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World Solar Summit
Sommet solaire mondial

Solar Energy in North America

Énergie solaire en Amérique du Nord

High-level Expert Meeting
Réunion d'experts de haut niveau

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Solar Energy in North America

Énergie solaire en Amérique du Nord

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SOLAR ENERGY IN NORTH AMERICA

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1.0 INTRODUCTION

The United States faces significant challenges throughout the 1990s: securing a reliable supply of competitively priced energy, improving the quality of our environment, and increasing our share of foreign markets for goods and services. The U.S. Department of Energy's (DOE) programs in renewable energy are working toward meeting these challenges by developing the technologies that make use of our nation's largest energy resource: renewable energy.

Within the context of the World Solar Summit, the term "solar" symbolizes all forms of renewable energy. The sunlight, wind, biomass, flowing water, and geothermal energy that make up the renewable energy resource base can be found throughout North America. These resources can provide all the forms of energy our nations needs: liquid fuels, electricity, and heating and cooling. Renewable energy meets about 10% of our need for these forms of energy today, yet the potential contribution is many times greater.

The U.S. Department of Energy programs in renewable energy are working side-by-side with American industry to develop technologies that convert renewable energy resources into practical, cost-competitive energy. After two decades of progress in research, several of these technologies are poised to make large contributions during the 1990s and beyond.

This report, *Solar Energy in North America*, describes the progress, status, and strategic objectives of four solar energy technologies -- photovoltaics, solar thermal, wind, and biomass -- to meet the critical needs for providing new supplies of affordable energy today, and in the next century.

2.0 SOLAR THERMAL

During the 1970s and early part of the 1980s, few people thought electricity could be produced economically from sunlight. Today, scores of utilities in the U.S. are looking closely at the performance of commercial solar thermal electric power systems, which convert the energy of the sun to heat energy and use this heat energy to generate electricity.

The fundamental motivation for developing solar thermal electric technology is to bring this renewable energy source to the marketplace as an economically competitive option for generating electric power. Current efforts in the U.S. represent a collaborative approach among industry, the research and development community, and potential users toward achieving this goal. Solar thermal electric systems are beginning to show potential in the utility marketplace just as the demand for modular, environmentally clean, fossil-fuel-independent power generation is beginning to surge; and they are poised to become dynamic competitors in both on- and off-grid power markets. Today's solar thermal electric systems, making use of parabolic dish/engine, central receiver power towers, and parabolic trough technologies, are proving that they can produce substantial amounts of electricity in an environmentally acceptable way.

2.1 Two Decades of Progress

Significant progress has been made in the last two decades toward generating economically competitive solar thermal energy for electrical applications. Research and development (R&D) efforts in the U.S. during the past decade have improved the performance and reliability of solar thermal systems and reduced both the capital installed costs ($/kW) and energy costs ($/kWh) of solar thermal systems to one-fifth the cost of early systems. This large reduction is a result of lower cost components and increased system efficiency. However, further cost reductions in the 1990's will be required to make solar thermal energy cost-competitive with energy generated by fossil fuels.

About 75% of the world population is without grid electricity, and there are some 2 million villages within 20 degrees latitude of the equator without electricity. Solar thermal electric technologies are leading candidates to supply this electricity. Versatility is a key attribute of solar thermal electric (STE) technology. STE systems are well suited to both grid-connected and off-grid applications, in both national and international markets. The basic requirements for a successful STE application are a sufficient solar resource, available and inexpensive land area for an installation, and a demand for electric power. Hybrid STE systems using another renewable or conventional fuel for use during sunless periods can supply continuous power at attractive life-cycle costs. Solar thermal electric technology has a number of attractive attributes that make it a very desirable energy supply option: it is an unlimited energy source; it has low environmental impact; and it requires short construction time and can be built in modules to respond to demand growth.

The type of concentrator/receiver system employed not only has a great effect on the system's performance, but it also affects the size of the system. Line concentrators predominate in today's commercial plants; each is about 80 MW_e in size. (Line concentrator systems are now appropriate for applications in developing countries where mature technologies are required.) However, point concentrator systems, dish concentrators and power towers, can achieve higher energy conversion efficiencies than can line concentrators because they can operate at higher temperatures. When commercial-scale power tower systems are built (probably by the year 2000), these modular solar thermal power systems will likely reach sizes of 100 to 200 MW_e.

By contrast, dish/engine systems are much smaller, typically about 5 to 25 kW_e. At this size, they are ideal for remote, stand-alone applications. The size of individual dish/engine systems is limited by the amount of energy that one dish concentrator can collect. To meet larger power requirements, several dish/engine systems can be connected together electrically to form power systems in sizes ranging from 100 kW_e to 100 MW_e.

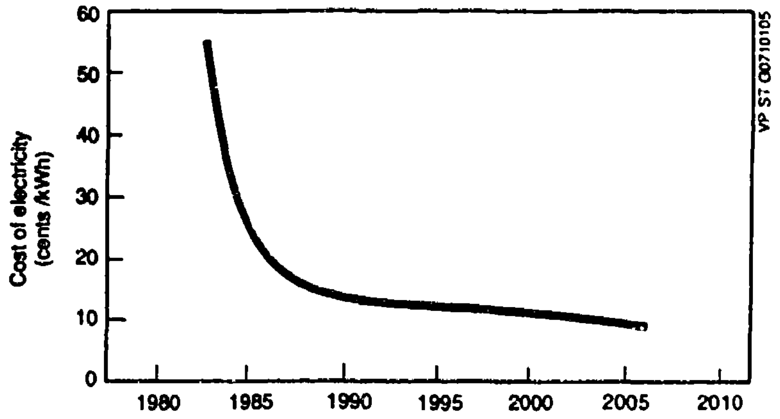
Over the past decade, the combined efforts of the STE Program, private industry, and research organizations have proven the technical viability of solar thermal systems for electric power generation. Thus far, the nine parabolic trough solar electric generating systems (SEGS) installed in California by the private sector represent over 90 percent of the world's installed solar electric capacity. The cost of electricity from line-concentrator solar thermal power plants decreased by 83% in less than a decade. The decrease is due to both technological improvements and manufacturers taking advantage of economies of scale in production.

Power-tower systems have been successfully demonstrated by the 10 MW_e Solar One pilot plant located near Barstow, California. The STE Program is continuing development of central receiver power tower technology by retrofitting the Solar One Plant. This retrofitted plant, known as Solar Two, will also be rated at 10 MW_e. Moreover, the STE Program, in cooperation with industry, will develop and commercialize a 7-kW_e dish/Stirling system over the next two to three years, and a 25-kW_e dish/engine system over the next five years.

The most commercially developed solar thermal electric technology is the parabolic trough system. With over 350 MW_e of installed capacity, parabolic trough power plants are a proven technology for producing reliable electric power. Installed costs of the most recent parabolic trough plants are around $3,100/$kW_e$ for 80 MW_e solar/gas hybrid plants. With an annual capacity factor of 35%, the levelized energy cost (LEC) of current generation trough electric plants is around 13 cents/kWh. (See Figure 1.) For summer-peaking utilities, these generation costs can be attractive today even without factoring in the environmental benefits of solar power. Further commercial development of the technology combined with larger plant sizes could eventually reduce the capital cost of the technology to around $2,200/$kW_e$ and the LEC to 10 cents/kWh.

Power tower technology is currently not as commercially developed as trough technology, but is expected to eventually replace parabolic troughs as the

Figure 1: Solar Thermal Cost of Energy



Source: The Potential of Renewable Energy: An Interlaboratory White Paper, 1990.

technology of choice for utility electricity production. Industry design studies have projected that the first commercial power tower plants, which should be ready near the end of the decade, will have a capital cost of \$3,000/kW$_e$ and a capacity factor of 40%. These plants, which will use energy storage rather than natural gas hybridization, will have an LEC of about 11 cents/kWh. Costs for power tower systems should drop substantially over the first few plants as design and manufacturing experience builds, allowing scale-up of plant sizes to 200 MW$_e$ and reduction of the costs of solar components. Industry estimates are that power tower plants built early in the next century can expect to have capital costs around \$3,000/kW$_e$ for plants with a 63% capacity factor. The LEC for these plants will be near 7 cents/kWh. In the longer term, advanced receivers, heliostats, and improved system designs are expected to reduce the LEC to less than 6 cents/kWh.

Dish/Stirling systems will enter the market differently than did either troughs or power towers. With their small module size (5-25 kW_e) and potential for unattended operation, the initial markets for dish/Stirling systems are likely to be small, remote applications where the value of power is quite high. The early commercial systems that will be available before the end of the decade are likely to have capital costs near \$3,000/kW_e initially. The first dish/Stirling systems will have capacity factors around 23% in nonhybrid designs, and will have an LEC of around 18 cents/kWh. Increasing the module size to 25 kW_e and designing distributed utility (1-10 MW_e) installations is expected to allow further reductions in cost. Coupled with efficiency improvements in the receiver and engine, grid-connected dish/Stirling systems are expected to eventually achieve capital costs of \$1,500/kW_e for systems with capacity factors augmented by the ability to operate on both solar and fossil fuels. These long-term systems will achieve an LEC of 6 cents/kWh.

2.2 DOE Programmatic Information

The role of the Department of Energy (DOE) is centered on the development of improved cost effectiveness and reliability of solar thermal electric components and development of additional energy markets with high strategic or economic value to U.S industry. This balanced approach to technology development and validation, coupled with joint-venture projects and market conditioning, will introduce essential technological improvements while allowing industry to acquire the production experience to further lower cost.

Implementation of this strategy relies on a core program of enabling: 1) high-risk research to identify and prove solar electric generation concepts for trough, power tower, and dish components and processes; 2) technology development to translate research into useful prototypical hardware; and 3) industry interaction through technical assistance and joint-venture projects to validate and commercialize the technology.

The program is supporting the development of solar thermal electric commercial applications to increase acceptance of this technology for generating cost-competitive power by utilities, both in the U.S. and abroad. By aggressively supporting development of the technology's industrial base through cost-shared, joint-venture projects with the private sector, the program seeks to help solar thermal electric technology penetrate energy applications and markets, creating new jobs and business opportunities. The program is developing reliable and efficient solar thermal electric systems to generate economically competitive power that can contribute significantly to the national energy mix.

Components that are being investigated include stretched-membrane heliostats with features such as a front-surface or sol-gel reflector. Stretched-membrane technology is also being developed for parabolic dishes. The solar concentrator is the most expensive component in any solar thermal system, with costs ranging from 40% to 50% of the total system cost. The reliability of the concentrator has a strong impact on overall performance of the system. Inexpensive and readily maintained solar concentrators are essential for the successful commercialization of solar thermal technologies, and are an integral part of the STE Program.

The program is also pursuing the development of power conversion systems for both dish/engine systems and power tower systems. Power tower receiver development is focusing on advanced salt-in-tube receivers, molten salt film receivers, and volumetric air receivers. Dish receiver development, particularly of the reflux type, is critical to the long-life reliable operation of parabolic dish/Stirling engine systems. The heart of a solar thermal dish/engine system is the subsystem that converts thermal energy into electricity: the engine generator. Power conversion development and technology validation efforts synchronize R&D activities with the needs of users, expanding the availability of resource data and improving system performance.

2.3 Strategic Objectives

The mission of the Solar Thermal Electric Program is to work with manufacturers and users of solar thermal electric technology and conduct research for technology development and validation to:

- Increase acceptance of this technology as a candidate for cost-competitive power generation by utilities, industry, and manufacturer/user groups, both in the U.S. and abroad.
- Develop reliable and efficient solar thermal electric systems for generation of economically competitive power that can contribute significantly to the

national energy mix and thereby reduce dependence on imported energy sources.

- Aggressively support the development of the industrial base required to penetrate the various energy applications and markets, creating new jobs and business opportunities.

Solar Thermal Electric Program strategy is consistent with the objectives set forth by the Office of Solar Energy Conversion in SOLAR 2000 - *A Collaborative Strategy*. The Department of Energy and its field laboratories are aiming to:

- Increase, through cooperative ventures, industrial participation in both the planning and execution of program elements.
- Utilize the analytical and experimental capabilities of the national labs to support the needs of, and to enlarge, the program's user, suppliers, and decision-making constituency.
- Contribute to the DOE Energy Efficiency and Renewable Energy's goal of making solar thermal electric technology a viable option for both the domestic and international power-generation markets.

Specifically, the STE program activities include:

- the Solar Two molten salt power tower project led by Southern California Edison will provide the technical base for Solar 100, the first 100-MW_e utility-scale power tower module, which is due for installation by the end of the decade.

- the Cummins Engine Company 7-kW$_e$ dish/Stirling System will be commercially available by 1996 for remote and grid-connected applications.
- contracts will be awarded under the Utility-Scale Joint-Venture Program for 25-kW$_e$ dish/engine systems, with the last phase of this program resulting in at least one megawatt of dish/engine system capacity installed by utilities by the late 1990s.
- the operations and maintenance cost reduction study for parabolic trough plants will be completed by 1995, thereby providing for lower levelized energy costs for power tower and dish/engine solar systems as well as trough plants.

2.4 Plan of Action for the Decade 1995-2005

The fundamental motivation for developing solar thermal electric technology is to bring this renewable energy source to the marketplace as an economically competitive option for generating electric power in the decade of 1995-2005. An integrated approach among industry, the research and development community, potential users, and the Federal government will lead the Solar Thermal Electric Program activities toward achieving this goal. From a market perspective, from an environmental viewpoint, and considering the status of the technology development, solar thermal electric systems are poised to become dynamic competitors in both on- and off-grid power markets. The technology is entering the marketplace just as the national and international demand for modular, environmentally clean, fossil-fuel-independent power generation is beginning to surge.

The decade of 1995-2005 will see progressive advances of U.S.-designed and -built solar thermal electric systems moving into the marketplace. Building on past successes in the areas of parabolic troughs, power towers, and parabolic dishes, and viewing past problems as hard-won lessons, the technology will continue moving forward:

- Power tower systems will shift from the demonstration stage to modular bulk power production.
- Trough systems, which have already made an aggressive market entry with more than 350 MW_e connected to the southern California grid, will continue their validation of solar thermal electric technology.
- Dish/engine systems will make their market debut in both remote and grid-connected applications.

The solar thermal electric industry will coalesce into a cohesive, competitive market force with a product mix ranging in capacity from a few kilowatts to hundreds of megawatts. The national and international market for solar thermal electric technology includes utilities, independent power producers, and off-grid applications.

During the decade of 1995-2005, individual solar thermal electric power tower systems could be competitive in utility-scale applications in the range of 100 to 200 megawatts. Individual parabolic dish/Stirling engine units (5- to 25-kW_e

range) could be available on a widespread basis for smaller-scale applications, either in place of utility line extensions, in remote environments, or in clusters for larger power requirements. Multi-megawatt parabolic trough solar electric systems such as the SEGS units will be operating on a commercial scale in a utility environment in the western part of the U.S.

The modern solar thermal electric industry began to be distinguishable from the broader solar industry in the mid-1970s. Even so, the industry is still in the formative stages; and in many ways, it is still evolving. As the technology moves further into the marketplace, expansion of the industry is expected to continue both in membership and in the level of commitment of its members to the technology. Research will remain an important component of industrial development, with the national laboratories continuing to conduct the longer-term, higher-risk research that has the potential to further benefit U.S. industry as a whole, particularly in helping it maintain a technologically competitive advantage in solar thermal electric systems or components.

Of the 100 gigawatts of capacity projected to be required by the U.S. over the next decade, approximately 20 gigawatts are not yet committed for construction. Construction and permitting lead times for large fossil and nuclear power plants almost eliminate them from the list of candidates for filling this capacity gap. Environmental pressures worldwide will also favor the use of renewable energy technologies. Solar thermal electric technology is an excellent candidate for filling this capacity gap because it features the following attributes:

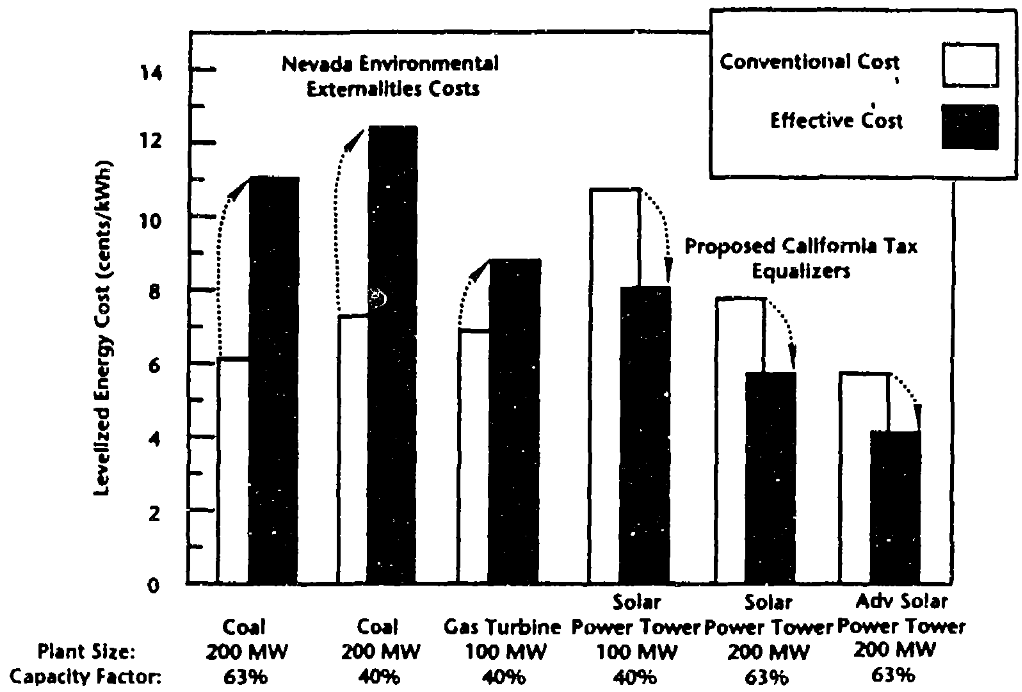
- Short Construction Lead Times—Installation times of 12 to 18 months have been projected for solar thermal electric systems; the most recent SEGS plant was installed in less than 8 months. Individual dish systems can be installed in less time still, just in a matter of weeks.
- Less Onerous Regulatory Hurdles—The environmental effects resulting from the installation and operation of solar thermal electric systems are small, especially in comparison to conventional nuclear and fossil-fueled plants.
- Modularity—The economical size of solar thermal electric systems ranges from 5 kilowatts to 100 megawatts or greater. Systems will be available in economical sizes that can be combined to serve virtually any power requirement—from remote villages to grid-connected high-capacity factor applications.
- Known Cost of Energy—At any given site, costs for energy produced by solar thermal electric systems are a function of capital costs required for initial installation as well as the costs of operation and maintenance personnel and equipment. For solar-only systems, energy costs are virtually independent of the sometimes volatile costs of fossil fuels and can be predicted with accuracy throughout the life of the plant. Even for hybrid (co-fired) systems, the link between fossil fuel costs and electricity prices is much weaker than for fossil-only plants.

- Potential for Dispatchability—Utilities and other users value the ability to bring a power plant on-line with minimal delay when it is needed. The dispatchability of co-fired solar thermal electric plants has been clearly demonstrated by the SEGS plants. All other types of solar thermal systems can also be hybridized. Thermal storage can accomplish the same effect without the use of fossil fuels or the creation of emissions.

These attributes make solar thermal electric technology an excellent candidate for numerous electric capacity requirements in the decade of 1995-2005.

Efforts in the late 1990s will continue to focus on dissemination of available evaluation tools that accurately reflect the true strengths of solar thermal electric technology. The basis for this effort stems from the unique characteristics of solar thermal electric technology when compared to conventional power generating options, as shown in Figure 2. First, it has a higher up-front capital cost per unit than conventional options, but a much lower operating cost because it uses a free-fuel source. Thus, solar thermal electric and other solar technologies are not subject to fuel price increases and escalation rates as are fossil-based options. Second, STE systems are modular in nature, and thus can be brought on-line in small increments by directly meeting customer needs, while reducing construction costs, lead times, and regulatory hurdles. Lastly, the technologies do not produce harmful emissions, and thus provide a solution for decision makers seeking ways to meet power requirements in an environmentally sound manner.

Figure 2: Fossil Versus Solar Energy Costs: the impact on environmental and tax equalizers.



Bibliography

1. Department of Energy, *Solar Thermal Electric Five Year (FY 1993-97) Program Plan*, April 1993.

2. Department of Energy, *DOE's Solar Thermal Electric Program brochure*, April 1993.

3. Department of Energy, Energy Information Agency (EIA), *Renewable Resources in the U.S. Electricity Supply*, February 1993.

4. Department of Energy, Energy Information Agency (EIA), *Annual Energy Outlook 1993 with Projections to 2010*, January 1993.

5. Department of Energy, *Solar 2000: A Collaborative Strategy Volume I and II*, February 1992.

6. Department of Energy, *Solar Thermal Electric and Biomass Power Program Overviews (Fiscal Year 1990-91), Programs in Utility Technologies*, June 1992.

3.0 PHOTOVOLTAICS

Using solid state technology, PV systems directly convert sunlight to DC electricity without high temperature fluids or moving parts that could cause mechanical failure. These factors make the technology very reliable.

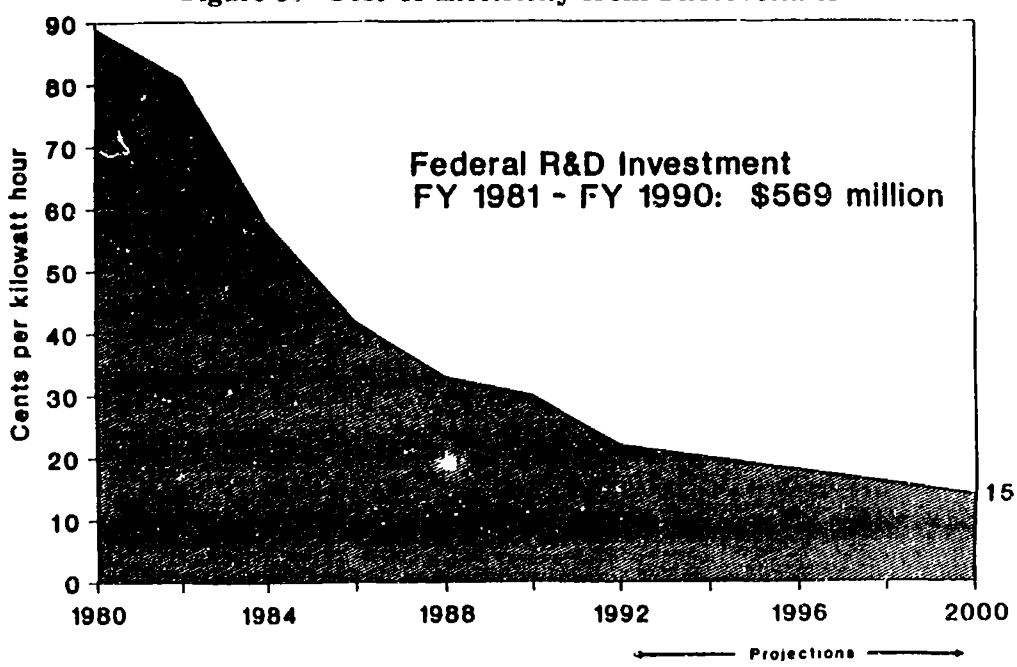
Over the last five years, the photovoltaics industry has enjoyed annual sales growth rates of approximately 15%. Rather than building large energy systems that perpetuate environmental and economic damage, there is a growing trend toward utilizing small renewable technologies that are matched to end-user needs and operating conditions. As demand grows and markets expand, investment capital will be drawn to the industry and new growth trends will emerge.

The National Photovoltaics Program is working to expand industrial capacity, while continuing strong basic and applied technology research and development. At the same time, the program is placing new emphasis on cost-shared, manufacturing process, development, and market conditioning and on collaborating with the U.S. PV industry in joint venture projects. Solar 2000, the program's development strategy for the 1990s, provides attractive incentives for industry to form partnerships with the Department of Energy (DOE). Through collaborative projects, whose costs are shared between DOE and private industry, PV technology can be quickly transferred from the laboratory to the marketplace.

3.1 Two Decades of Progress

Over the last two decades there has been significant improvement in photovoltaic technologies. Since the start of the development of photovoltaics for terrestrial use in 1972, module prices have dropped to less than 1/100 of their 1972 prices. The cost of PV modules has dropped from about $500 per watt in 1972 to less than $4.00 per watt in 1993. This decrease has contributed to a dramatic and continuous decline in the cost of energy from PV cells. As the graph in Figure 3 shows, the cost of PV generated electricity has dropped from almost 90 cents per kWh to less than 30 cents per kWh today.

Figure 3: Cost of Electricity from Photovoltaics

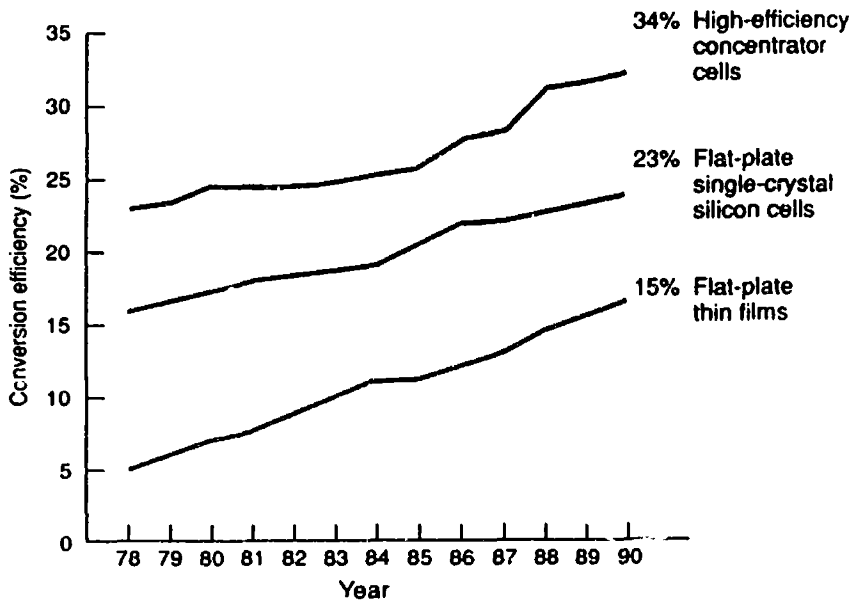


Source: "A Decade of Progress," Solar World Congress, 1991.

Since 1978, research and development in areas such as polycrystalline thin films and amorphous silicon, has substantially increased module efficiencies.

Figure 4 shows that flat plate thin-film laboratory cell efficiencies have grown by over 60%, and single crystal cell efficiencies have improved by more than 25%. High-efficiency concentrator cell efficiencies have grown by more than 35%. These improvements have allowed sales of PV equipment and systems to rise continually. Since 1987, worldwide sales have risen from about 30 MW to 58 MW in 1992. The United States has continued as a leading producer, with about one-third of the total sales worldwide.

Figure 4: Efficiency of Laboratory Cells, 1978 to 1990.



Source: Photovoltaics Program Plan, FY 1991 - FY 1995.

World leadership has been gained through aggressive development of cells and manufacturing technology and substantial investment by both industry and government. It is estimated that the U.S. government has funded more than $1 billion into PV research since the early 1970's, while private industry has invested more than $2 billion. Since 1980, there has been a Federal investment of about $600 millon in photovoltaic R&D, while industry has increased its investment in this technology by more than 400% from about $500 million in 1980 to more than $2 billion today.

3.2 DOE Programmatic Information

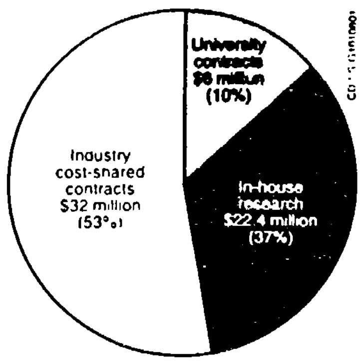
The mission of the National Photovoltaics Program is to help U.S. industry develop PV technology for large-scale generation of economically competitive electric power. The program is managed by DOE Headquarters and research centers at the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories. In addition to in-house laboratories and activities, the research centers direct and manage contracted research at universities, other research centers, small businesses, and large industrial concerns. The total budget for fiscal year (FY) 1992 for the PV program was $60.4 million and was allocated as shown in Figure 5.

Until 1991, the PV program concentrated on strategic research and development in materials and cell design. To keep pace with changing institutional and public views, DOE began a new planning process in FY 1992. The effort included industry, utilities, researchers, and policy makers. The plan they developed -- Solar 2000: A Collaborative Strategy -- is designed to accelerate the development of a stronger solar industrial base, increase energy security, and achieve a cleaner environment. Solar 2000 challenges the nation to develop the significant technological advances of the 1980's into a healthy manufacturing base

Figure 5: Total FY 1992 budget allocation for the National Photovoltaics Program.

The Department of Energy Invests in Photovoltaics

The Photovoltaics Division is part of the Department of Energy's Office of Solar Energy Conversion. The National Photovoltaic Energy Program is managed by DOE headquarters and research centers at the National Renewable Energy Laboratory (NREL, formerly the Solar Energy Research Institute [SERI]) and Sandia National Laboratories (Sandia). In addition to in-house laboratories and activities, the research centers direct and manage contracted research performed at universities, other research centers, small businesses, and large industrial concerns. These activities include cost-shared, multiyear, government-industry partnerships and technology initiatives.



The total FY 1992 budget for the PV Program was $60.4 million

Source: Photovoltaics: Program Overview Fiscal Year 1992.

that creates products for sustainable markets for the 1990's and beyond.

As a result, the PV program plans to provide a more balanced approach to photovoltaics R&D. While continuing in research in materials and cell design, the program will also begin work on PV systems and helping industry encourage new markets for photovoltaics. The program promotes wider use of PV by helping industry develop and expand markets. The program shares the costs of pilot projects and applied research. In addition, it disseminates information about PV technology to important markets such as utilities, state and federal agencies, and international groups. Of these groups, bulk power electricity generation by utilities is seen as the largest and most important market for PV.

The PV program is encouraging U.S. electric utilities to hasten their acceptance of PV technologies into everyday operations. To facilitate this effort, DOE has joined with utilities, state and local government, and other industry groups to sponsor Photovoltaics for Utility Scale Applications (PVUSA). PVUSA is a joint venture for installing and operating PV systems connected to a utility grid. Through this program utilities are gaining hands-on experience in procuring, evaluating, and using PV systems. Manufacturers gain early market experience and a test bed for their new products. In turn, test performance information helps them refine systems to meet utility requirements.

The project began in 1987 under the sponsorship of Pacific Gas & Electric Company (PG&E), the Electric Power Research Institute (EPRI), the California Energy Commission and the Department of Energy. The consortium has since expanded to include more than ten utilities and about a dozen manufacturers and distributors of PV components and systems. The program's supporting facilities are located at the National Renewable Energy Laboratory (NREL) and the Sandia National Laboratories (SNL). There, DOE researchers have drafted performance qualification test procedures, conducted hardware tests, and served on technical review committees.

Other projects include distributed utility applications. An analysis conducted by PG&E indicted that PV could help reduce loads on transmission and distribution equipment throughout a utility network. These application represent a market where PV is often more cost-effective than competing technology. Using PV in place of electric grid line extensions could increase demand for these systems by 5 MW per year or 30% of the total U.S. production for 1991, according to a study conducted by EPRI.

The PV program is also working with industry to improve the competitiveness of U.S. PV products. When the U.S. PV industry invests in new capacity, the products and processes they develop must be competitive in the world market. The PV Manufacturing Technology Project (PVMaT) translates recent prototype production processes into advanced manufacturing technology for industry. PVMaT is a major undertaking for industry as well as for DOE. During the 5-year life of the project, more than $100 million will be invested -- $55 million from the government and a nearly equal amount from industry. In addition to contract funding, the PV program will make available its materials and device fabrication and analysis laboratories at NREL and SNL to help industry test concepts and analyze results.

Since each manufacturer faces unique problems in attempting to achieve commercial success, the initial phase of PVMaT allowed 22 U.S. companies to identify manufacturing process barriers and approaches to overcome them. In the second phase, seven companies -- under cost shared contracts -- are solving the process-specific problems identified in Phase One. By the end of 1992, progress had been made in all three types of technologies: thin films, crystalline silicon, and concentrators. Each company has modules undergoing tests at NREL or Sandia as part of its contract.

Thin-film semiconductor materials for modules offer many advantages. Although generally lower in efficiency than conventional crystalline silicon materials, thin films can be applied in very thin layers on inexpensive backing materials. The potential for cost reductions through improvements in manufacturing processes is substantial. During Phase One, 10 companies identified ways to reduce the cost of modules. These included increasing production rates, using low-cost backing materials, developing mass production techniques, improving conversion efficiencies and automating production lines to reduce labor costs while improving yields. During Phase Two, Energy Conversion Devices, Inc., has improved their processing of triple-junction amorphous silicon modules. NREL has documented a 25% increase in stable power output over previous modules. The improvement stems from a new double-back reflective layer applied to a stainless steel substrate.

In Phase One, five manufacturers of crystalline silicon semiconductor materials saw a need to improve techniques for producing wafers, reduce labor costs through automation, and improve cell processing. In Phase Two, Mobil Solar Energy Corporation is improving its proprietary process in which octagonal tubes of silicon material are produced. The company intends to produce thinner material and automate its cutting and processing steps to speed production and reduce costs.

Again, in Phase One, six U.S. concentrator module manufacturers described needs to reduce the cost of producing high-efficiency cells, improve module-housing production, develop techniques for mass-producing lenses and reduce labor cost through automation. A contract with ENTECH, Inc., is supporting development of both a new prismatic cell cover and an in-line lens lamination process. The subtier contractor, 3M Company, developed a high-speed, continuous silicon casting process for the manufacture of the cell prism cover used in ENTECH's 21X linear concentrator module. This reduced the cost by mass-producing the material in "tape" form. The lens lamination technology improves lens quality, reduces lamination costs, lowers shipping volume and cost, and greatly facilitates the module assembly process.

The third phase of PVMaT, beginning this year, will fund U.S. research teams led by industrial organizations and made up of firms and universities which will explore some of the generic R&D problems in the PV industry. The teams will focus on module-related research problems. They will work with material and components manufacturers and with utilities to help strengthen the PV industry.

3.3 Strategic Objectives

To fully achieve its objective of making PV a significant part of the national energy mix, the National Photovoltaics Program has established the following long-term goals. First, to reduce the price of delivered electricity to 5 to 6 cent per kWh. Second, to increase module lifetimes to 30 years. And finally, to increase module efficiencies to 15% for flat plate and 25% for concentrator technologies. If progress continues at its current pace, it is expected that the PV industry will have installed about 1000 MW of capacity in the U.S. and 500 MW internationally by the year 2000.

The program's major objective is to stimulate the improvement of PV cost-effectiveness for electric power generation and fuel production for the utility, buildings, transportation and industrial sectors. To accomplish this objective, the PV program has formulated a strategy consisting of five critical steps:

- Improve cost-effectiveness by lowering production costs and improving the lifetime, efficiency, reliability and safety of photovoltaic devices;
- Characterize photovoltaic technologies in terms of societal benefits as well as competitiveness with conventional options;
- Work closely with both manufacturers and potential users to expand the market and foster a viable PV industry;
- Implement a program to hasten the acceptance of PV systems by utilities; and
- Integrate program activities to be compatible with the National Energy strategy.

In addition, taking advantage of other DOE-sponsored research in advanced concepts may lead to more efficient storage, transmission, and distribution of energy produced by photovoltaic systems and may also contribute to solutions of critical environmental problems. These concepts include PV-generated hydrogen, superconducting magnetic energy storage, and the transmission of electricity through superconductors. Figure 6 quantifies the mid- and long-term utility goals and achievements as of 1991.

Figure 6: Photovoltaic Program Achievements and Goals

Factor	Current Achievements (1991)	Mid-Term Goals (1995-2000)	Long-Term Goals (2010-2030)
Module Efficiency (%)	5-15	10-20	15-25
Electricity Price (¢/kWh, $ 1990)	25-50	12-20	5-6
System Lifetime (years)	10-15	20	30
Installed Capacity (MW)	<50	200-1000	10,000-50,000

Source: Photovoltaics Program Plan, FY 1991 - FY 1995.

3.4 Plan of Action for the Decade 1995-2005

To fulfill the mission of the National Photovoltaics Program, the cost of energy from PV systems must be competitive with that of other sources of energy. But there is more than one way to make PV systems cost-competitive: by making more efficient devices, by making less expensive devices, by stimulating the market toward higher sales and production volumes, by employing combinations of these options and by emphasizing values that have traditionally been ignored, such as environmental acceptability, modularity, and decentralization. Module reliability must also be enhanced.

Device efficiency, the ratio of the electrical output power to the power of the incident sunlight, is limited by the light absorption and loss mechanisms. The largest limiting factor is the inability of the device to effectively utilize all wavelengths in the solar spectrum. Other limiting factors include the quality and type of material, reflection of light from the surface and intersurfaces, shading by the metallic grid, and series and contact resistances. The efficiencies of all types of photovoltaic cells have steadily increased as a result of research and development by both industry and government laboratories.

Crystalline devices are generally more efficient and reliable today. Thin-film devices are expected to show large manufacturing cost reduction and become more efficient in the future. Concentrator technologies combine less-expensive optical components with small area, highly efficient, and somewhat more expensive PV devices to achieve low cost.

There is no known reliable method that tells us which material, which design, or which system potentially will be the most effective in fulfilling the PV Program's mission. Therefore, the National Photovoltaics Program supports research and development in several different technologies being developed by industry. The plan of action for the future will be organized around the three following major R&D tasks:

- PV research and development that addresses scientific and engineering questions pertaining to photovoltaic materials, cells and devices.
- PV manufacturing technology development that surveys the problems involved in developing, testing, and manufacturing PV modules.
- PV systems and market development that assesses the performance of PV systems today and recommends ways to develop PV technology for both near-term and long-term markets.

Improving the way that PV devices are manufactured is vital to achieving national goals. The PV program intends to take two complementary approaches to improving PV manufacturing technology. One approach, the Photovoltaic Manufacturing Technology project (PVMaT), calls on the PV industry and DOE to work together to advance PV manufacturing technology. The other approach involves module development research and uses the resources of the DOE Laboratories to evaluate modules and module performance and suggest solutions to common module problems.

The primary goal of module development is to develop the collector manufacturing technology for producing cost-effective PV modules. Improvements in encapsulation and materials technology will be sought. New module designs must be producible through automated, low-cost manufacturing with high yields and excellent product quality.

The objective of the PV Systems and Market Development will be to create the environment whereby systems technology, user acceptance, and the PV industry can accommodate the continued expansion of photovoltaics into larger applications and markets. These are needed to achieve the goal of 1000 MW installed by the year 2000.

To achieve this goal, the National PV Program will focus on four key activities: assessment of the field performance of systems and components; development of the system and balance-of-system technologies needed for cost-effective applications; support of industry in the definition and development of near-term and long-term markets; and acceleration of the acceptance of PV by disseminating information and transferring technology to industry and potential users. The unprecedented market growth represented by the goals for the year

2000 require that the U.S. pursue these activities for the broadest possible set of potential markets.

Bibliography

1. U.S. Department of Energy. Photovoltaics Program Plan FY 1991 - FY1995, (Washington, D.C.: U.S. Department of Energy, DOE/CH10093-92, 1991).

2. U.S. Department of Energy. Photovoltaics: Program Overview Fiscal Year 1992, (Washington, D.C.: U.S. Department of Energy, DOE/CH10093-190, 1993).

3. U.S. Department of Energy. Photovoltaic Energy Program Overview Fiscal Year 1991, (Washington, D.C.: U.S. Department of Energy, DOE/CH10093-129, 1992).

4. U.S. Department of Energy. Photovoltaic Energy Program Summary, Volume I: Overview, Fiscal Year 1989, (Washington, D.C.: U.S. Department of Energy, DOE/CH10093-58, 1990).

4.0 BIOMASS

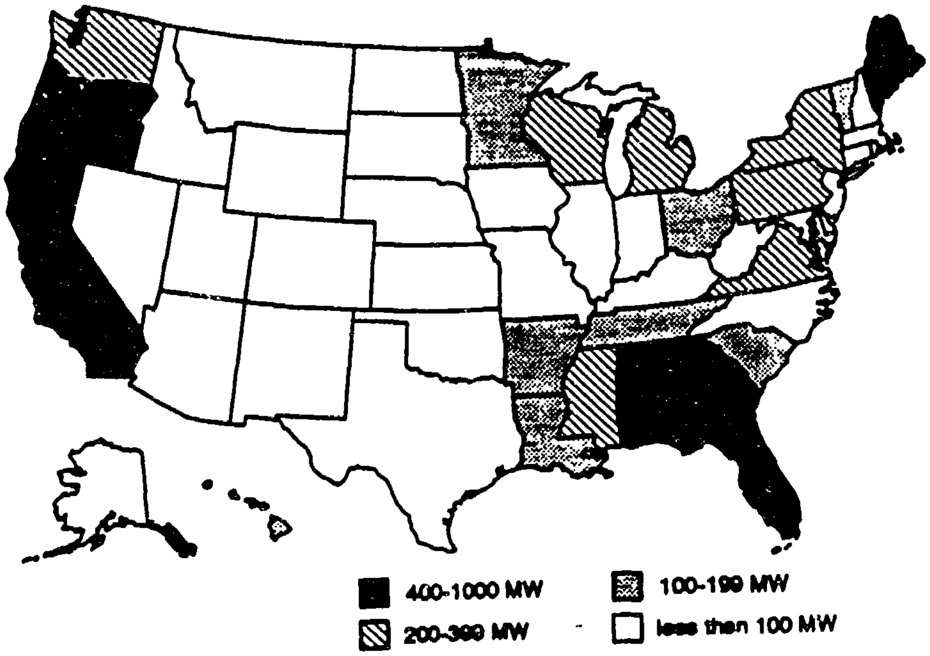
Biomass -- solid, liquid, and gaseous fuels derived from plant materials and wastes -- are not a new source of energy. More correctly, they are an underused source of energy that, along with other renewable resources, are capable of assisting in providing a solution to the energy needs of North America without damaging the environment. Since its development in the 1980's, biomass has grown to become the second largest renewable energy industry in the United States. In 1990, biomass contributed approximately 2.9 quadrillion Btu to the United States' power supply, or about 3.4% of total U.S. energy consumption. Most power production from biomass in the U.S. has been in the generation of electricity; and for years, biomass technology for electric generation has been considered to be a mature technology able to compete with conventional fuels. Government research efforts then focused on studying the use of biomass for transportation. However, with increased interest in improving the environment and in increasing energy self-sufficiency, the U.S. Department of Energy (DOE) has expanded its biomass research efforts into the cost-effective generation of electricity.

The use of biomass in electric generation could be dramatic for the United States. It has been estimated by DOE's National Biomass Power Program that 6,000 MW of commercially competitive renewable biomass power capacity could be added to the U.S. power generating base by the year 2000, and with newly developing technologies, the Electric Power Research Institute (EPRI) projects that as much as 50,000 MW of biomass power could be in place by the year 2010. Even with this potential, the industry is currently in a low-growth phase because of current market conditions, which include low fossil fuel prices, competitive bidding for power sales, loss of federal tax credits, and costly permitting procedures. In addition, the structure of the biomass industry is a large factor contributing to its weak market condition. Rather than being strongly vertically integrated so that each industry segment depends on, and contributes to, the success of the other segments, the biomass industry in the United States consists of many horizontally integrated industries functioning independently of one another. To allow for biomass electric power generation to achieve its potential and to enable it to grow as much as EPRI projects, technological advancements are needed to improve efficiency, and cost effectiveness, while maintaining and improving environmental performance.

4.1 Two Decades of Progress

Historically, biomass energy consumption in the United States consisted primarily of energy derived from the direct combustion of wood. The energy crisis of the 1970's and early 1980's, as well as the decreasing availability of landfill sites have increased the use and awareness of wood and municipal solid (MSW) as biomass fuels for electricity production. Over 6,500 MW of biomass energy based generating capacity was installed in the United States by 1989, primarily owned and operated by industrial entities up from less than 200 MW_e in 1979. By comparison, the Energy Information Agency (EIA) estimates that coal-fired electric utility units in the U.S. accounted for approximately 297,000 MW of capacity, or about 43% of the total U.S. electric generating capacity. Most of today's biomass power installations are the smaller scale independent power and cogeneration systems. To date, utilities have been involved in only a handful of dedicated wood-fired plants in the 40 to 50 MW size range, and in some cofiring of wood and municipal solid waste in conventional coal-fired plants. In the U.S., more than 70% of biomass power is cogenerated with process heat, and wood-fired units account for 88% of the total biomass capacity. Figure 7 below illustrates the current biomass power generation in the U.S.

Figure 7: Biomass Electric Generation Capacity in the U.S.



Source: "Electricity from Biomass," U.S. DOE, April 1992

In the U.S., biomass electric power generation experienced dramatic growth after the Public Utility Regulatory Policies Act (PURPA) of 1978 guaranteed small electricity producers that utilities would purchase their surplus electricity at a price based on the utilities' avoided cost of production. From less than 200 MW in 1979, biomass energy-based generating capacity in the U.S. grew to over 6,500 MW by 1989. National interest quickly grew in wood-burning electric generating plants as a direct result of federal tax policy and state utility regulatory actions in the 1980s. In 1986, 1,839 MW of electricity from wood-burning generators went into operation, more than half the 3,054 MW of power introduced from 1980 to 1985. It is estimated that there are nearly 1,000 wood-fired plants in the U.S., typically ranging from 10 MW to 25 MW. Only a third of these plants offer electricity for sale. The rest are owned and operated by the paper and wood products industries for their own use. However, in 1989, according to the National Wood Energy Association, without the tax credits, only 614 MW of wood-fired capacity was added, and in 1990 this number dropped to between 250 MW to 300 MW of additional capacity. Low fossil fuel prices, slow electricity demand growth, and low feedstock supply in some areas undermined the commercial attractiveness of the current small-scale biomass steam generators. Other contributing factors include loss of tax credits, shifts in the implementation of PURPA toward competitive bidding, waste feedstock supply shortages in some areas and lack of acceptance by large independent power producers.

4.2 DOE Programmatic Information

Recognizing the untapped potential for biomass power to provide clean, efficient power to meet expanding U.S. and global energy needs, the U.S. DOE established the National Biomass Power Program in 1991. The program is a collaborative strategy involving industry, the research and development community, regulators, potential users, and state and federal agencies. Through consultation with industry and other key stakeholders, DOE plans to expand the use of biomass power in the marketplace, which in turn will create jobs, revitalize rural America, reduce dependence on fossil fuels, and protect the environment. Already in its brief history, the program has identified nine major elements of the industry in which to concentrate its efforts.

Direct Combustion Systems - The program is working with existing biomass power producers and equipment manufacturers to improve the performance of today's biomass power plants that use direct combustion equipment with a wide variety of feedstocks including agricultural residues high in ash content. This activity establishes a critical bridge to the development and commercialization of advanced biomass power systems by helping maintain the current industry while introducing more cost-effective, higher-efficiency systems. A key activity is the evaluation of approaches to mitigate boiler fouling problems that occur with a variety of biomass fuels. By expanding the range of acceptable feedstock sources, the economic supply of available biomass will be significantly expanded. Fuel diversity will also provide a productive use for residues currently creating environmental disposal problems.

Cofiring Initiative - The new Clean Air Act Amendments (CAAA), and their call for substantial reductions in sulfur dioxide emissions from utility power plants, have caused biomass cofiring to receive increasing utility interest as a low-cost option for attaining compliance. Cofiring requires minimal to moderate capital investment to modify existing coal facilities for the handling and combustion of biomass fuel at high efficiency. Additionally, existing pollution control equipment can often be used. The program plans an aggressive effort to assist target utilities in evaluating and utilizing biomass fuels for cofiring. Prefeasibility studies will be conducted to identify utility cofiring project opportunities, and viable projects will be cost shared.

Dedicated Feedstock Supply System (DFSS) - A critical element in developing new biomass power facilities is the assured availability of biomass supplies. The DFSS initiative will address technical, economic, and environmental issues of concern to farmers/landowners, environmental groups, equipment suppliers, system engineers, project developers, and financiers. Several cost-shared DFSS scale-up demonstration projects are planned as a stimulus for widespread implementation of these systems. DOE's efforts to help build and expand the DFSS infrastructure will also play a key role in creating a cohesive biomass power industry by bringing together the conversion and supply industry players in cooperative ventures. The initial feasibility of biomass case studies with DFSS has been cost-shared by EPRI.

Next Generation Technology Development - To maintain a strong level of competitiveness in future markets, biomass power must be able to meet increasingly stringent environmental requirements. With advanced biomass power systems currently under development, significant improvements in system performance are possible, including reduced emissions and higher system efficiencies. Next-generation technologies being developed include advanced steam cycle systems; integrated gasification/advance turbine systems, with development of higher efficiency gas clean-up systems; biocrude-fired combustion turbine and diesel systems, with pyrolysis technology refinements; and fuel cell systems, with assessment of fuel cell technology that can utilize biomass-derived gases.

Education and Outreach - Extensive DOE/industry meetings made clear that the costs, benefits, and applications of biomass power are misunderstood by a significant portion of the public and by many regulators and utilities. Furthermore, the lack of sufficient data and information to adequately evaluate biomass power is a principle hurdle for the expansion of this industry. The National Biomass Power Program is supporting an aggressive and sustained communications effort to ensure that the advantages of biomass are adequately disseminated in the marketplace. Activities to be undertaken include public communications, conference participation, and targeted workshops.

Planning, Regulatory, and Policy Assistance - This Program will ensure that policy makers have the tools, data, and analytical input necessary to make equitable decisions regarding development of biomass power facilities. This information will help ensure that appropriate policy and regulatory measures are in place to level the playing field for these technologies.

Design Assistance - This Program is exploring direct avenues for regional technical assistance to suppliers and users of biomass technologies.

Environmental, Safety, and Health Issues - This Program will conduct environmental assessments of the benefits and impacts of biomass power systems, particularly with regard to atmospheric, liquid, and solid waste emissions at power plants and from energy crops. Another key activity will be to assess the role for biomass power and energy crops in mitigating global climate change through recycling atmospheric carbon, particularly CO_2.

International Opportunities - U.S. industry has established a strong capability and presence in the U.S. biomass power market. The market base for U.S. industry could be significantly expanded by taking advantage of substantial international opportunities for developing biomass power. The program will participate in market conditioning efforts to expand U.S. industry into these international markets. To help strengthen U.S. marketing opportunities, the National Biomass Power Program will facilitate the development and deployment of packaged, modular biomass power systems specifically designed to meet international market requirements for smaller-scale systems.

4.3 Strategic Objectives

Because they employ mature generating technologies used for fossil fuels, biomass-powered, electricity-generating technologies are not expected to enjoy large additional breakthroughs that lead to marked drops in production costs per kilowatthour. Of course, experience will bring incremental reductions. For biomass to make significantly greater contributions to the electric power market, two general objectives must be achieved: (1) a dedicated feedstock must be developed, and (2) conversion technologies must be improved. Biomass power stations depend on the availability and variable quality of forest and agriculture residues and waste materials from the wood and paper products industry. Development of a more effective fuel supply system is critical to removing the current dependency. Biomass facilities that burn wood will be affected by the rate of growth of the parent industries, by alternative uses for combustible wood waste, and in the future, by crops grown specifically for energy production. Growth in the use of crops dedicated for energy use is also dependent on demands for the use of land for other crops or other purposes.

Currently, the biomass market consists of a diverse group of organizations with varied needs and a range of technologies at various stages of development. To achieve its goal of doubling the biomass capacity in the U.S. to 12,000 MW by 2000, the DOE will work with stakeholders to simultaneously advance today's direct combustion technologies while continuing R&D on the next generation of technologies. The National Biomass Power Program will work to eliminate regulatory and legislative barriers inhibiting the expansion of biomass power; utilize its analytical and experimental capabilities for R&D efforts; identify and develop collaborative ventures to expedite commercialization of biomass power; develop a reliable and efficient dedicated feedstock supply; and design and implement an educational and outreach program to facilitate the expansion of biomass use.

In order to reach its objective, the DOE has developed a strategy concentrating on three fronts: technology development and validation, market conditioning, and collaborative commercialization through joint ventures.

The first strategic front, technology development and validation, will focus on proof-of-concept activities relevant to current and emerging biomass power technologies and their performance validation. This component includes synchronizing the RD&D efforts with the needs of users, expanding the availability of resource data, and improving system performance. This first strategy is required to ensure the future of biomass power's contribution to U.S. generating and industrial manufacturing capacity. Without a sustained RD&D program, fuel supply and generating efficiency problems that have surfaced in the past will inhibit the competitiveness of this technology as an alternative to traditional means of power generation.

Within the biomass power field, RD&D efforts focus on overcoming these problems by improving generation efficiency and expanding fuel supply capabilities. In fuel supply, RD&D is focused on enlarging fuel supplies, increasing fuel mix, improving the infrastructure, reducing fuel cost, and improving fuel access. In generation efficiency, RD&D is aimed at enabling plant operators to provide more power for a given unit of fuel. Generation efficiency improvements can also be achieved through further development of current direct combustion steam turbine technologies and advanced concepts such as high-efficiency steam cycles, the direct combustion/gas turbine, the gasification/gas turbine, and the biocrude oil/gas turbine.

The second strategic front, market conditioning efforts, will involve working with potential users to mitigate market and regulatory barriers to biomass technology. Market development is vital to the technology development and commercialization process. In the case of biomass technology a current market does exist; however, barriers are hindering the technology's accelerated use, and if not addressed, they may deter biomass power options for electric sector applications in the near and mid terms. Eliminating these barriers paves a way for introducing more advanced technologies. Keeping the financial community, industry, and other participants abreast of DOE activities in risk reduction is important to bolstering market acceptance and confidence. To address these issues, the National Biomass Power Program is supporting a number of activities designed to increase utility and public confidence in biomass electric power. These activities will focus on education and outreach, planning, regulatory and policy assistance, and design assistance.

The final strategic front, collaborative commercialization through joint ventures, will be undertaken to accelerate the commercial acceptance of new technologies by leveraging private-sector resources to help absorb the high up-front costs, reducing the risks inherent in new technology investments, and demonstrating the cost-effectiveness, performance, and reliability of biomass power plants. These joint venture projects between industry, utilities, and other endusers could lead to the implementation of commercially viable projects and enhanced penetration of the national and international marketplace.

The major area of uncertainty for the Biomass Power Program is in the cost-shared field demonstration and joint venture arena to expedite the commercialization of improved high-efficiency electricity generation systems. The technology validation activities presently planned for the program will require demonstrations of such technologies at a significant scale to reduce their risk. The market conditioning activities will increasingly inform public and industrial sectors to facilitate the acceptance of efficient and environmentally acceptable biomass power.

4.4 Plan of Action for the Decade 1995 - 2005

Given the current economic and regulatory environment in the United States, there is a window of opportunity for the growth of biomass technologies in electricity production. One opportunity is the need to revitalize the economies of rural America. The biomass power industry has the potential to increase agricultural income, decrease the flow of energy dollars out of the United States, and promote regional economic development by creating jobs and opportunities in biomass production, harvesting, transportation, and conversion. Biomass production can also expand related industries such as pesticides, fertilizers, and agricultural equipment. A second advantage of biomass is in environmental concerns such as global warming and acid rain regulations. Biomass is one of the most attractive options for addressing CO_2 concerns because both growth and conversion involve recycling of atmospheric carbon, resulting in no net addition of CO_2 to the atmosphere. Also, as a fuel with minimal sulfur content, biomass represents an attractive alternative to conventional fuels for compliance to the nation's Clean Air Act Amendments (CAAA). A final opportunity for biomass is in solving the waste disposal problem of the U.S. Landfill costs are rapidly rising, creating an increasingly urgent desire to find alternative uses for residual biomass materials. Large amounts of biomass fuel are available at a very low or even negative cost to the user.

With all this promise, the biomass power industry still has six major obstacles in its path of wide acceptance and utilization in the electric generating industry: technology awareness, reliable fuel supplies, competition, environment, permitting, and financing.

- Technology Awareness: One of the top priorities identified by industry is the need for better information on the impacts and merits of biomass power for the public. Currently, the general public has little understanding of current biomass technology and is unaware of the benefits of biomass power or its potential.
- Reliable Fuel Supplies: The need for assured supplies of biomass is critical to secure financing and to operate biomass power facilities. Lenders across the U.S. have become increasingly conservative in requiring assured biomass supplies when considering to fund a biomass power plant.
- Competition: Declines in the cost of fossil fuels have put biomass power at a competitive disadvantage in some instances. Use of advanced technologies (such as combined cycle systems) have also increased in the fossil fuel area, particularly for natural gas fired power plants; these advanced technologies have made it difficult for conventional biomass power systems to compete. Potential legislative changes such as carbon taxes or Btu taxes not applied to renewables could enhance the biomass position.

- Environment: A broad range of emission concerns exist, such as NO_x emissions or heavy metals if demolition wood is used. These concerns need to be addressed in order to strengthen the viability of biomass power.
- Permitting: Permitting has become an extremely costly, time-consuming process. Industry often needs assistance in streamlining the permitting process. There has been an increasing tendency for the public to have a "not in my backyard" reaction to the siting of new biomass power plants.
- Financing: The financial community considers a number of risks when making project financial decisions. These include: feedstock supply risk, feedstock price risk, operations risk, technology risk, and environmental risk. Overcoming the financing hurdle will require addressing all barriers.

In addressing these barriers, the National Biomass Power Program has developed specific projects under each of its three strategies. Within the technology development and validation strategy, the RD&D efforts are concentrating on developing new technologies for commercialization. The primary biomass installations over the next 10 to 15 years will be the direct combustion systems. As RD&D efforts lower the costs of short-rotation woody crops, energy crops will spread to areas where more conventional supplies are not available. However, because the biomass/steam electric generating systems are mature technologies, only modest improvements are expected in production cost.

A key RD&D direction for the technology development strategy is to investigate the unique handling and combustion characteristics of biomass fuels when cofired with coal. Additionally, the environmental benefits associated with the cofiring will be explored. According to the National Biomass Power Program, studies are likely to include levels of cofiring from 10% to 40% biomass (per heat input basis).

Implementation of biomass gasification systems is yet another technology development direction of the Biomass Program. RD&D efforts are centering around ensuring that fuel characteristics are compatible with turbine components. Because gas clean-up technology represents one of the greatest hurdles for rapid commercialization of biomass gasification systems, the National Biomass Power Program plans to accelerate scale-up and testing of this technology. To achieve commercialization of the gasification process, the research will test and evaluate the technology in discrete steps. The first phase of the biomass power technology development program -- engineering research -- includes demonstration of a 9.1 tonnes per day unit capable of producing 300 kW. Operation of this primary unit will resolve key process issues such as the level of clean-up required to meet power equipment specifications. In the proof-of-concept phase, a gasifier/turbine combination producing 3 to 5 MW is needed to demonstrate feasibility at precommercial scale.

The technology development strategy also involves the investigation of a biomass pyrolysis system. This type of technology is needed to produce enough pyrolytic oil for long-term turbine tests by a turbine manufacturer. Determining the combustion characteristics of biocrude oil is necessary in order to allow the technologies to be commercialized during the 1990's. Industrial interest in biomass pyrolysis exists, with four private sector companies proceeding with scale-up and commercialization; but there has been a reluctance of users to proceed with oil utilization prior to developing scale-up data. However, potential exists for significant industry and DOE cost sharing to reduce the risk of investment and allow this high-energy oil to be produced in applications where handling how-density solids are restricted.

Biomass fuel cell systems are a final major new biomass electric generating technology being developed. Three cells are considered by utilities to be primary candidates for commercialization. These are the phosphoric acid fuel cell (PAFC), the molten carbonate fuel cell (MCFC), and the solid oxide fuel cell (SOFC). The MCFC appears to be the most suitable fuel cell for power generation using biomass-derived gas because it has the ability to convert more of the gas constituents. MCFC may be able to achieve power cycle efficiencies approaching 60%.

The market conditioning strategy involves two general projects. The first is to develop an education and outreach program. Adequate information to evaluate biomass technologies is lacking in a number of areas. For example, the economic and environmental benefits of the technology are not well known. Despite the technology's similarity to conventional fuel combustion, biomass systems can be acquired in a multitude of configurations utilizing different feedstocks and feedstock combinations. A variety of information is needed as feedstocks have different handling requirements, specific combustion performance characteristics, diverse impacts on plant and equipment, and different levels and types of emissions. Tools to be used in educating stakeholders and enhancing communications include conferences, workshops, and specific information products.

The second project under market conditioning is planning, regulatory, and policy assistance. The successful acceleration of biomass power technologies in the U.S. energy marketplace will require changes in the present legal, regulatory, and planning framework to level the current playing field. To accomplish this, policy makers will need the appropriate tools to make favorable investment decisions regarding development of biomass power facilities.

For the final strategy -- collaborative commercialization through joint ventures -- the expansion of biomass technology will be supported by the National Biomass Power Program using a number of cost- and risk-sharing initiatives involving the various technologies discussed earlier. Two specific projects include the Hawaii Gasifier Scaleup and the Post-Pacific International Center for High Technology Research (PITCHER) Gasification Combine Cycle.

Currently, a major DOE initiative is underway in Hawaii to demonstrate biomass gasification technology. As a follow-up to this project, the National Biomass Power Program will work to facilitate a full-scale 60 to 80 MW demonstration of a biomass gasification combined-cycle power plant. A preliminary study is underway to assess the possible siting of such a facility in the state of Vermont where there is strong support for such a project from the state government, local utility, and community.

In addition to the establishment of the National Biomass Power Program working toward the commercialization of biomass power, the DOE's Office of Solar Energy Conversion has also created a program -- Solar 2000 -- as a collaborative effort to accelerate the adoption of all solar electric technologies (including biomass) by utilities and other electric producers. The effort has developed three projects specifically designed for the commercialization of biomass:

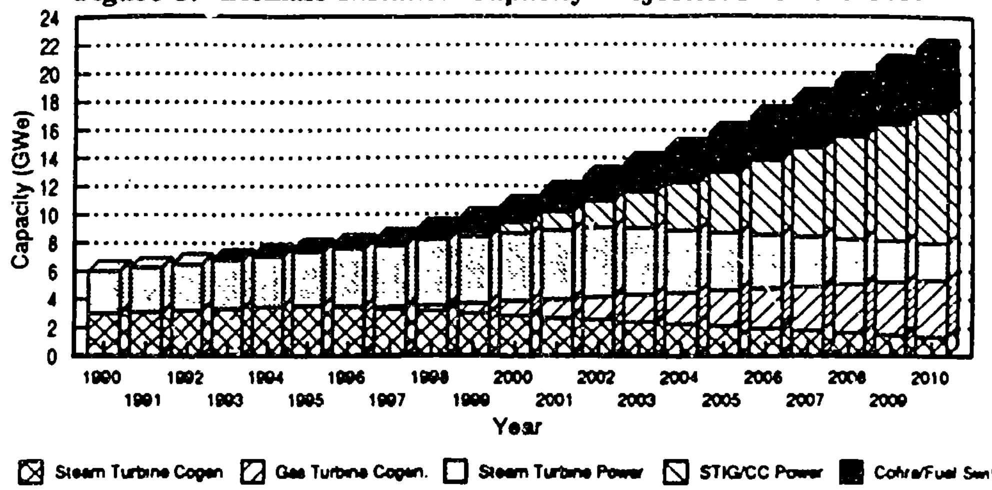
- Biomass Direct Wood-Fired Gas Turbine Project: Negotiations are underway with Power Generating Incorporated for a 3-year, $5 million cost-shared effort to commercialize the direct wood-fired concept.
- Biomass Repowering Project: This project includes supporting the conversion of a coal-fired steam plant to a biomass fuel plant. Plants under consideration are those units that can be converted from coal to fluidized bed combustion, high-efficiency steam cycles such as whole tree burners, hydro-cooled grates or other biomass energy technologies. Such conversions will allow comparisons between the technologies and provide demonstrations of biomass energy potential, credibility, and government support for a cleaner electric power generating technology.
- Biomass Power Plantation Project: DOE is building a collaborative effort to establish a joint venture with major utilities for biomass power

plantations to supply 10 MW to 60 MW grid-connected biomass power systems, in various locations of the country.

Continued development of these new technologies and programs, as well as taking advantage of the economic and regulatory opportunities available to biomass technologies, the future expansion of biomass has a positive future. Figure 8 illustrates the anticipated capacity additions for 1990 through 2010 based on an aggressive DOE/industry effort to develop and commercialize advanced technology systems. This exhibit includes the capacity of existing units which are expected to cofire biomass and biomass derived fuels, or to switch completely to using these fuels. In these cases, the data represent the equivalent biomass capacity rather than the full capacity of the dual-fueled plant. In the aggregate forecast shown here, the growth of the pyrolysis and gasification-based technologies begins to overtake conventional steam capacity growth by 1996 and 1998, respectively. Direct-fired gas turbines also are expected to make limited inroads into the market in this time frame. It is assumed that, until 1995, approximately 100 MW of cogeneration power and approximately 150 MW of dedicated utility power (based on improving steam turbine technology) will be added annually. After 1996, improved steam systems may continue to be added to independent power producers through 2001.

It is projected, however, that gas turbine-based technologies available in the late 1990's will gradually become the technology of choice for larger plants. Utilities are expected to begin to switch to gas turbine and heat recovery boilers in

Figure 8: Biomass Installed Capacity Projections for the U.S.

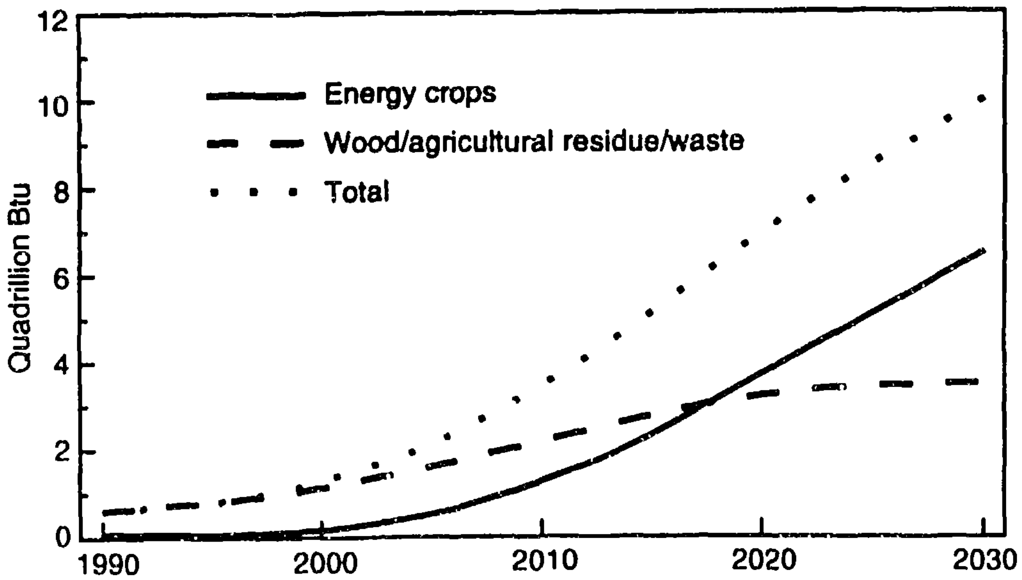


Source: "Electricity from Biomass," U.S. DOE, April 1992

1995, with capacity expected to grow at an annual rate of up to 300 MW per year. Regulatory considerations, exemplified by the CAAA and recent U.S. Environmental Protection Agency (EPA) codifications will encourage fuel switching or cofiring of biocrude beginning in 1995. These factors will accelerate annual additions to 1,000 MW_e beyond 2000. As capacity additions become significant at the turn of the century, combined cycle units with efficiencies near 40% may be built. This will allow 1,000 MW annual capacity additions to continue to 2005 and beyond. These overall projections are about helf of what EPRI has projected. For 2010, EPRI projects that 50,000 MW_e will be installed.

An abundant and reliable supply of low-cost biomass feedstock is critical for significant growth to occur in the biomass power industry. Figure 9 shows the expected expansion in the use of biomass feedstocks for power production over the next 40 years. The supply of biomass coproducts and residues is expected to continue to expand throughout the decade, reaching a plateau after 2010 and remaining near 3 exajoules of energy production through 2030. A key premise of the National Biomass Power Program is that a dramatic expansion in the future availability of biomass feedstocks will occur toward the end of the decade, growing to 15 exajoules by 2030. This expansion will be the result of the development of DFSSs based on low-cost, high-productivity energy crops.

Figure 9: Forecast of Energy from Wastes and Feedstocks in the U.S.



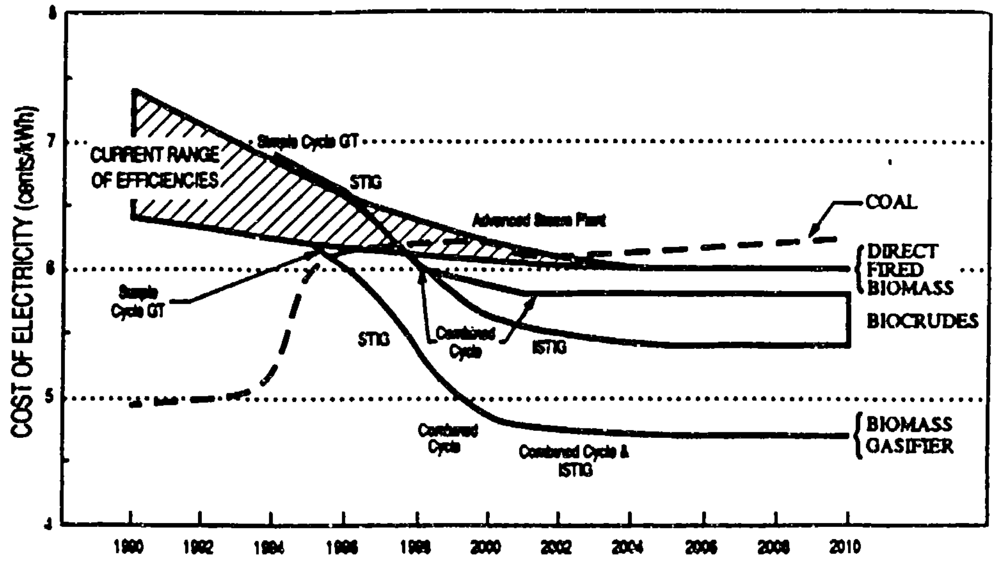
Source: "National Biomass Power Program 5-Year Plan," U.S. DOE, April 1993

Finally, according to a report produced by the U.S. Office of Solar Energy Conversion, by 1995, field tests of small, commercial-scale gasifiers and pyrolysis reactors should be complete. These should provide the needed process validation and data to convince industry to consider these systems for repowering projects in the late 1990s. A number of near-term markets exist in which conversion of existing plants to high-efficiency cycles is possible with a smaller investment than would be necessary for new installations. These markets are divided into three categories as shown below.

- Market Segment: Combined heat and power for industry and independent producers. Early applications: cofiring biocrude oil or wood with coal, improved fuel handling and combustion for existing steam turbine systems, and direct-fired gas turbines with HRSG.
- Market Segment: Modular scale power stations (< 100 MW) for independent producers and municipal utilities. Early applications: cofiring biocrude oils or wood with coal, improved fuel handling and combustion for existing steam turbine systems, and repower via direct-fired GT and HRSG.
- Market Segment: Intermediate scale power stations (100 - 200 MW) for independent producers and utilities. Early applications: Biocrude oil-fired turbine combined cycle systems, repowering via integrated gasifier GT and HRSG.

In the absence of a focused and multi-party R&D effort, the biomass power industry can be expected to continue to exploit niche selected markets where conventional steam technology is competitive. However, this will be an increasingly narrow market with serious resource constraints. In this "business as usual" environment, technology progress is likely to be limited to gradual improvements as shown in Figure 10.

Figure 10: Biomass Technology Evolution in the U.S.



Source: "Electricity from Biomass," U.S. DOE, April 1992

Bibliography

1. U.S. Department of Energy, Solar Thermal and Biomass Power Division, Office of Solar Energy Conversion, "Electricity from Biomass: National Biomass Power Program, Five Year Plan (FY 1994 - FY 1998)", April 1993.

2. U.S. Department of Energy, Solar Thermal and Biomass Power Division, Office of Solar Energy Conversion, "Electricity from Biomass: A Development Strategy," April 1992.

3. U.S. Department of Energy, "Biofuels Program Summary, Volume 1, FY 1989," January 1990.

5.0 WIND ENERGY

Wind energy is receiving increased consideration as a supply option by electric utilities and independent power producers. In the United States, growth has been phenomenal, from almost zero to more than 1,600 megawatts of installed capacity through the early 1990's, primarily in California and Hawaii. Wind power now represents about 3% of California's installed electric generation capacity, the highest market penetration of wind energy in the world. These accomplishments, in light of growing environmental awareness, signal a new era in the commercialization of wind power.

Adequate wind resources for cost-effective energy production are found in all regions of the country, although the Midwest, West, Northwest, and Northeast parts of the U.S. tend to have the best wind resources. Even with modest development of these resources, wind can make a major impact on the country's energy supply. The Pacific Northwest Laboratory reports that more than 2,200 GW of wind energy are available from sites with at least a Class 4 resource (a site with higher than 5.6 m/s (12.5 mph) average annual wind speed measured at 10 m above the ground).

The use of wind energy as an electric generating option is expected to accelerate over the next decade as a result of several factors. Technological advances, reduced system costs, and new government financial incentives are all contributing to the technology's increasing prominence. Inclusion of external costs into electricity rates is being discussed or examined in most states.

Substantial wind energy installations have either been negotiated or are being seriously considered in at least eight states. At the Federal level, new energy legislation has been signed that authorizes production incentives of $0.015 per kilowatt-hour for wind plants installed after 1993. The economic package of the new Clinton Administration includes substantial increases in federally funded conservation and renewable energy research and development (R&D) through 1998. At the same time, wind energy technology has progressed to the point that U.S. Department of Energy-supported advanced turbine prototypes are being fabricated and installed, and are expected to be able to produce energy at $0.05 per kilowatt-hour (at 5.8 m./sec. sites, measured at 10 meters). The wind industry is poised at the confluence of these developments, preparing for strong growth in the last half of the last decade of the century.

This section will discuss the wind technology performance record over the past 20 years as well as some of the new initiatives in legislation and utility planning. The role that the Federal government has in supporting wind energy research and development will be examined with particular reference to the research, development and marketing agenda for 1995-2005.

5.1 Two Decades of Progress

In the 1970s, government-sponsored research and development programs were instituted in the United States as the oil embargo of late 1973 and early 1974 marked the end of the era of secure and cheap oil. Furthermore, the Public Utility Regulatory Policies Act (PURPA) of 1978 and the Wind Energy Systems

Act (WESA) of 1980 were established. PURPA was enacted to encourage small power production from renewable resources and mandated that electric utilities purchase power, at "just" rates, from qualifying small power production facilities employing renewable resources such as wind to generate power. WESA established goals for wind power to be reached in an 8-year period. The primary goals of the legislation were to reduce the cost of wind-generated electricity, achieve 800 MW of wind-energy capacity installed in the United States by 1988, and establish a competitive industry. These three goals were met in the 1980's.

During the 1980s, the nation's first wind power machines capable of supplying power to utility systems came on line in the California mountain passes of Altamont and San Gorgonio and the wind-swept ridges of the Tehachapi area. By the end of 1990, wind turbines installed in the United States numbered approximately 16,000, with a total generating capacity of approximately 1,600 MW. The average size of turbines installed in 1990 was about 160 kW. By way of comparison, a typical nuclear power plant has a rated capacity of 1000 megawatts, and a typical coal power plant is rated at about 400 to 700 megawatts. Few other emerging renewable technologies can match the rapid growth of wind power in the 1980s. In addition, over 30,000 smaller electrical systems (0.5 to 10 kW) are being used in remote and standalone applications.

While wind energy is generally considered an intermittent power source, its statistical reliability at some sites to provide intermediate and peaking power has been demonstrated by electric utilities. At these sites, the periods of highest wind output correspond well to the periods of highest utility demand. In remote applications, hybrid systems, using backup sources such as diesel generators and storage systems, can allow wind systems to serve loads reliably and cost-competitively.

Over the past 10 years, the wind industry has been hammering its costs downward through standardization, improvement in the turbines, and experience in the daily operation and maintenance of wind plants. While installations in the early 1980s were plagued with reliability and performance problems, the industry has improved the technology to the point that today's utility-interconnected machines produce power at costs of \$0.07 to \$0.09/kWh at a 5.8 m/s (13 mph) site, rivaling many non-renewable sources. It appears likely that costs will go down to \$0.05/kWh in the near future.

Another major step forward for wind and other renewable energy systems was the passage of the Energy Policy Act of 1992 (EPAct) by the U.S. Congress in October. This new law provides wind energy production incentives, access to transmission lines, and other programs helpful to wind energy development. The new law provides a tax credit of \$0.015/kWh for wind facilities that are brought on line between January 1, 1994 and July 1999. Contrary to previous incentives, investor-owned utilities are eligible for the production incentive. In addition, renewable energy production incentive payments of \$0.015/kWh are provided to publicly owned (e.g., municipal, cooperatives, and public utility districts) and qualified renewable energy facilities, although funds for these payments are subject to annual appropriations.

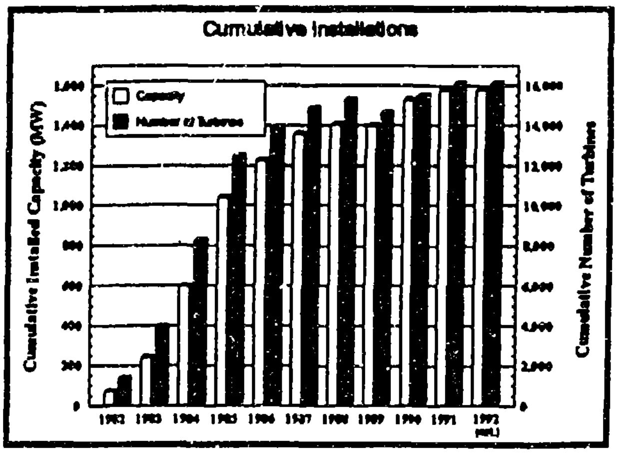
Other new EPAct procedures provide for transmission access for third-party wind developers. This will expand the ability of wind power developers to "wheel" their power over different utility districts to areas of the most need. For instance, wind energy produced in Montana or the Dakotas could be wheeled down to Denver. Another example where this would be a significant factor would be in the Appalachian Mountains where wind potential exists, with electricity wheeled to the populated Atlantic Coast.

EPAct also implements programs designed to encourage the use of wind systems through training and education. In addition, some important initiatives favorable to wind were proposed and in some cases implemented on the regional and state level in 1992.

Although 1992 was a landmark year for progress on new energy legislation and research, new wind installations were down when compared to recent years. By the end of the year, new wind capacity was expected to amount to less than 10 MW. This is attributed in large part to the continuing phase-out of Standard Offer 4 power purchase contracts, begun in California in the early 1980s. Also retirements of outdated turbines were expected to be slightly greater than new installations in some regions. As shown in Figure 11, the total installation will remain approximately the same, about 1600 MW. Energy production is expected to be up slightly from prior years due to improved performance of new turbines.

Rapid growth in new installation in 1993-1994 is expected to result from the new market incentives and advanced turbine developments.

Figure 11: Wind Installations In The U.S.



Source: "The U.S. Wind Energy Program," U.S. DOE, 1992.

5.2 DOE Programmatic Information

The U.S. Department of Energy Wind Energy Program is strengthening joint efforts with industry in a program to maintain and improve existing wind installations, develop advanced wind turbines for the near- and mid-term, and upgrade the technology base through applied research. Three national laboratories are working with industry and universities to effect near-term improvements in the efficiency and reliability of wind farms, and develop a new generation of wind turbines for the next century, while continuing the fundamental research that supports these efforts.

The U.S. Department of Energy's program is focused on activities that are closely coordinated with industry and the utility user community. This past year has seen the start-up of several new initiatives intended to complement the U.S. Department of Energy's existing program, among them projects to address utility integration issues through demonstrations involving installations of state-of-the-art turbines and efforts to re-engineer existing turbines for near-term cost and efficiency improvements. After a near-doubling of funding from $11.1 million in Fiscal Year (FY) 1991 to $21.4 in FY 1992, the funding level has risen again this year to $24.0 million.

DOE recently announced the establishment of a National Wind Technology Center, intended to be the new base of operation for the National Renewable Energy Laboratory's Wind Technology Division, and to include full turbine performance verification and other testing and research facilities. The center, located at Rocky Flats, Colorado, on 280 acres of land, will provide the U.S. with a world-class wind energy research and development center. It will provide specialized component test facilities, computer modeling facilities, and a turbine test capability for use by industry on a user facility basis. The center will support a wide variety of activities, including the development of performance standards.

The DOE Wind Energy Program, in consultation with industry, has identified several key issues to be addressed to achieve the potential of wind energy. These include the following:

- Until recently, electric utilities have not been active participants in developing and operating wind plants. This lack of direct involvement has caused them to be cautions about expanding the role of wind. In addition, the availability of transmission capacity is expected to play an important role in extending utility-scale wind technology to regions beyond California. Increasing utility participation in wind energy development is therefore essential.

- Wind plants presently receive little, if any, credit for their contribution to system reliability (often called a capacity credit). This is because wind energy cannot now be considered dispatchable and output cannot always be relied upon to coincide with utility loads. Improved site-specific wind forecasting techniques and better methodologies for use by utilities in defining wind energy operational benefits can be expected to change this situation.
- Cost of energy reductions can be achieved through increases in performance, through careful attention to design, and through the development of efficient manufacturing techniques that can be used in wind turbine mass production. Performance improvement areas include advanced airfoils, site tailoring, and improved operating strategies. Advanced design tools for modeling turbulence, aerodynamics, structural characterization and fatigue life will be required. Opportunities for system cost reductions and manufacturing efficiencies are just now being explored by the industry.

- Improvements in reliability will also be required to meet cost goals. For example, new rotors designed to better withstand fatigue loads would help to provide this reliability improvement.
- Wind farms have historically experienced operational difficulties stemming from causes such as poor control strategies and improper wind turbine siting practices. Working to solve these problems has consumed a significant amount of the industry's resources, making it difficult for most companies to perform research aimed at more fundamental near-term design improvements or investing in a new generation of machines.
- Present wind turbines are currently cost-effective to install in applications with high fuel costs and excellent wind resources that match periods of peak use. There will be a gap of several years until tested machines capable of \$0.05 to \$0.06/kWh (at 5.8 m/s sites) electricity production are available.
- International markets will be a major opportunity for U.S. manufacturers over the coming decade. However, for them to complete successfully in this marketplace, significant market conditioning efforts will be required. Barriers include unfavorable tariffs and foreign government subsidies for exports. Activities to facilitate market accessibility, tailored to the unique needs of the wind community, can foster greater U.S. participation in this emerging market.

5.3 Strategic Objectives

The program has recognized the need for a different approach to meeting industry's needs. Therefore, additional resources are being focused on activities that are closely coordinated with industry and the utility user community. The strategy has four thrusts:

- Upgrade the current base of installed turbines and assist industry in finding solutions to operational problems. This activity will work to increase utility confidence in wind systems viability and enhance prospects for future market expansion. Technology developed in recent years will be applied to make important improvements in existing turbines.
- Increase wind industry competitiveness. Strengthen DOE's ties with industry to help broaden industry's base. The program is pursuing a variety of mechanisms for working with industry. including partnerships and consortia with utilities, industry, laboratories, and universities. This will help in the development of new domestic and international markets.
- Develop advanced wind turbines, in close cooperation with industry. It became clear in the late 1980s that a very effective way to move the technology toward the technical goals for the late 1990s would be to initiate a cooperative development program with industry to help bring a series of advanced turbine designs to the marketplace. This program was begun last year and is described more fully later in this paper.

- Continue to upgrade the applied research base. The program will continue to fund research to establish the technical underpinnings, new technology, and design tools required for future progress.

One activity already underway to implement this strategy is the Utility Wind Interest Group, being sponsored by the Electric Power Research Institute and the National Renewable Energy Laboratory. The goal of this organization is to support the integration of wind technology into electric utility generating and transmission systems. Its focus is on disseminating up-to-date, accurate information about wind power to utilities, via brochures, workshops, and regional meetings.

5.4 Plan of Action for the Decade (1995-2005)

The U.S. Federal wind technology program has set as its goal "to assist utilities and industry in developing new markets and applications for wind systems and to develop advanced wind turbine technology to be economically competitive as an energy source in the long-term marketplace." This represents a recent recognition that the emphasis of the 1980s, which was solely to provide a technical research base, was no longer sufficient for meeting the needs of an emerging industry in an expanding marketplace. Support for utility and industry program activities now occupies an important place in the program mission. To achieve this goal, the program has identified two specific objectives for the late 1990 time frame:

- To increase performance 50%, lower cost 10-15%, increase availability to greater than 95%, lower operation and maintenance costs to around $.01/kWh, and double machine lifetime. These, taken together, would meet the cost of energy targets described earlier.
- To move the domestic market to regions beyond California, with a target of having utility-interconnected windfarms in the Great Plains and the Northeast by the end of the decade.

In addition, certain technology support program activities will work to expand markets for small-scale, on-and-off-grid systems and for wind/hybrid systems and to develop expected opportunities for international joint ventures and marketing. This success will result from an aggressive program of applied research, coupled with close cooperation with industry. This cooperation will enhance current technology for the near-term and help in developing advanced technology for the mid-to-long-term.

In the near-term, as a direct result of programs targeted toward industry participation,

- several state-of-the-art wind turbines will be available in the 1994-1995 timeframe to complete with the best foreign turbines. These machines will generate electricity for $0.05/kWh (at 5.8 m/s average wind speed sites).
- an upgraded vertical axis technology will be an alternate design configuration to the current horizontal axis designs.

- the average performance of the California wind plants will continue to increase, as older, poorer performing machines are replaced by technology upgrades available in the mid-1990s. For example, National Renewable Energy Laboratory (NREL)-designed blades now being tested offer performance increases of up to 30% under certain operating conditions.

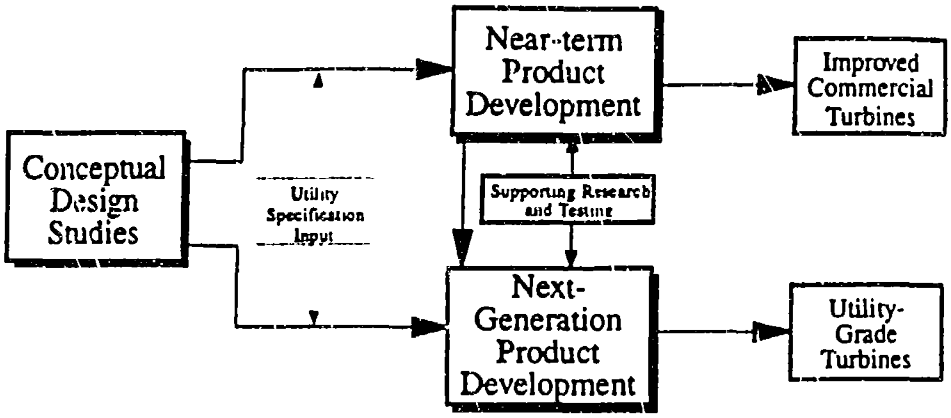
In the mid-term (1995-2010),

- industry, working closely with DOE, will have completed development and testing of several innovative, utility-grade wind turbines that will enable U.S. manufacturers to compete on a broad geographic basis, both domestically and internationally. These machines will generate electricity for $0.04/kWh (at 5.8 m/s average wind speed sites).
- wind power will be generated in resource-rich regions of the country and wheeled through the Power Marketing Administration (PMA) and other grids to areas with high demand and expensive conventional fuels.
- U.S. manufacturers will capture an increasing share of the international market, including those of small machines for wind/hybrid systems, in the mid-1990s and, by 2000, will account for one-half of the machines installed overseas.

Programs supporting both these near and mid-term goals include the Advanced Wind Turbine Program, the Utility Integration Program, the Collaborative Wind Technology Program, and the applied Research Program elaborated upon below.

Advanced Wind Turbines - Industry needs for research to advance mid-term and long-term wind turbine design are addressed through the Advanced Wind Turbine (AWT) program. The AWT program is a collaborative venture with utilities and industry with the goal of bringing wind-generated electricity costs to levels competitive with those of fossil-fuel generators in most regions of the U.S. Figure 12 illustrates the fundamental program structure.

Figure 12: U.S. DOE Advanced Wind Turbine Program



Source: U.S. DOE Wind Energy Multi-Year Program Plan, 1993.

The AWT program has two major thrusts: the development of improved turbines incorporating incremental refinements into existing designs by the mid-1990s and the development of next-generation technology by the turn of the century. Both of these elements began with conceptual design studies in late 1990 with the award of three subcontracts, and were concluded in 1992. The Near-Term Product Development phase of the program is currently being funded, with three contracts awarded so far in 1992, and two more being negotiated. The specific goal of the Near-Term Product Development activity is to develop wind turbine systems to be commercially available in the 1994-95 time frame that produce electricity for $0.05 per kilowatt-hour at 13 mph wind sites.

Both near-term and next generation technologies will incorporate multiple advanced concepts. For instance, the advanced turbines will incorporate blades with advanced airfoils designed specifically for the turbines, based on aerodynamics research performed at the DOE's National Renewable Energy Laboratory (NREL). In field testing, these airfoil families have demonstrated energy capture 30% greater than that of commonly used blades. For one near-term design, a single piece generator housing is being used to reduce long-term manufacturing costs. In another near-term design, ailerons are being used for rotor speed control. Power electronics, with associated variable speed operation, is being considered for the next generation turbines.

Utility Integration Program - The wind program has initiated a series of activities to help address the concerns that electric utilities have expressed about integrating wind systems into their normal operations.

A utility studies activity explores a wide range of issues such as system stability, wind energy capacity credit, transmission, distribution, integration with storage, and dispatchability. These are addressed in close coordination with utilities. Utility transmission and distribution systems in many areas of the country are approaching maximum capacity. This activity will examine the benefits of adding advanced small wind turbines systems to the existing utility distribution network at selected sites close to demand centers. Various types of dispersed applications and utility scenarios may be considered to cover a wide range of potential markets in the 1995 to 2005 time frame.

Collaborative Wind Technology Program - Activities under the Collaborative Wind Technology Program respond to the needs of the industry for assistance in research to maintain current competitiveness, as well as helping address aspects of system development not addressed in other programs. These include the need for things as diverse and practical as the redesign of existing turbine components and access to turbine testing facilities.

The Cooperative Wind Technology Applications activity assists the wind industry in seeking near-term commercial opportunities, both domestic and international, for wind energy. Seven companies have received awards under the initial round of this activity. These cooperative cost-shared research activities are assisting the industry in the design, development, testing, and analysis of solutions to current operational problems. Specific problems being addressed include, but are not limited to, verification testing of existing, new, or improved wind turbines; design, development and testing to verify new technology components or subsystems; site engineering optimization; control and utility interconnection optimization; and application demonstrations in new operational environments (for example, hybrid systems using small machines).

A Value Engineered Turbine (VET) effort was initiated in 1992 to assist the U.S. wind industry in developing near-term commercial wind turbines for both the domestic and international marketplace. The focus of this activity is on re-engineering and/or remanufacturing conventional wind turbine configurations. Many of these designs have proven to be reliable suppliers of electricity in California and Europe. However, the cost of energy achieved by these machines has been above the goals that have been set for wind energy. The VET will support, on a cost-shared basis, value analyses, manufacturing, and commercialization of these machines. Awards under this activity are expected in June 1993.

Applied Research Program - Applied research is necessary to ensure that fundamental design tools will be available for performing detailed designs of future advanced wind turbines. For example, the program has developed new computer models for aerodynamic performance, structural dynamics, and yaw dynamics that run on personal computers. These codes are being used by many wind turbine companies and university research programs. However, enhancements to the models are required to predict the behavior of advanced rotor configurations that will result from advanced conceptual design studies.

Aerodynamics research currently underway involves exploring the characteristics of the wind at actual wind turbine sites (atmosphere fluid dynamics) and investigates the aerodynamic phenomena experienced and created by wind turbines during operation. One of the efforts has been the analysis of Combined Experiment pressure measurements to determine the effects of delayed stall on wind turbine steady and dynamic loads. Testing is done on the heavily instrumented research turbine operated by NREL and located at their test facility at Rocky Flats, Colorado. Aerodynamic investigations on vertical axis turbines are being undertaken at Sandia National Laboratories (SNL). Much of SNL's efforts, in support of all areas of applied research, have been conducted on the 500 kW, 34 meter vertical axis wind turbine test bed located in Bushland, Texas.

A new Structural Test Facility, located at NREL, has been developed to perform static and dynamic tests of wind turbine components, such as blades. Static tests will determine ultimate strength limits and weak points in the component designs for later detailed investigation. Dynamic tests using hydraulic actuators will submit components to cyclical fatigue loads similar to those experienced during actual operation.

Research is continuing into the effect of wind turbines on operational control and power quality in utility grids, electrical utility interconnection, and wind/hybrid systems. Because wind turbines usually operate in clusters, research on controls and adaptive controls will take a systems approach to all operational control issues. The goal of activities in this area is to define electrical characteristics and controls that will minimize undesirable power fluctuations and maximize the energy contribution that wind turbines can make to a utility grid.

Work is also continuing on development of advanced airfoils and blade designs, variable speed generator and advanced drive train research, advanced tower concept development, and the evaluation of aerodynamic rotor brakes.

During the decade of 1995 to 2005, several projections of wind energy use have been developed by the U.S. Department of Energy's Energy Information Administration. Under a high world oil price scenario, projected electricity capacity grows to 5670 MW by 2005. In contrast, in a low world oil price scenario, projected capacity would grow less rapidly to 4220 MW by 2005.

Bibliography

1. Swedish National Board for Industrial and Technical Development. "IEA Wind Energy Annual Report 1992." Stockholm, Sweden 1993.

2. Energy Policy Act of 1992. Public Law 102-486. October 24, 1992.

3. U.S. Energy Information Administration. "Annual Energy Outlook 1993 with Projections to 2010." Publication. #D)E/EIA-0383(93). January, 1993.

4. U.S. Energy Information Administration. "Renewable Resources in the U.S. Electricity Supply." #DOE/EIA-0561. February, 1993.

5. D. Ancona, R. Loose, J. Cadogan, U.S. Department of Energy, "The United States Wind Energy Program In A Decade of Change." Presented at European Community Wind Energy Conference. Travemunde, Germany, March, 1993.

6. National Renewable Energy Laboratory, "Office of Utility Technology Success Stories." Golden, Colorado. #DOE/CH10093-125. March 1993.

7. American Wind Energy Association, "Wind Energy for a Growing World: With a Directory of the U.S. Wind Industry." Washington, D.C. Undated.

8. Ronald R. Loose and Daniel F. Ancona, "The U.S. Wind Energy Program." U.S. Department of Energy, Washington, D.C. 1992.

9. U.S. Department of Energy, Wind Energy: Program Overview. Fiscal Years 1990-1991. Washington, D.C. 1991.

10. David Eide, "Bright Prospects for Wind." *Strategic Planning for Energy and the Environment.* Vol. II, No. 1, 1991. Lilburn, Georgia.

11. Jon Naar, <u>The New Wind Power</u>. Penguin Books. New York, New York. 1982.

12. Randy Swisher, Daniel F. Ancona, and Jason Edworthy, "Wind Energy Developments in the Americas." Presented at the 1990 European Community Wind Energy Conference. Madrid, Spain. September 10, 1990.

6.0 SUMMARY

The United States faces significant challenges throughout the 1990s: securing a reliable supply of competitively priced energy, improving the quality of our environment, and increasing our share of foreign markets for goods and services. The U.S. Department of Energy's (DOE) programs in renewable energy are working toward meeting these challenges by developing the technologies that make use of our nation's largest energy resource: renewable energy.

Within the context of the World Solar Summit, the term "solar" symbolizes all forms of renewable energy. The sunlight, wind, biomass, flowing water, ocean energy, and geothermal energy that make up the renewable energy resource can be found throughout North America. These resources can provide all the forms of energy our nations needs: liquid fuels, electricity, and heating and cooling. Renewable energy meets about 10% of our need for these forms of energy today, yet the potential contribution is many times greater.

The U.S. Department of Energy programs in renewable energy are working side-by-side with American industry to develop technologies that convert renewable energy resources into practical, cost-competitive energy. After two decades of progress in research, several of these technologies are poised to make large contributions during the 1990s and beyond.

This report, *Solar Energy in North America*, describes the progress, status, and strategic objectives of four solar energy technologies -- photovoltaics, solar thermal, wind, and biomass -- to meet the critical needs for providing new supplies of affordable energy today, and in the next century.

6.1 Solar Thermal Electric

Solar thermal electric technology is poised to enter the commercial power generation market. Some systems already are available to meet the needs of a broad range of users from remote power applications of just a few kilowatts to utility-scale applications of hundreds of megawatts. The market potential for this technology is substantial. The combined new capacity requirements for all domestic and international power markets is estimated at 6500 gigawatts during the 1990s.

Current realities in the power market, such as increasingly stringent environmental regulations, smaller incremental capacity requirements, short planning horizons, and uncertainty in costs of conventional energy due to fluctuating fuel costs have created favorable conditions for the rapid deployment of solar thermal electric technology. Remote power users, who have been straining under the steadily increasing cost of diesel fuel, are ready for a clean, renewable alternative.

While not a panacea for all of the nation's energy problems, solar thermal electric technology has a formidable potential for filling a critical near-term need for electric capacity requirements.

The solar thermal electric industry is developing into a cohesive, competitive force. In collaboration with the industry, regulators, researchers, and users, a strategy has been developed for enhanced market penetration by solar thermal electric technology. The strategy has three elements:

- Technology development by industry with support in key areas from the national laboratories;
- DOE/industry joint ventures that move the technology more quickly to market through risk reduction; and
- Market conditioning that prepares users and regulatory decision makers to accept and use the technology as it becomes available.

Within the partnership are industrial participants, state and Federal regulators, researchers, and utilities, as well as independent, industrial, and remote power users. Each of these partners has a role in achieving this goal. The collective efforts of these partners will turn this vision into reality.

6.2 Photovoltaics

The National Photovoltaics Program is confident that these programs will support industry's efforts to develop PV technology for large scale generation of economically competitive electric power. It will also fulfill many interim needs in the consumer, industrial, military, and space sectors.

These programs will provide benefits to the private sector in helping them establish a strong PV industry, to the federal government in strengthening national security, and to the public by supplying needed energy while protecting the environment. In addition, the program provides a balanced approach to all areas of photovoltaic research and development and aims for realistic cost and performance goals. These goal are based on projections developed in the 1970's and 1980's. As costs drop, PV will be phased into new utility applications and become a cost-effective alternative in increasingly larger markets.

Equally as important, this program could help to meet a significant portion of the United States's energy needs with environmentally benign technologies. It is anticipated that within the next few years economically justified, non-polluting photovoltaic systems will be fulfilling many utility applications.

The potential for photovoltaic-generated electricity is enormous, with estimates running as high as 100,000 MW of installed capacity by the year 2030. Cumulative sales of photovoltaics by that time may total on the order of one-half trillion, bringing substantial profits and electric power not only to Americans but to millions of people around the world.

6.3 Biomass

A viable solution to the energy and environmental concerns of the U.S. electric generation industry is biomass power, and the United States is making a strong, conscious effort to develop biomass power with the implementation of the National Biomass Power Program and Solar 2000. Biomass power already accounts for over 6,500 MW of utility generation in the United States. The resources for fueling biomass power stations could evolve from current waste sources to dedicated, high-productivity energy crops specifically developed for fuel applications by the mid-1990's. The end result would be a new, widely available, low sulfur renewable fuel for utility power production, and a potentially profitable new crop for American agriculture. Similar to coal, biomass resources are expected to be one of the lowest-priced fuels at $1.50 to $2.00 per MMBtu. Unlike coal, however, biomass fuels contain very little sulfur, and on a production-to-power generation basis, generate no net CO_2. With emissions of SO_2 now strictly controlled by law and carbon dioxide being monitored for possible future control, biomass fuels provide an important option for U.S. power producers.

Currently, biomass resources contribute about 2.9 quads to the U.S. energy base. The development and use of greatly improved forest management and recovery techniques could allow natural forest systems to provide up to 3.2 quads per year of wood feedstock for electric power production by 2010. Accelerated energy crop RD&D could allow biomass energy farms to contribute another 6.5 quads per year of energy for biomass power, making an estimated total of nearly 10 quads per year of biomass for fuel for future power production. Future widespread availability of abundant biomass feedstocks resulting from high productivity energy crop development may allow utilities and independent producers in the U.S. to ultimately develop about 100 GW of biomass powered facilities.

The successful execution of the research and development programs and the resolution of technical and economic risks will pave the way for widespread use of biomass power.

The electric utility industry in the United States continues a process of change marked by increasingly stringent environmental constraints on new and existing power generation sources and regulatory reform aimed at opening power generation markets to new non-utility producers. The uncertainties of the utility business have been compounded by the fluctuations in the price and availability of premium fuels such as natural gas, oil, and low sulfur coals. With requirements for new capacity in the next 20 years projected at nearly 210 GW in the United States, utilities have broadened their portfolio of power options to include non-utility generation sources, demand-side management and conservation, greater use of imported power, and nonconventional fuels. Advances in power generation technology, such as biomass, are providing power producers with some of the flexibility and capabilities needed for success in this changing market.

6.4 Wind

Wind energy in the United States has made significant progress in moving toward broad use as an alternative to fossil-fueled conventional generation. The number of turbines installed continues to increase and costs are dropping as the performance of wind systems continues to improve as the technology matures. A financial incentive of $0.015/kWh was recently enacted for wind. More legislation is planned that will affect the economics of fossil fuels, and thereby benefit renewables.

Recent studies have identified a large resource that could supply a significant portion of the nation's electricity needs. The Department of Energy's

Energy Information Administration has projected sizeable contributions from wind energy in several regions of the country depending on such factors as economic growth and world oil prices.

The U.S. Department of Energy wind technology program is increasing its emphasis on working closely with utilities and industry to apply new technology and to develop new markets. Moreover, funding levels are increasing as new cooperative efforts are initiated. In the near-term, activities will focus on assisting industry in solving current problems and on identifying upgraded designs that will be more broadly competitive in the mid-1990s. In the longer term from 1995 to 2005, an advanced turbine activity targeted at the design of next generation wind turbines should ensure wind technology's continued success into the next century.

During the next decade of 1995-2005, broad-based development of the vast wind resources in the United States will begin. As a result of improved technology, new financial incentives and increasing concerns about the environment and dependence on fossil fuels, the use of wind energy to generate electricity is expected to grow dramatically. By 2005, the installed capacity of wind systems in the United States could grow four-fold from today, to 5.7 GW. This world-leading deployment of wind systems will be accompanied by expected rapid expansion of wind system exports.

7.0 MASTER BIBLIOGRAPHY

American Wind Energy Association, "Wind Energy for a Growing World: With a Directory of the U.S. Wind Industry." Washington, D.C. Undated.

D. Ancona, R. Loose, J. Cadogan, U.S. Department of Energy, "The United States Wind Energy Program In A Decade of Change." Presented at European Community Wind Energy Conference. Travemunde, Germany, March, 1993.

David Eide, "Bright Prospects for Wind." *Strategic Planning for Energy and the Environment.* Vol. II, No. 1, 1991. Lilburn, Georgia.

Energy Policy Act of 1992. Public Law 102-486. October 24, 1992.

Jon Naar, The New Wind Power. Penguin Books. New York, New York. 1982.

National Renewable Energy Laboratory, "Office of Utility Technology Success Stories." Golden, Colorado. #DOE/CH10093-125. March 1993.

Randy Swisher, Daniel F. Ancona, and Jason Edworthy, "Wind Energy Developments in the Americas." Presented at the 1990 European Community Wind Energy Conference. Madrid, Spain. September 10, 1990.

Ronald R. Loose and Daniel F. Ancona, "The U.S. Wind Energy Program." U.S. Department of Energy, Washington, D.C. 1992.

Swedish National Board for Industrial and Technical Development. "IEA Wind Energy Annual Report 1992." Stockholm, Sweden 1993.

U.S. Department of Energy, "Biofuels Program Summary, Volume 1, FY 1989," January 1990.

U.S. Department of Energy, *DOE's Solar Thermal Electric Program brochure*, April 1993.

U.S. Department of Energy, Energy Information Agency (EIA), *Annual Energy Outlook 1993 with Projections to 2010*, January 1993.

U.S. Department of Energy, Energy Information Agency (EIA), *Renewable Resources in the U.S. Electricity Supply*, February 1993.

U.S. Department of Energy, *Solar 2000: A Collaborative Strategy Volume I and II*, February 1992.

U.S. Department of Energy, Solar Thermal and Biomass Power Division, Office of Solar Energy Conversion, "Electricity from Biomass: National Biomass Power Program, Five Year Plan (FY 1994 - FY 1998)," April 1993.

U.S. Department of Energy, Solar Thermal and Biomass Power Division, Office of Solar Energy Conversion, "Electricity from Biomass: A Development Strategy," April 1992.

U.S. Department of Energy, *Solar Thermal Electric and Biomass Power Program Overviews (Fiscal Year 1990-91), Programs in Utility Technologies*, June 1992.

U.S. Department of Energy, *Solar Thermal Electric Five Year (FY 1993-97) Program Plan*, April 1993.

U.S. Department of Energy, Wind Energy: Program Overview. Fiscal Years 1990-1991. Washington, D.C. 1991.

U.S. Department of Energy. Photovoltaic Energy Program Overview Fiscal Year 1991, (Washington, D.C.: U.S. Department of Energy, DOE/CH10093-129, 1992).

U.S. Department of Energy. Photovoltaic Energy Program Summary, Volume I: Overview, Fiscal Year 1989, (Washington, D.C.: U.S. Department of Energy, DOE/CH10093-58, 1990).

U.S. Department of Energy. Photovoltaics Program Plan FY 1991 - FY 1995, (Washington, D.C.: U.S. Department of Energy, DOE/CH10093-92, 1991).

U.S. Department of Energy. Photovoltaics: Program Overview Fiscal Year 1992, (Washington, D.C.: U.S. Department of Energy, DOE/CH10093-190, 1993).

U.S. Energy Information Administration. "Annual Energy Outlook 1993 with Projections to 2010." Publication. #D)E/EIA-0383(93). January, 1993.

U.S. Energy Information Administration. "Renewable Resources in the U.S. Electricity Supply." #DOE/EIA-0561. February, 1993.