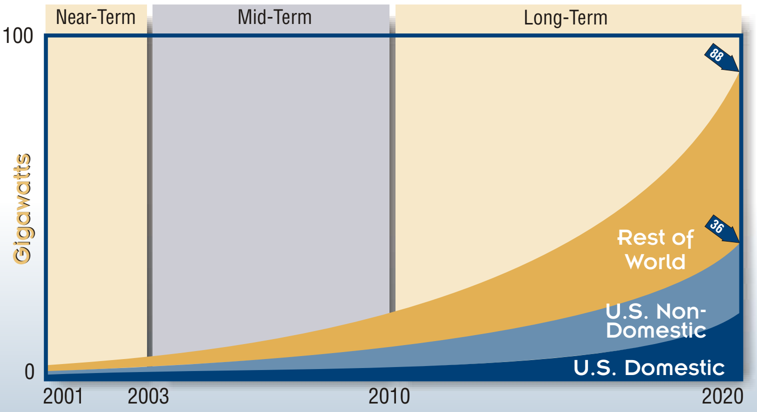


Figure 7 - Goals for cumulative world PV shipments showing U.S. share and distribution in domestic and non-domestic markets.

Our Strategy

We have four strategies for implementing the Vision:

- **Maintain the U.S. industry's worldwide technological leadership** — Technological leadership is necessary both for economic competitiveness and to become a significant contributor to the nation's energy portfolio. Mounting foreign investments have eroded U.S. market share on the business side and have overtaken our R&D lead on the technology front. It is essential to strengthen and expand our investments to secure our future. We must take our core research, development, and other intellectual resources and integrate them with U.S. industry's best interests — resulting in sound and well-conceived programs and *sustained* investments that clearly support and guide U.S. PV industry leadership worldwide. A critical element of this effort is sustained partnerships between the U.S. solar-electric industry and national laboratories and universities.

- **Achieve economic competitiveness with conventional technologies** — During the past 25 years, the cost of photovoltaics has come down by several orders of magnitude. Concurrently, our industry has grown at average annualized rates of 15% to 20% — a growth rate comparable to that of the semiconductor and computer industries. Based on the actual cost of electricity at the point of use, current PV systems are within a factor of 2 to 5 of conventional sources for distributed applications (e.g., residential rooftops). Enormous markets will be established for PV as its cost approaches that of conventional technologies. Our roadmap charts a course that will provide competitive power (i.e., costs of under $3 to $4 per peak watt) in a timeframe that will ensure a competitive position.

- **Maintain a sustained PV market with accompanying production growth** — Sustained growth in production capacity and markets will establish solar electricity as a significant contributor to the nation's energy portfolio, which consisted of about 825 gigawatts[8] (GW) in 2000 of peak electrical generation capacity. Our expectation for industry growth is 25% per year — a level that should be achievable according to recent market data.[9] At this level of growth, domestic PV capacity will approach 10% of U.S. peak generation by 2030. PV will strongly impact AC distributed generation and DC value applications.

- **Make the PV industry profitable and attractive to investors** — Our aggressive growth strategy will require considerable private investment. Our industry must be profitable and attractive to investors to earn their financial support. To grow into a domestic business with an annual revenue of $10 to $15 billion, we must establish strategic guidance and attract foundational funding now.

[8] *IEA's World EnergyOutlook 2001, Executive Summary* (See www.eia.doe.gov/oiaf/aeo).

[9] P. Maycock, *PV News*, February 2001.

If our PV industry grows by 25% per year, cumulative installed solar electric systems will grow substantially from 2000 levels of 75 peak megawatts (MW_p). U.S. generation capacity is projected to grow at 1% to 3% per year; this incremental capacity addition is expected to be about 22 GW in 2020.

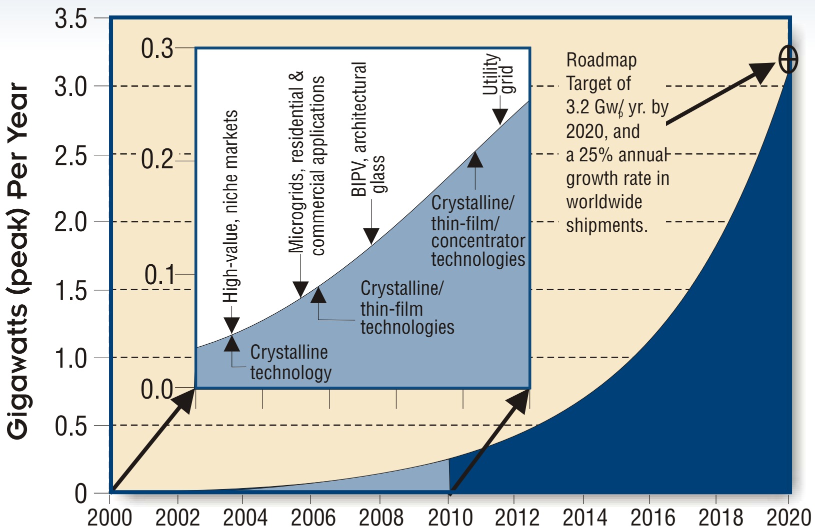


Figure 8 - Goal for U.S. manufactured PV modules installed in U.S. domestic applications, for a U.S. market share that increases linearly from 30% to 50% from 2000 to 2020. Inset shows the evolution of the impact of various markets and technologies.

We project the following "endpoint" in 2020:

> *"The domestic photovoltaic industry will provide up to 15% (about 3,200 MW_p, or 3.2 GW_p) of **new** U.S. peak electricity generating capacity expected to be required in 2020. Cumulative U.S. PV shipments will be about 36 GW_p at this time."*

Our endpoint is important because we focus not only on *replacing* a fraction of U.S. electricity generation, but also, on *displacing* the **right** 15%. PV will shave peak-load demand, when energy is most constrained and expensive. Peak shaving alleviates the need to build new intra-city power plants and transmission lines — projects that burden utility budgets and typically meet with customer resistance. This critical long-term strategy moves the load off the grid and handles peak loads at the point of consumer use — true distributed generation.

If we do not focus on and develop U.S. markets — that is, if the percentage of U.S. shipments to domestic and international markets remains at the current level — then the 3.2 GW_p goal in 2020 cannot be met. Without this focus on domestic markets, as well as complementary activities in the global marketplace, the United States' opportunity to serve its citizens and its own national interests will be lost to foreign competition.

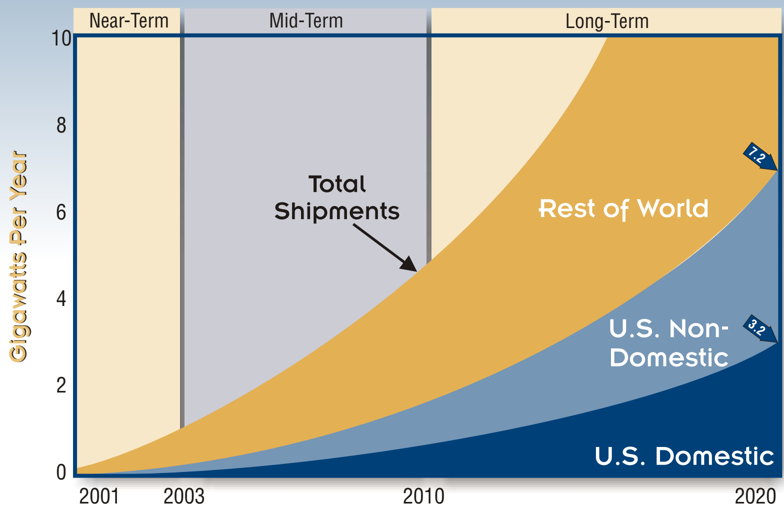


Figure 9 - Goals for annual U.S.-based industry shipments from 2001 to 2020 showing both world and U.S. domestic and non-domestic markets. Targeted total shipments in 2020 will be 17 GW/year.

Non-domestic markets are significant and will continue to represent a substantial portion of sales — especially in the near-term period of the roadmap. However, the importance of PV technology to the interests of the United States makes it imperative to focus on our domestic markets as major targets for growth, sales, and consumer use.

Our Goals

We have categorized the *specific* goals for the roadmap in two major industry target areas:

Total installed (annual) peak capacity — This will be at about 7 GW_p installed worldwide by our domestic PV industry during 2020, of which 3.2 GW_p will be used in domestic installations. We estimate the mix of applications to be: 1/2 AC distributed generation, 1/3 DC and AC value applications, and 1/6 AC grid (wholesale) generation. This expectation is based on business plans and market trend projections of the PV industry, and published independent analyses.[10]

Installed volumes will continue to increase, exceeding 25 GW_p of domestic photovoltaics during 2030. In 2020, 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.

Prices — The system price paid by the end-user (including operating and maintenance costs) will be $3 to $4 per watt AC in 2010. Total manufacturing costs — or the cost to produce the components in the system — are projected to be 50% to 60% of the price of the installed system.

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. Our roadmap sets 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 with an environmentally clean, reliable, and competitive energy source.

[10] Strategies Unlimited, "Photovoltaic Five-Year Market Forecast 2000-2005" Report PM-48, April 2000; P. Maycock, *PV News*, February 2001; proprietary report by Raymond James & Associates, Equity Report, August 31, 2000.

CHAPTER 5

TECHNICAL, MARKET, AND INSTITUTIONAL BARRIERS ... BUMPS IN THE ROAD

Barriers to widespread use of solar electricity reflect technical (e.g., scientific and engineering), market, and institutional problems that can be solved if we as an industry, along with our partners, address them in a unified and complementary manner. We play a key role in removing barriers that block solar-electric technologies from being a prominent power of choice for our nation — a point that became clear during intensive roadmap workshops in Chicago and Dallas during the last year involving key PV industry players. Some solutions where we take a leading role require working with other members of the PV community. Improving intra-industry coordination may even result in formal partnerships among our industry members. Other solutions where we must take the lead will require forming alliances with others, including non-traditional partners. A common theme from the roadmap workshops is that a coalition of forces can bring great power to any potential solution. We are largely responsible for controlling our own destiny.

Technical barriers. For our industry to reach the goals of this roadmap, we must address a variety of technical issues. One such issue topping the list concerns reducing the cost of manufacturing solar-electric power components. We need to develop low-cost high-throughput manufacturing technologies for high-efficiency thin-film and crystalline-silicon cells. For example, the industry has established an 18% to 20% conversion efficiency goal at a cost of less than 50 cents per watt for each module technology. Currently, thin-film and crystalline-silicon modules are 7% to 10% and 12% to 14% efficient, respectively. In addition, to increase the production of crystalline silicon at the projected rates, a dedicated supply of solar-grade silicon feedstock must be available at less than $20 per kilogram.

In developing our roadmap, we have given considerable attention to the technical barriers facing PV manufacturing processes. Table 1 gives some representative examples that indicate the depth to which this barrier has been discussed at the roadmap workshops.

Other technical barriers include the need for an improved manufacturing infrastructure to increase throughput and yield. The rate at which PV components are manufactured is still too low, and the projected steady increase in manufacturing output will create even higher demands. Process controls are inadequate, and automation is still insufficient to improve the cost efficiency of production. Continued research and development is needed to improve annual throughputs to about 200 megawatts per factory.

We recommend establishing a *Manufacturing Center of Excellence*, a key element of which will be an *Industry Technology Consortium,* composed of core equipment manufacturers, PV manufacturing industry representatives, and university/national laboratory research groups. Members would contribute their multidisciplinary expertise for development of programs and facilities for understanding and improving PV component processing and system manufacturing.

Table 1 - Roadmap Workshop Analysis of One Technical Barrier Facing Manufacturing Processes

The Problem

- Achieving flexible high-speed manufacturing to reach the 2020 roadmap goals

The Solution

- Create a 200-MW factory by 2020

Incremental Needs

- A 5-fold reduction in module manufacturing costs by 2010
- A 10-fold reduction in module manufacturing costs by 2020
- A 40-fold increase in module manufacturing by 2020
- Realize that PV — as systems are now designed — is not always geared for mass production

Short-Term Industry Actions (0-3 Years)

- Develop partnerships so manufacturers can work with suppliers to develop next-generation PV equipment — a "key" industry-government interaction
- Develop in-line diagnostic tools and systems to enhance process control and development — a "key" industry-university interaction
- Conduct equipment demonstrations at high volume so other industry members can observe and analyze data for common goals
- Identify common equipment needs among all members of the PV industry

Longer-Term Industry Actions (>3 Years)

- Design lower-cost module packaging
- Develop high-volume, high-throughput, high-efficiency cell processes
- Move from company-specific equipment manufacturing toward equipment designs that can be transferred to and used by more than one manufacturer

The precedent exists for such successful joint research efforts — for example, the Microelectronics and Computer Technology Corp. and SEMATECH (the Semiconductor Manufacturing Research Consortium).[11] An important function of the Center would be regularly held industry forums to develop standards for common equipment and to collaborate on equipment development. These forums would also identify common problems and solutions, including development of standard module electrical and mechanical "interfaces," improved balance-of-systems component reliability, and assistance in developing a more highly trained PV manufacturing labor force.

Another barrier to the widespread use of photovoltaics is the high cost of module materials and encapsulation. In addition, continued R&D on materials and devices must further improve the efficiency of PV systems. Some representative examples of critical R&D needs include high-efficiency thin-film devices, low-temperature interconnect and contact material, and low-cost lattice-matched substrates for compound semiconductors.

We understand that system simplicity and reliability will greatly enhance the widespread acceptance and use of solar electricity, so we aim toward complete systems solutions. As such, a successful PV system should be pre-engineered, pre-packaged, and even "plug-and-play"; highly reliable, long-lived, fault-tolerant, and shade-resistant; and easy to maintain, use standardized components, and sold as a complete service solution.

[11] See www.mcc.com and www.sematech.org.

Successful systems can be achieved in many ways, including the following consensus ideas we formulated during the Chicago and Dallas roadmap workshops:

- Continue to support large numbers of rooftop installations, gleaning valuable systems performance and reliability data for future use
- Educate the PV industry itself on successful systems integration
- Increase the experience of PV systems engineers
- Develop an incentive program — a “Golden Carrot” program — to spur the creation of packaged PV systems
- Continue national meetings on system performance and reliability, jointly sponsored by industry and the national laboratories.

Balance of systems, or BOS, is another area critical to successful PV systems. BOS components include power inverters and other power-conditioning equipment. In the past, less attention was paid to BOS, compared to cell and module manufacturing, when defining our PV industry. Today, however, we clearly realize that we must consider the entire PV installation if we are to achieve our goals. This renewed spirit of collaboration among companies from all segments of our industry is one of the major outcomes of the roadmap process.

Likewise, we in the PV industry are taking the lead in going outside the PV world to develop formal partnerships with inverter manufacturers, to create highly reliable, relatively inexpensive, flexible, trouble-free inverters. In the future, inverters may look more like conventional electronic systems, be free of noise, and incorporate new power electronic topologies.

We realize that inverters must meet qualification tests and satisfy rigid interconnection standards to help stave off the burgeoning influx into the United States of foreign BOS components. Ideally, we will agree on and develop common power-conversion equipment. To address BOS needs, we must initiate a research project representing a collaboration of industry and national laboratories.

Table 2 - Technical Barriers to Solar-Electricty Development
• Lack of widespread availability of low-cost feedstock and packaging materials
• Performance and manufacturing costs of high-efficiency silicon, thin-film, and concentrator cells and modules
• Improved reliability of modules and, especially, of balance-of-systems components
• Lack of standard products, packages, and service offerings
• Need for Manufacturing Center of Excellence
• Lack of knowledge of high-throughput processes
• Lack of standard module electrical/mechanical "interfaces"

Market barriers. A variety of market-related issues impede the robust development of solar electricity, such as: consumer awareness and education; government, legislative, and regulatory roadblocks; and financing. We understand industry's lead role in modifying marketing strategies. Toward this goal, Table 3 presents one outcome from the Chicago and Dallas roadmap workshops of specific strategies that we ourselves will strive to implement.

Table 3 - Roadmap Workshop Consensus on Specific Strategies That Industry Must Pursue to Overcome Market Barriers
• Increase value proposition to customers
• Develop alliances with other groups
• Develop a common message
• Form an industry coalition to strategize
• Strengthen the industry's trade association
• Lower product price
• Improve the distribution infrastructure
• Consider developing alliances with energy service companies
• Target end-user groups with appropriate messages
• Reduce technical jargon in advertising
• Reduce all market barriers with a plug-and-play application
• Develop a killer application

Consumers must become better educated about using solar energy — not just for hot water and space heating, but for their electricity needs. They do not need to worry about understanding the underlying physics of solar-electric generation; but they will want to be firmly convinced of the practicality and performance of PV systems over time. Consumer awareness of and familiarity with solar technologies should start at an early age in educational institutions and should continue into the marketplace. When solar-electric systems become available in home repair and hardware stores, and when consumers are offered installation assistance, PV will then become more "mainstream."

At the same time, the construction, installation, and maintenance infrastructure remains a barrier to widespread use of PV systems, particularly of stand-alone systems. Installation and maintenance professionals must become familiar with solar-electric components and systems so that they can select, install, and maintain them for their customers.

Successfully integrated solar electricity on commercial and residential buildings will significantly boost the marketing of building-integrated photovoltaics (BIPV) by removing a number of "perceived" barriers to its use. For example, we have developed the following key steps to address BIPV. Our short-term actions over a period of 0 to 3 years include striving for architectural integration, and developing wiring systems for curtain-wall applications. Our longer-term actions over a period of 3 to 10 years include: demonstrating examples of good building design and integration; designing value-added building products using PV; and striving for flexibility (e.g., range of colors) in products for architects, designers, and builders.

Other significant market barriers include the need to develop brand-name recognition and pricing for solar-electric components and systems. Currently, consumers — whether residential, commercial, institutional, or government — purchase heating, ventilation, and air-conditioning (HVAC) products (e.g., water heaters, furnaces) by catalog or through vendors who sell specific manufacturers' products. Similarly, the market for PV products will increase through more effective branding and competitive pricing.

Table 4 - Market Barriers to Solar-Electricty Development
• Lack of consumer awareness and understanding
• Disincentives against net metering
• Lack of purchasing channels
• Lack of trained installers and inspectors
• Inadequate codes and standards related to PV
• Minimal financing options for PV systems

Institutional barriers remain, including excessive standby and interconnection charges that prohibit integrating PV systems with grid electricity. Even before electricity restructuring spreads across the country, state legislatures and regulatory agencies should be deciding on equitable interconnection charges, standby charges, and net-metering requirements and fees for solar electricity generated in distributed applications and then sold to the grid. Energy customers should find themselves with greater choice under both traditional regulation and retail competition. Where traditional regulation continues, customers ought to be free to pursue more energy efficiency and to acquire distributed generation, including PV. Individuals and organizations who install PV systems must not be "punished" with high charges for interconnection, standby, and sell-back services. Yet, they need to be confident that their distribution utility will work cooperatively with them to allow — and indeed, encourage — grid interconnection. Equity in tax policies for PV compared to other energy sources remains an issue on the state and federal levels.

Table 5 - Institutional Barriers to Solar-Electricity Development
• Lack of communication within industry in identifying common technical problems
• Insufficiently trained and available PV manufacturing labor force
• No solar-electric appliance ratings/standards
• Interconnection standards that inhibit solar-electric development
• Inconsistent government policy related to photovoltaics

The value of photovoltaics is becoming clearer as consumers look to more distributed energy opportunities in our increasingly volatile energy environment. Barriers to a robust PV industry do exist. Nevertheless, the product is basically sound, the market opportunities exist, and our industry's track record has improved dramatically. Although there is much to do, we remain confident that the barriers can be overcome and that cost can be reduced to realize PV's promise. We will pursue the manufacturing of PV products and the use of these commercial products in a broad range of applications within diverse markets. Our industry will also rely on the core R&D activities of the government and universities to help overcome technical barriers and to address the technical issues related to the market and institutional barriers.

Some barriers are best overcome by state or federal initiatives, whereas others are best approached by R&D efforts in academic institutions or national laboratories. Our PV industry members realize that breaking down many other barriers is within their own purview. Continuing to identify and address barriers that are clearly the responsibility of the PV industry will be a critical activity for reaching the goals set forth in this roadmap.

CHAPTER 6

COMMERCIALIZING PHOTOVOLTAIC SOLAR-ELECTRIC POWER … ENSURING OUR ARRIVAL

Photovoltaic solar-electric technology uniquely satisfies the requirements of the three drivers of the new power-generation landscape: premium power for high reliability, distributed generation for point-of-use economics, and renewable energy for environmental value and energy security.

Despite these attributes, the value of this enabling technology is not fully appreciated in the United States. Thus, our industry's commercialization plan will rely on market-driven incentives in federal procurement, tax, deregulation, pollution prevention, and research, development, and deployment. With ever-growing pressures — of energy imports, energy price volatility, power outages, and energy shortages — solar technologies represent a technological safety valve for American home and business owners. We in the solar industry urge that these cutting-edge technologies receive increased attention and that this attention be at least equal to that given by our industrialized competitors in Germany, Japan, and other countries around the globe.

Our Main Focus

Our PV industry, seeking to address vital energy issues, endorses a roadmap that:

- Tailors research and development programs to address market solutions
- Enhances pollution prevention approaches to focus on clean alternatives
- Ensures customer choice
- Provides targeted tax incentives that seed the market without distorting it

To achieve these goals, we are pursuing the following five strategies:

Develop Opportunities Based on Electric Utility Deregulation — Rational deregulation leads to customer choice. Photovoltaic solar-electric power adds unique value in alleviating the problems of supply shortages, price volatility, random and planned power outages, and constraints in transmission and distribution. Required actions involve work in the areas of net metering, consumer education, renewable energy portfolio standards, and system benefits trust funds.

Establish Tax Equity — National and state tax incentives, whether investment or production credits or property and sales taxes waivers, must be prioritized for emerging technologies in less mature markets. At the federal level, most energy tax benefits focus on mature energy technologies in mature markets, with estimated federal subsidies ranging from $2 to $8 billion per year. As a whole, renewable energy technologies receive only a small share of these energy subsidies — about $100 million per year of federal tax subsidy — with more than 80 percent of this amount going to wind and geothermal.

We recommend the following tax incentives:

- *Legislatively establish a 15% residential tax credit for solar-thermal and solar-electric installation.* This residential tax credit — as proposed under S. 1634 and H.R. 1465 — has been scored by the Joint Tax Committee at $92 million over 5 years. This modest tax credit becomes effective if coupled with a system benefits charge for electricity at the state level.

- *Institute an alternative minimum tax (AMT) waiver similar to that currently enjoyed by domestic oil producers.* Oil producers receive a waiver from the AMT because the national interest is served by sustaining a domestic energy industry, albeit a very small one. The same justification should apply to domestic producers of solar energy.

- *Further expand state incentives.* Currently, 35 states have some type of solar incentive — from investment credits to sales tax and property tax waivers. Such programs help establish tax equity for capital-intensive, fuel-free energy technologies. Also, if adequately promoted to the public, these programs will establish key market-driven incentives for allowing solar technologies to reach a critical market share for sustained growth.

Increase Funding of Research, Development, and Deployment (RD&D) — The United States' investment in photovoltaic RD&D has been in the range of $50 to $75 million per year, significantly less than the government's investment in conventional energy technologies. A sufficient baseline investment for federal solar-electric RD&D must be established. In addition, existing programs in other agencies should co-invest in the development and demonstration (deployment) portion of the PV RD&D budget.

Specifically, we recommend the following:

- Consistent funding levels of the next 5-year period for photovoltaic RD&D programs through the U.S. Department of Energy of *at least* $100 million per year, to maintain technical leadership, which includes the ownership of next-generation technologies.

- Support for validation for PV technology development and deployment by *other* federal agencies — including the Department of Defense, Environmental Protection Agency, Housing and Urban Development, National Institute of Science and Technology, and other DOE programs. Specifically, these funds should support other government agencies to continue to expand the use of solar-electric power for their own power needs.

Establish Procurement Incentives for Federal Agencies — The nation's energy procurement budget should include capital expenditures by federal agencies for cost-effective uses of photovoltaics in four categories: uninterruptible power supplies, lighting, off-grid power systems, and diesel generator replacement.

Target Pollution Prevention and Emissions Reduction — The extraction, conversion, and use of energy is the single largest cause of air and water pollution, as well as of emissions that may lead to global climate change. Solar-electric power technologies are now available that can cost-effectively provide clean, safe, reliable power.

Energy Source	SO_x (gSO_x/kWh)	NO_x (gNO_x/kWh)	C in CO_2 (gC/kWh)	C in CO_2 from non-generating portion of fuel cycle* (gC/kWh)
Coal	3.400	1.8	322.8	50.0
Oil	1.700	0.88	258.5	50.0
Natural Gas	0.001	0.9	178.0	30.0
Nuclear	0.030	0.003	7.8	7.8
Photovoltaics	0.020	0.007	5.3	5.3

*Estimated emissions related only to the gathering and processing of fuel, and to the building and decommissioning of the generation plant. Based on calculations derived from: R. Dones and R. Frischknecht, "Life Cycle Assessment of Photovoltaic Systems: Results of Swiss Studies on Energy Chains," *Environmental Aspects of PV Power Systems: Report on the IEA PVPS Task 1*, Report No. 97072, December 1997. Emission factors for fossil fuel from The American Gas Association; emission factors for nuclear and renewable energy sources from the Council for Renewable Energy Education (as reported by SEIA, ref. 7).

Figure 10 - Pollutant emission factors for the total and non-generating portion of the fuel cycle.

However, traditional "command and control" regulatory strategies do not promote market-driven approaches to emissions reductions. Newer "allowance trading" programs, whether for clean air or climate change, do not reward the cleanest technologies. Thus, they have not fostered the use of solar and other zero-emission technologies. To this end, we recommend the following initiatives as a fresh approach to solving this problem:

- **RD&D programs, particularly at the Environmental Protection Agency, should provide analytical tools for federal and state environmental regulators and program implementers.** These tools should provide "rules of thumb" for quantifying emissions and pollution-prevention attributes of solar energy — both on a project level and consolidated.

- **Trading programs for clean air and climate-change emissions should reward zero-emissions technologies, rather than least-cost options that provide purely short-term incremental reductions.** The goal for U.S. environmental regulation should be to promote market-driven solutions that translate into the cleanest available technologies and installations.

- **Federal and state promotional and RD&D programs should be leveraged, aggregated, and implemented through states toward technology validation (demonstration) and deployment.** Aggregating the use of solar technologies is the only way to demonstrate and validate significant emissions reductions. To achieve this result, federal and state governments should focus on projects that can be replicated.

- **Government agencies should increase consumer awareness of the cost-effective uses of solar technologies.** EPA's and DOE's *Energy Star* program — which places public service ads and provides logos and consumer awareness — should be broadened for zero-emissions technologies such as solar. National recognition programs, such as that employed by *Energy Star*, must also be used to acknowledge early significant users of replicable projects.

- **More aggressive funding should be made available for programs that not only promote solar technologies in schools to reduce energy, but also, as an integral part of the curriculum from elementary through college levels.** According to the Department of Energy, energy is the third highest cost of education after teacher salaries and benefits. Solar energy will offset energy costs and potentially limit increases in property taxes; additionally, though, it will provide future consumers with some "first-hand" experience in clean technologies. Student involvement has made paper and plastic recycling a universal practice over the last 25 years — and such involvement could do the same for solar technologies over the next two decades.

Industry must embark immediately on a more proactive and coordinated program of analysis, market aggregation, consumer awareness and education, and deployment. This effort will significantly reduce pollution through a broad portfolio of solar technologies and applications. Our national goal should go beyond simply cleaning up dirtier fuels and processes. Indeed, our goal should be to enhance the use of the cleanest technologies as a way to drive pollution reduction in a more comprehensive and fundamental way.

In Conclusion

If we are successful in pursuing our overall commercialization strategy, we will create thousands of new, high-value jobs. We will reduce energy imports. We will displace pollution equal to the emissions of one million vehicles. We will provide a more stable energy environment. We will provide energy choice to our citizens. And we will lessen the pressure on energy rates and supply, making sure that the lights will stay on for all Americans.

PV Roadmap Workshop Participants Lists

Note: The affiliations of some of the participants may have changed since the time of the workshop.

NCPV: Workshop on PV Program Strategic Direction, July 14-15, 1997 (Golden, CO)

- Clay Aldrich, Siemens Solar Industries
- Tim Anderson, University of Florida
- Chuck Backus, Arizona State University East
- Allen Barnett, AstroPower, Inc.
- Bulent Basol, ISET
- John Benner, National Renewable Energy Laboratory
- Robert Birkmire, Institute of Energy Conversion, University of Delaware
- William Bottenberg, PVI Photovoltaics International Inc.
- Chris Cameron, Sandia National Laboratories
- David Carlson, BP Solarex
- Steve Chalmers, PowerMark
- Vikram Dalal, Iowa State University
- Michael Eckhart, Management & Financial Services
- Alan Fahrenbruch, Stanford University
- Todd Foley, BP America Inc.
- Christopher Frietas, Trace Engineering
- Robert Gay, Siemens Solar Industries
- Jessica Glicken, Ecological Planning and Toxicology, Inc.
- Ray Gordon, Harvard University
- Subhendu Guha, United Solar Systems Corporation
- Don Gwinner, National Renewable Energy Laboratory
- Brian Huff, The University of Texas at Arlington
- Roland Hulstrom, National Renewable Energy Laboratory
- Vijay Kapur, ISET
- Lawrence Kazmerski, National Renewable Energy Laboratory
- Ron Kenedi, Photocomm, Inc.
- Edward Kern, Ascension Technology
- Richard King, U.S. Department of Energy
- Roger Little, Spire Corporation
- Rose McKinney-James, Corporation for Solar Technology and Renewable Resources
- Hans Meyer, Omnion Power Engineering Corp.
- Mohan Misra, ITN Energy Systems
- Donald Osborn, Sacramento Municipal Utility District
- James Rannels, U.S. Department of Energy
- Ajeet Rohatgi, Georgia Institute of Technology
- Dan Sandwisch, Solar Cells, Inc.
- Richard Schwartz, Purdue University
- Mary Shaffner, Solar Energy Industries Association
- Jawid Shahryar, Solec International, Inc.
- Mike Stern, Utility Power Group
- Steven Strong, Solar Design Associates
- Tom Surek, National Renewable Energy Laboratory
- Margie Tatro, Sandia National Laboratories
- Jerry Ventre, Florida Solar Energy Center
- Cecile Warner, National Renewable Energy Laboratory
- John Wiles, Southwest Technology Development Institute

U.S. Photovoltaics Industry PV Technology Roadmap Workshop, June 23-25, 1999 (Chicago, IL)

- Clay Aldrich, Siemens Solar Industries
- Tim Anderson, University of Florida
- Allen M. Barnett, AstroPower, Inc.
- Bulent Basol, ISET
- John Benner, National Renewable Energy Laboratory
- William Bottenberg, PVI Photovoltaics International Inc.
- Gerry Braun, BP Solarex
- Jeff Britt, Global Solar Energy
- Connie Brooks, Sandia National Laboratories
- Chris Cameron, Sandia National Laboratories
- David Carlson, BP Solarex
- Steve Chalmers, PowerMark
- Clint (Jito) Coleman, Northern Power Systems
- Maurice Covino, Spire Corporation
- Ghazi Darkazalli, GT Solar Technologies, Inc.
- Alan E. Delahoy, Energy Photovoltaics, Inc.
- Tom Dinwoodie, PowerLight Corporation
- Erten Eser, Institute of Energy Conversion, University of Delaware
- Jim Galica, STR
- James Gee, Sandia National Laboratories
- Subhendu Guha, United Solar Systems Corporation
- Jack Hanoka, Evergreen Solar, Inc.
- Roland Hulstrom, National Renewable Energy Laboratory
- Joe Iannucci, Distributed Utility Associates
- Masat Izu, Energy Conversion Devices, Inc.
- Theresa Jester, Siemens Solar Industries
- Robert Johnson, Strategies Unlimited
- Juris Kalejs, ASE Americas
- Lawrence Kazmerski, National Renewable Energy Laboratory
- Richard King, U.S. Department of Energy
- David Lillington, Spectrolab, Inc.
- Hans Meyer, Omnion Power Engineering Corp.
- James Rand, AstroPower
- Ajeet Rohatgi, Georgia Institute of Technology
- Bill Roppenecker, Trace Engineering
- Bob Shaw, Arete Ventures, Inc.
- Chris Sherring, PVI Photovoltaics International Inc.
- Mike Stern, UPG Golden Genesis
- Tom Surek, National Renewable Energy Laboratory
- Jerry Ventre, Florida Solar Energy Center
- Howard Wenger, AstroPower, Inc.
- Chuck Whitaker, Endecon/PVUSA
- John Wiles, Southwest Technology Development Institute
- Paul Wormser, Solar Design Associates Inc.
- Jan Brinch, Melissa Eichner, Robyn McGuckin, Joseph Philip, Kim Reichart, Jennifer Ryan, Richard Scheer, Paula Taylor, Energetics, Incorporated

PV Roadmap Conference, December 13-14, 2000 (Dallas, TX)

- Rajeewa Arya, BP Solar
- John Benner, National Renewable Energy Laboratory
- Bob Birkmire, Institute of Energy Conversion, University of Delaware
- Gerry Braun, BP Solar
- Jan Brinch, Energetics, Inc.
- Connie Brooks, Sandia National Laboratories
- Steve Chalmers, Power Mark
- Jerry Culik, AstroPower
- Alan Delahoy, Energy Photovoltaics
- Jennifer Dunleavey, Energetics, Inc.
- Jim Dunlop, Florida Solar Energy Center
- Chris Eberspacher, Unisun
- Andrew Gabor, Evergreen Solar
- James Gee, Sandia National Laboratories
- Christy Herig, National Renewable Energy Laboratory
- Tom Huber, S&C Electric
- Roland Hulstrom, National Renewable Energy Laboratory
- Terry Jester, Siemens Solar Industries
- Juris Kalejs, ASE Americas
- Larry Kazmerski, National Renewable Energy Laboratory
- Edward Kern, Applied Power
- Richard King, U.S. Department of Energy
- Paul Klimas, Sandia National Laboratories
- Dave Lillington, Spectrolab
- Paul Maycock, PV Energy Systems
- Ron Pitt, Xantrex Technology
- Ajeet Rohatgi, Georgia Institute of Technology
- Rich Scheer, Energetics, Inc.
- Pete Sheldon, National Renewable Energy Laboratory
- Alison Silverstein, Public Utility Commission of Texas
- Ed Skolnik, Energetics, Inc.
- Tom Surek, National Renewable Energy Laboratory
- Blair Swezey, National Renewable Energy Laboratory
- Joe Tillerson, Sandia National Laboratories
- Bob Walters, ENTECH
- Chuck Whitaker, Endecon Engineering
- John Wiles, Southwest Technology Development Institute
- Paul Wormser, Solar Design Associates
- Bob Yorgensen, Specialized Technology Resources

Produced and originally printed by the United States photovoltaics industry.
Facilitated by the National Center for Photovoltaics.
Reprinted by the National Renewable Energy Laboratory, a national laboratory of the U.S. Department of Energy
Reprinted January 2003

Printed on recycled paper