United States General Accounting Office

GAO

Report to Congressional Requesters

May 1999

RENEWABLE ENERGY

DOE's Funding and Markets for Wind Energy and Solar Cell Technologies

GAO/RCED-99-130

GAO

United States
General Accounting Office
Washington, D.C. 20548

Resources, Community, and
Economic Development Division

B-282303

May 14, 1999

The Honorable John R. Kasich
Chairman, Committee on the Budget
House of Representatives

The Honorable F. James Sensenbrenner, Jr.
Chairman, Committee on Science
House of Representatives

For many years, the federal government has supported the research, development, and deployment of renewable energy technologies. From fiscal year 1978 through fiscal year 1998, the U.S. Department of Energy (DOE) was provided nearly $10.3 billion for research and development (R&D) of renewable energy through programs now managed by its Office of Energy Efficiency and Renewable Energy. Although DOE funds research on many forms of renewable energy, it has provided a large portion of its money to technologies that convert wind or sunlight into electricity.[1] Wind is converted into electricity through the use of wind turbines, while sunlight can be converted into electricity through the use of solar cell technology, known as photovoltaics. These technologies are still developing with various forms of government assistance, but they are also manufactured and sold today in the marketplace.

As requested, we are providing you with information on wind and photovoltaic technologies.[2] Specifically, for wind energy technologies, we answered the following questions: (1) How much has DOE spent on R&D and how have DOE's objectives for its programs changed over time? and (2) what are the characteristics of the markets for these technologies? We also answered the same questions for photovoltaic energy technologies. As agreed with your offices, we reviewed DOE's funding and objectives for fiscal years 1978 through 1999.[3] On January 7, 1999, we briefed you on the results of our work and agreed to provide you with this report.

[1]About $7.3 billion of DOE's funding supported other renewable energy technologies, such as geothermal, solar thermal, and biofuels.

[2]In this report, "photovoltaic technologies" include the basic photovoltaic cell that converts sunlight into electricity as well as the combining of cells into photovoltaic panels or systems.

[3]DOE was created in 1977. Prior to passage of the Government Performance and Results Act (GRPA) in 1993, DOE referred to the overall purposes of its wind and photovoltaic programs using several terms, including "goals," "objectives," "purposes," and "outcomes." Since the passage of GPRA, DOE now refers to these purposes as "goals." For consistency with your request, in this report we refer to all of these purposes as objectives.

Results in Brief

Since fiscal year 1978, DOE has been provided more than $3 billion to develop wind and photovoltaic technologies. Since the 1970s, the objectives of the wind and photovoltaic programs have expanded from fundamental research to include larger market shares for U.S. wind turbine companies and increased domestic and international sales by U.S. photovoltaic companies. The markets for wind and photovoltaic technologies have grown rapidly in recent years and now extend internationally.

Wind Energy Technologies

During fiscal years 1978 through 1998, DOE was provided $967 million for wind energy technologies, and it was provided $34.8 million to fund such programs for fiscal year 1999.[4] In the 1970s, the objectives for DOE's wind program emphasized fundamental research on wind, including wind turbine dynamics. In its fiscal year 2000 budget request, DOE's objectives included improving the world market shares of U.S. companies that sell wind energy technologies and increasing the production of wind generated electricity in the United States.

The world market for wind energy technologies has grown dramatically in recent years, is increasingly dominated by international companies and markets, and uses public subsidies to promote sales. Industry sales increased by 29 percent a year from 1994 through 1997 and reached $1.5 billion in 1997.[5] Sales for wind turbines have shifted from the United States to overseas. Over time, the industry has consolidated, and a small number of European companies currently dominate production of wind turbines. Despite significant reductions in cost, wind turbines currently generate electricity at costs that are higher than the costs of traditional generating sources such as natural gas or coal. According to industry representatives, although wind power may be economical in some markets, tax credits and incentive programs are important to increasing wind turbine sales in the United States and internationally.

Photovoltaic Energy Technologies

During fiscal years 1978 through 1998, DOE was provided about $2 billion for photovoltaic technologies, and it was provided $72.2 million to fund such programs for fiscal year 1999. DOE's original objectives were to develop the technology and reduce the cost of generating electricity with photovoltaic cells to levels that are comparable to traditional sources of generation, such as natural gas or coal. In its fiscal year 2000 budget

[4]All DOE's funding totals from fiscal years 1978 through 1998 are in 1998 constant dollars.

[5]The most recent data publicly available at the time of our review.

request, DOE's objectives include increasing the efficiency of photovoltaic panels, reducing costs of production, lengthening the service lives of photovoltaic technologies, and boosting sales by U.S. companies of photovoltaics by more than three-fold.

The market for photovoltaic energy systems is characterized by significant increases in international sales, a dominance of manufacturers owned by large multinational corporations, and the emergence of two distinct types of uses. World sales of photovoltaic technologies increased 16 percent annually from 1985 through 1997 and exceeded $1 billion in 1997. Currently, large multinational companies that produce photovoltaic cells through subsidiaries account for more than half of the world market. The market for photovoltaic technologies is now divided into two types of uses: those that are connected to local electrical powerlines and those that are not connected to the local electrical powerlines. Currently, photovoltaic cells produce electricity at higher costs than traditional electricity delivered through local powerlines. As a result, for uses connected to local electrical powerlines, such as photovoltaic power plants, government subsidies in the United States and other countries are important to promoting sales. In contrast, for uses not connected to powerlines, such as navigation buoys or communication towers, photovoltaic cells can produce electricity at lower costs than what it would cost to connect to the local electric system or generate electricity on-site. Several representatives of the photovoltaic industry stated that these markets would continue without federal R&D funding or other assistance.

Wind Energy Technologies

From 1978 through 1998, DOE was provided over $967 million for R&D on wind energy technologies.[6] DOE's objectives have expanded from an initial emphasis on developing the technology to a current emphasis on increasing the market share of U.S. wind turbine companies. The world market for wind energy technologies has grown significantly in recent years and extends internationally.

Wind Energy Technologies—DOE's Funding and Objectives

From fiscal years 1978 through 1998, direct federal funding for wind energy R&D totaled over $967 million, and the objectives of the wind energy programs have evolved over time. Federal funding has experienced significant variation over these years, and fiscal year 1999 funding has been provided $34.8 million. Early objectives of the wind energy program

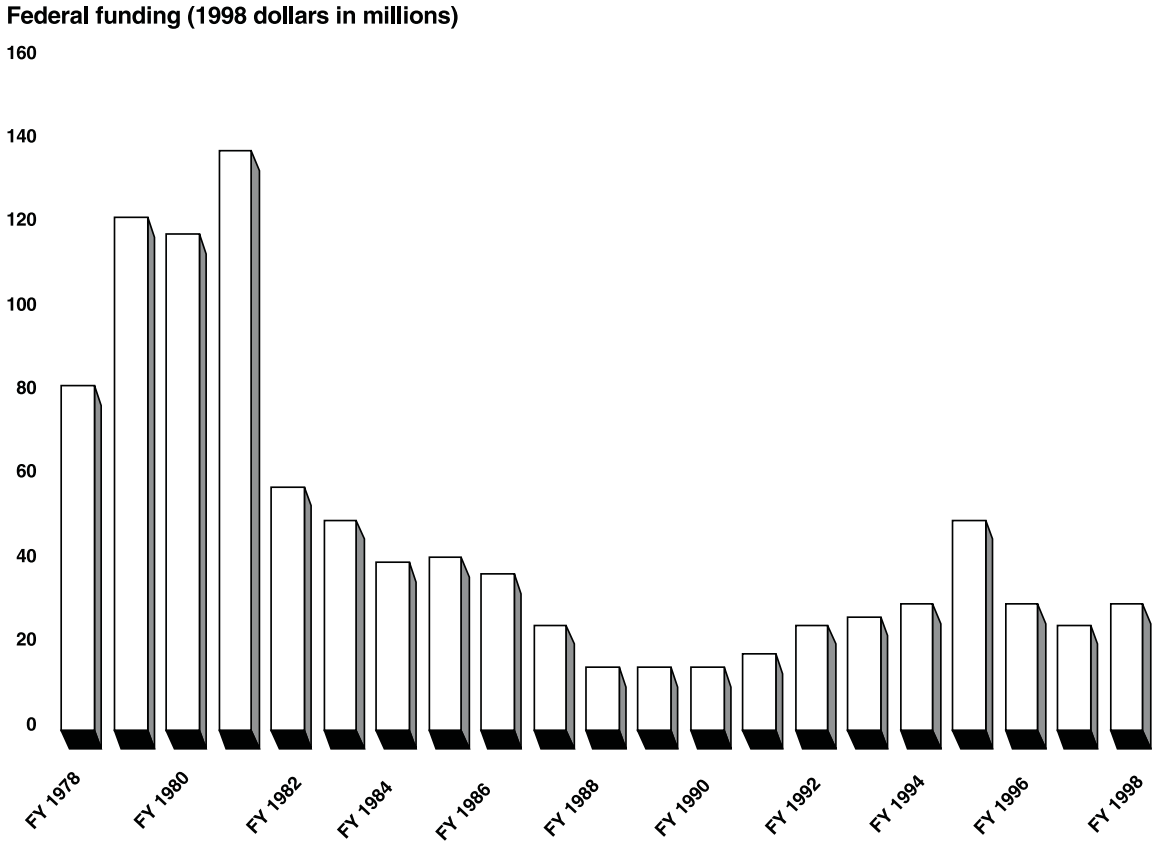
[6]All figures are in 1998 constant dollars.

focused on developing a viable energy supply option and included fundamental research, while the most recent objectives include expanding the market share of U.S. wind turbine companies.

Funding for Wind Energy Technologies Exceeds $967 Million

Since fiscal year 1978, DOE has been provided over $967 million for R&D of wind energy technologies. As shown in figure 1, federal funding for wind energy has been uneven from fiscal year 1978 through fiscal year 1998. Funding over this period peaked during fiscal year 1981, reaching just under $135 million. Since reaching a low of $10.6 million during fiscal year 1990, funding has increased to about $30 million annually for each of the past 3 years.

Figure 1: DOE's Funding for Wind Energy Systems, Fiscal Years 1978 Through 1998



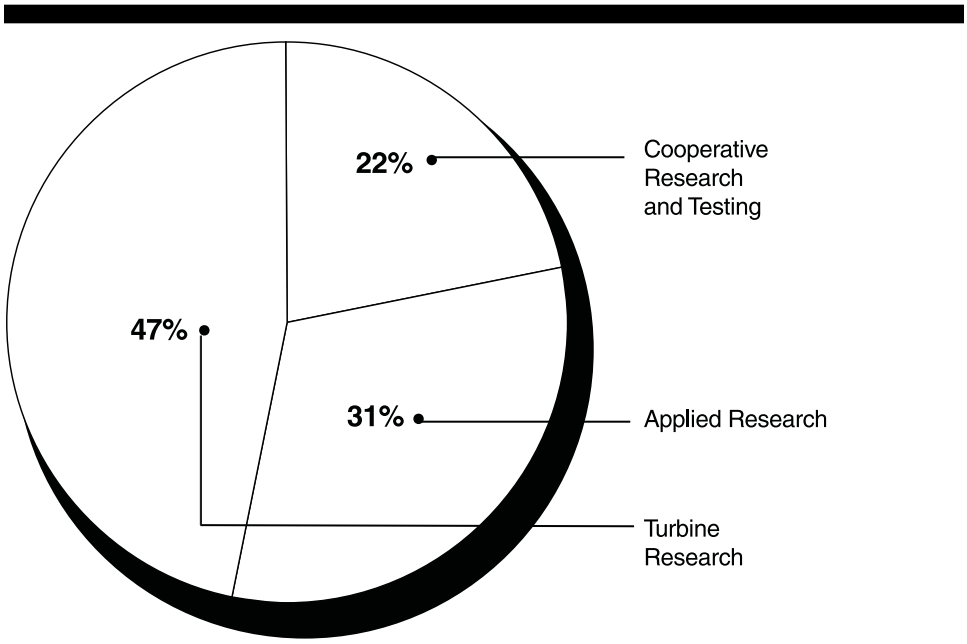
Note: Fiscal year 1978-92 figures represent actual spending. Fiscal year 1993-98 figures represent adjusted or actual appropriations.

Source: Developed by GAO from data provided by DOE.

During fiscal year 1999, DOE has been provided $34.8 million in funding for R&D of wind energy systems and directed these funds towards three specific program areas (see fig. 2). Cooperative Research and Testing ($7.7 million) supports industrial research and federal testing of wind energy technologies. Applied Research ($10.7 million) examines fundamental engineering issues related to component design, manufacturing techniques, and component development (for advanced generators, for instance) and technology improvements. Turbine Research

($16.4 million) works with industry to support the research and testing of large wind turbines that are targeted to current and near-term markets as well as the R&D of small wind turbines. The program is also funding DOE's Next Generation Wind Turbine project, which is attempting to develop a new large-capacity wind turbine.[7]

Figure 2: Planned Funding for Wind Energy Systems, Fiscal Year 1999



Source: Developed by GAO from data provided by DOE.

Objectives of DOE's Wind Energy Program Have Changed

In the 1970s, federal research objectives included wind research and other research that DOE believed industry was unlikely to undertake. In the first 5-year plan, issued in January 1985, DOE characterized the program objectives as improving technology and examining wind energy as a potential energy supply option. Since that time, DOE has expanded the objectives of the wind energy program to include the expansion of the domestic wind industry in the domestic and international markets. More specifically, DOE's current program objectives include (1) enabling U.S. industry to capture 25 percent of worldwide markets for wind-generating

[7]Capacity reflects the amount of electricity an electric generator can produce based on its design.

capacity and (2) achieving 10,000 megawatts (MW)[8] of wind-generating capacity in the United States by 2010.[9]

The Next Generation Wind Turbine Project

As one example of its efforts to reach these objectives, DOE has funded R&D undertaken by two U.S. companies through the Next Generation Wind Turbine project. This project seeks to improve the international competitiveness of the U.S. wind turbine industry. Started in 1997, this project planned to distribute about $30 million over 5 years to develop large utility-scale wind turbines that are capable of lower-cost operation than current turbines manufactured in the United States.

The objectives of the Next Generation Wind Turbine project are to increase the generating capacity and lower the cost of electricity produced by U.S.-manufactured wind turbines. This project is targeted at helping the domestic industry increase the scale of existing turbines from their current range of producing approximately 600-750 kilowatts (kW) to about 1 megawatt (MW). According to DOE and industry representatives, these larger turbines are likely to be become the industry standard. In addition to the objective of developing larger turbines, the Next Generation Wind Turbine project attempts to lower the cost of electricity generated by them. DOE estimates that the cost of generating electricity from current turbines ranges from $0.03 to $0.06 per kWh.[10] The objective of the Next Generation Wind Turbine project is to lower the cost of generating electricity for these new turbines to $0.025 per kWh, in moderate winds. According to DOE officials, at $0.025 per kWh, the cost of electricity generated by wind turbines would be competitive with traditional energy sources, such as coal and natural gas.[11]

The Next Generation Wind Turbine project has awarded contracts to two companies: Zond Energy Systems and The Wind Turbine Company. As shown in figure 3, the first company, Zond Energy Systems, a subsidiary of

[8]A watt is the basic unit used to measure electric power. A kilowatt equals 1,000 watts, and a megawatt equals 1 million watts.

[9]10,000 MW is approximately equivalent to 5 to10 typical coal or nuclear powerplants. Currently, the United States has installed approximately 2,000 MW of wind turbines.

[10]The range of $0.03 to $0.06 per kWh (in 1996 dollars) represents DOE's estimated average costs for current technology wind turbines that, among other things, operate in moderate-to-high-wind areas and are favorably financed.

[11]Some representatives of the energy and financial industries maintain that, even at a comparable cost of production, wind turbines may not compete with traditional generating resources because wind-generated electricity is not always available on demand at any time.

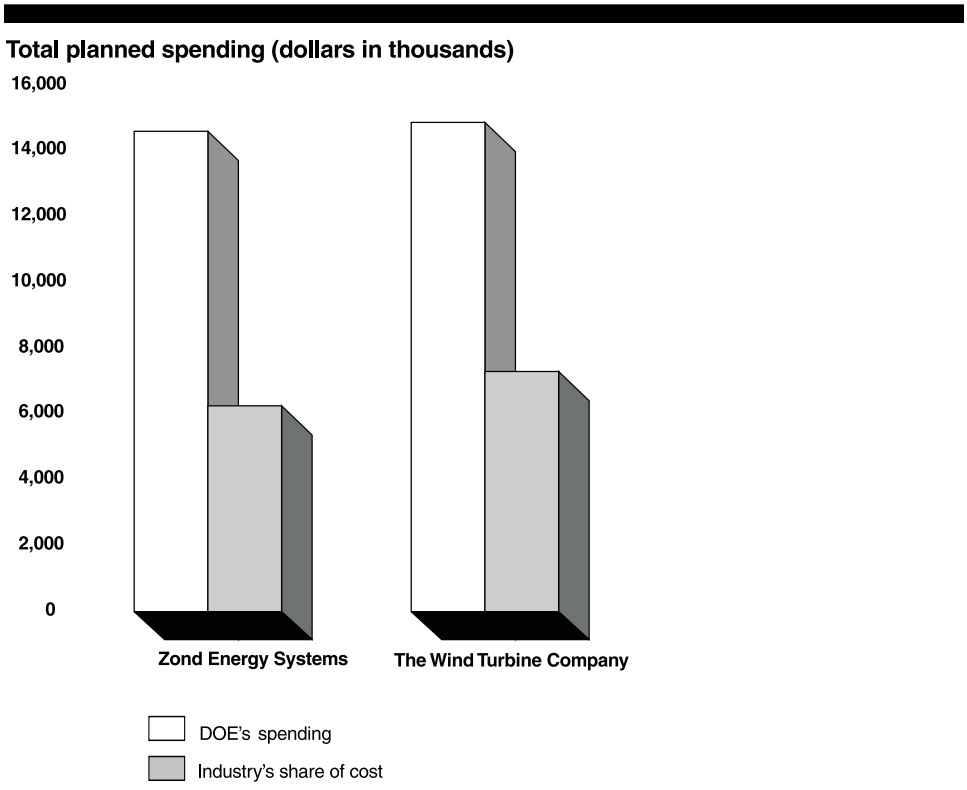
the Enron Corporation,[12] is scheduled to receive about $14.6 million over the next 5 years. Zond is the sole domestic manufacturer of large utility-scale wind turbines. Using DOE funds, Zond is developing a 1 MW turbine that has a design similar to the 750 kW turbines it currently sells.[13]

[12]The Enron Corporation is a U.S. energy company active in the oil, natural gas, electric distribution, electricity generation, and electricity marketing businesses. During 1997, Enron Corporation reported revenues of $20.2 billion.

[13]After we completed the interviews and research for this review, DOE stated that Zond had changed its design. However, DOE would not explain the nature of the new design or how it differed from the existing Zond turbine.

Other companies have already fielded turbines larger than 1 MW.[14] Zond has agreed to spend $6.3 million of its own funds to develop its 1 MW Next Generation turbine design. According to DOE, developing this larger turbine is a financial risk beyond the likely scope of Zond's planned R&D efforts but is required for Zond to remain a viable economic competitor in the industry. Officials at Zond stated that they were not likely to pursue the larger turbine design at this time without DOE's assistance.

Figure 3: Planned Funding for Next Generation Wind Turbine Project, 1997 Through 2003



Source: Developed by GAO from data provided by DOE.

The second company, The Wind Turbine Company, which DOE refers to as "a start-up company," is scheduled to receive $14.9 million from DOE over the next 5 years. The Wind Turbine Company has also agreed to share the development cost of its planned turbine with $7.3 million of non-DOE funds. The Wind Turbine Company's planned turbine is an untested, new design. According to DOE, this turbine has a promising technological design

[14]Tacke Windenergie, another subsidiary of Enron, and NEG Micon each currently sell a 1.5 MW wind turbine.

that will feature a more flexible blade and components that can move in several directions. In choosing to fund The Wind Turbine Company, DOE determined that it was necessary to create at least two other U.S. manufacturers to compete in international markets and help ensure a presence by U.S. companies in the consolidating international wind turbine industry.

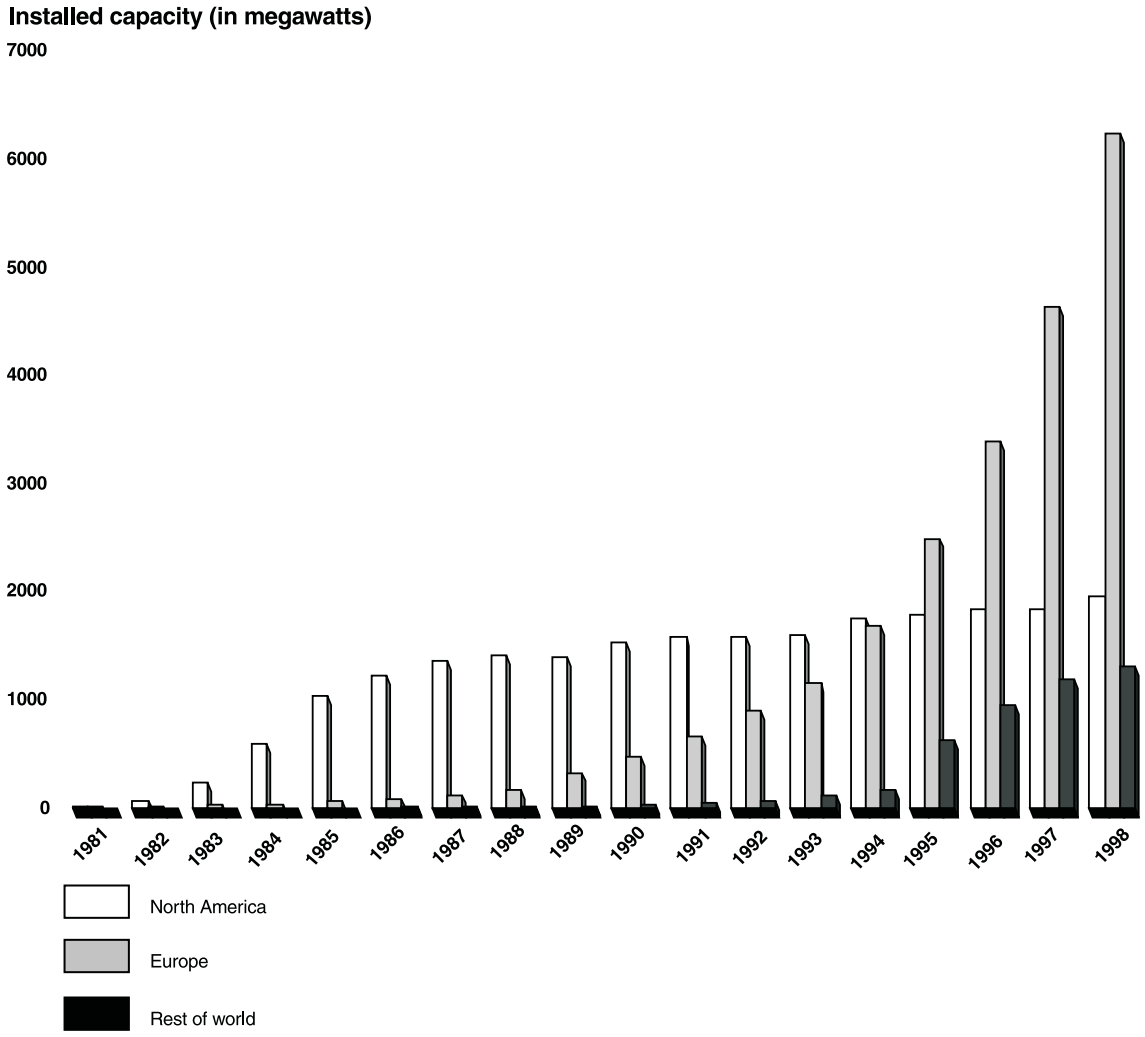
Wind Energy Technologies—Characteristics of the Market

Since DOE began R&D in wind energy, the market for wind turbines has grown significantly, and the industry has changed. The current market for wind turbines is large, and sales extend internationally. European companies currently produce most wind turbines, and the international industry has consolidated during recent years. Although the industry has made significant reductions in costs, the cost of wind-generated electricity in most cases remains higher than traditional sources of generating electricity, such as coal and natural gas. Industry representatives state that public support programs are important to the market for wind turbines.

Sales of Wind Turbines Are Growing Rapidly and Are Concentrated in Europe

Sales of wind turbines have increased dramatically since the beginning of the first federally funded wind energy research. During the early 1970s, sales of wind turbines were limited to small stand-alone systems. In 1973, there were only a few companies selling wind turbines. By 1997, international sales of large-scale wind turbines reached 1,542 MW of capacity and approximately $1.5 billion, and the industry included over 15 manufacturers. From 1994 through 1997, the generating capacity of wind turbines installed worldwide grew at an average rate of 29 percent per year. More recently, the Assistant Secretary for Energy Efficiency and Renewable Energy stated, in his testimony to the Subcommittee on Energy and Water Development, House Committee on Appropriations, that worldwide sales of wind turbines during 1998 exceeded $2 billion.

Figure 4: Installed Capacity of Wind Turbines, 1981 Through 1998



Source: Figure provided by DOE.

Wind turbine purchases have shifted from North America (mostly in the United States) to Europe. Through the mid-1980s, purchases of wind turbines were largely concentrated in the U.S. By 1987, wind turbine generating capacity installed in the United States exceeded 1,300 MW and

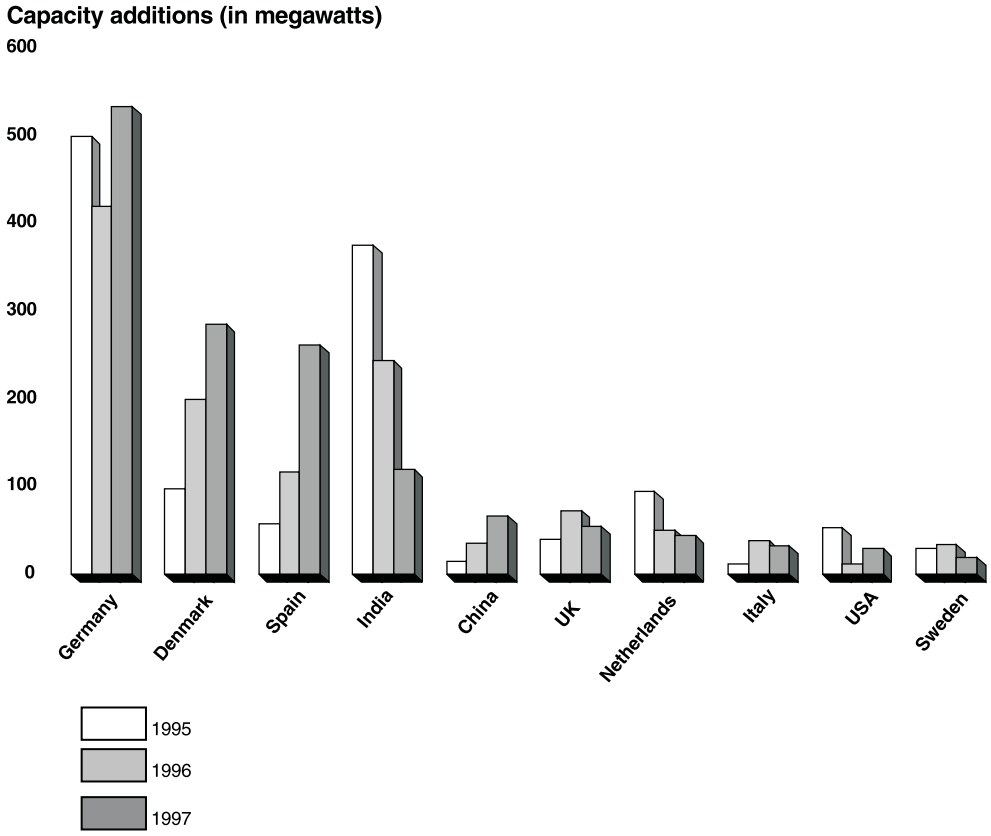
accounted for approximately 90 percent of world capacity.[15] European countries rapidly added generating capacity and exceeded North American installed capacity in 1995 (see fig. 4).

From 1995 through 1997, four countries installed the majority of wind turbine capacity (see fig. 5). For example, in 1997, Germany, Denmark, Spain, and India made over 77 percent of purchases. In contrast, purchases in the United States during that same period were significantly lower. As a result, total generating capacity from wind turbines in the United States is now second in the world to Germany, and both Denmark and India are quickly approaching the level of generating capacity in the United States.

Although worldwide sales of wind turbines have increased significantly, wind-generated electricity contributes only a small share of overall electricity. For example, according to the Energy Information Administration (EIA), wind-generated electricity in the United States accounted for approximately 3.39 billion kWh, or about 0.1 percent of total U.S. electricity in 1997. However, during 1997, wind accounted for approximately 2.3 percent of the total electricity generated in California, where most of the wind turbines are installed in the United States. Recently completed, announced, and planned wind turbine electricity generation includes large capacity additions in California, Iowa, Minnesota, and Texas.

[15]World capacity represents documented electric generation turbines larger than 50 kW.

Figure 5: Annual Capacity Additions in 10 Largest Markets for Wind Turbines, 1995 Through 1997



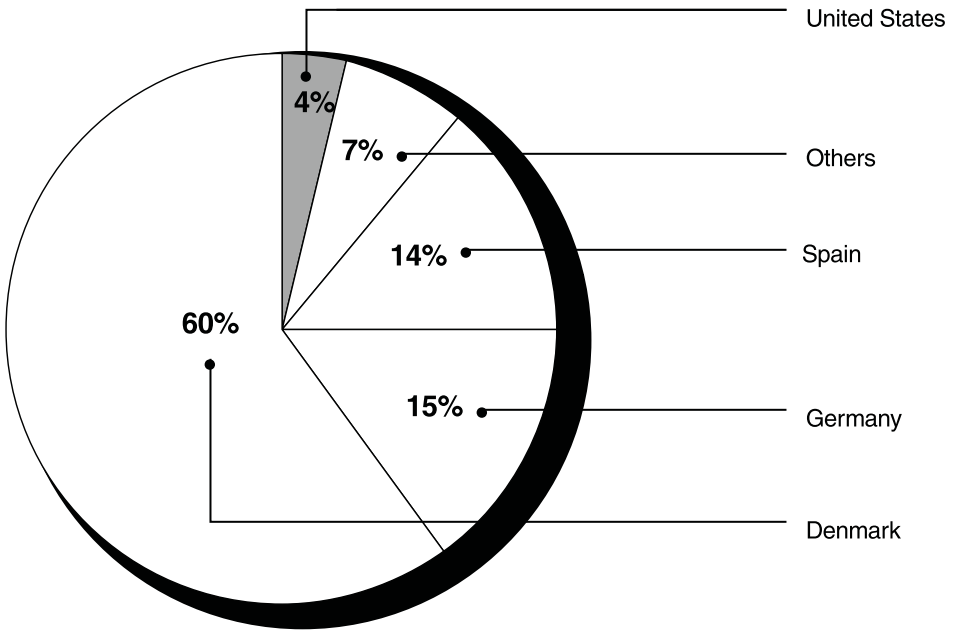
Note: Data based on capacity installations in 1997.

Source: Developed by GAO from data provided by BTM Consult ApS.

Europeans Dominate the Consolidating Wind Turbine Manufacturing Industry

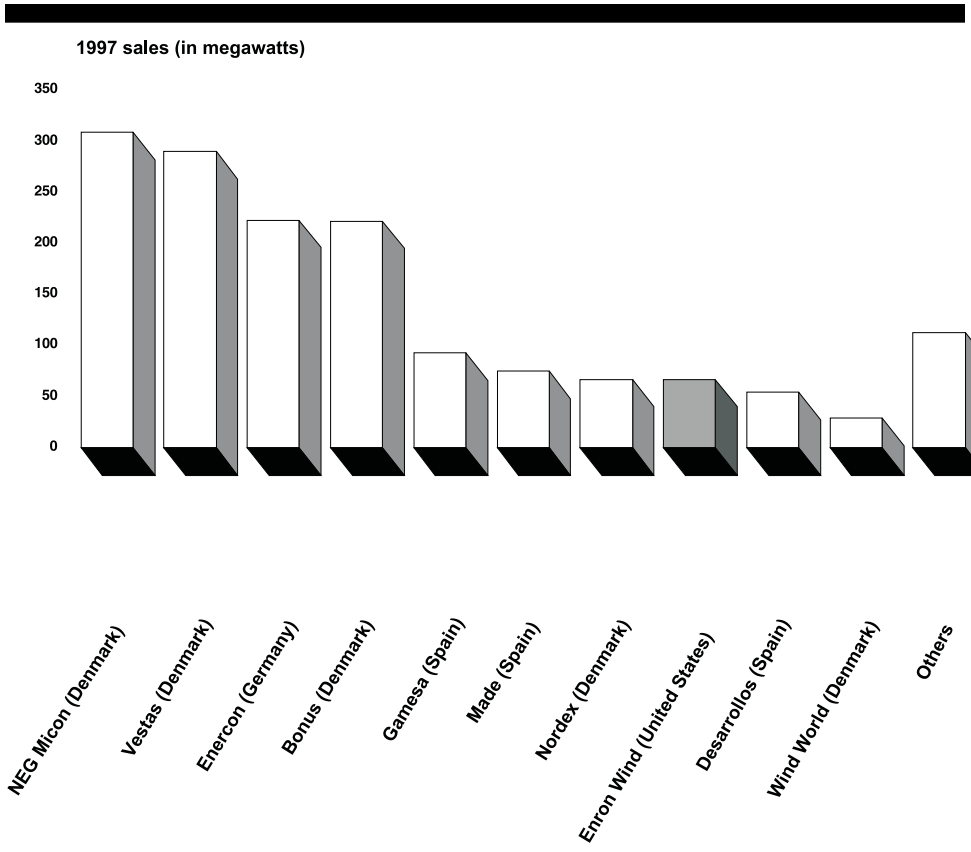
During 1997, European companies dominated the wind turbine manufacturing industry. Figure 6 illustrates that European companies accounted for approximately 90 percent of worldwide sales in 1997. As shown in figure 7, of these, the four largest companies accounted for two-thirds of total worldwide sales during the year.

Figure 6: International Sales of Wind Turbines, by Country, 1997



Source: Developed by GAO from data provided by BTM Consult ApS.

Figure 7: Sales of Wind Turbines for 10 Largest Companies (With Headquarters' Country)**, 1997**



Notes: Companies ranked by total 1997 sales in megawatts.

Data for NEG Micon reflect combined sales for two companies, NEG and Micon, that merged. Data for ENRON Wind reflects combined sales for two companies, Zond Energy and Tacke Windenergie, that Enron purchased.

Source: Developed by GAO from data provided by BTM Consult ApS.

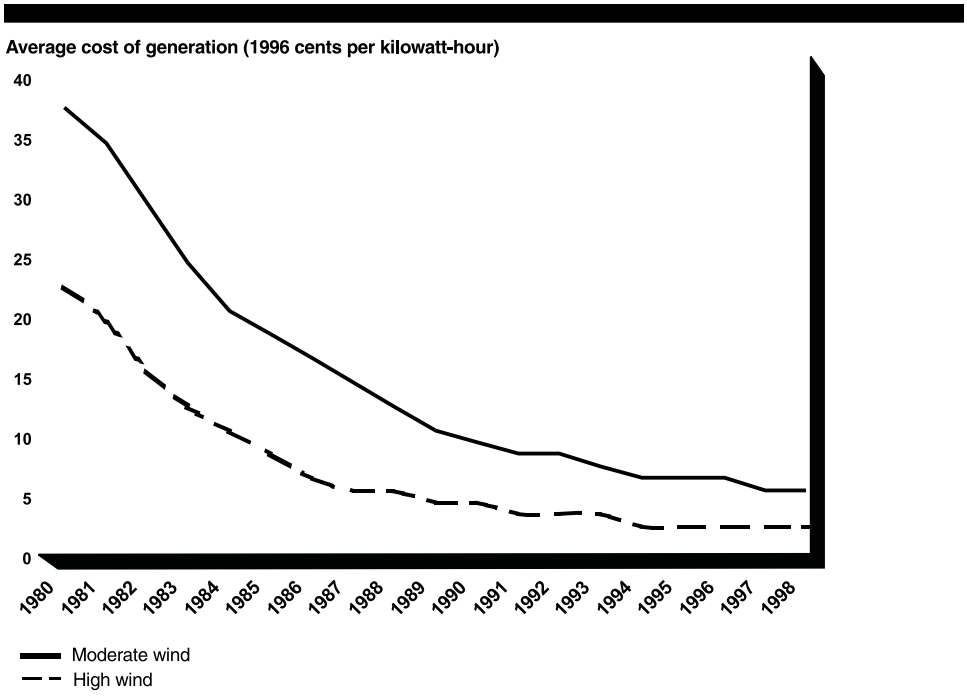
Over the past several years, the wind turbine manufacturing industry has consolidated. Some European companies have merged, acquired a competitor, or filed for bankruptcy. In the United States, the largest domestic wind turbine manufacturer at the time, Kenetech Corporation, filed for bankruptcy protection in 1996 and its assets were ultimately sold. In 1997, another domestic manufacturer, FloWind, filed for bankruptcy protection. As a result of consolidation in the United States, Zond Energy Systems is now the largest domestic wind turbine manufacturer and the

only U.S. company currently manufacturing large-capacity machines, those typically installed by electric-generating companies.

Cost of Production Declining, but Remains High

Since the 1970s, the cost of electricity generated by wind turbines has decreased dramatically. According to DOE officials, costs have decreased from approximately $0.20 to $0.40 per kWh in 1980 to approximately $0.03 to $0.06 per kWh in 1998 (see fig. 8).[16]

Figure 8: Historical Cost of Wind-Generated Electricity, 1981 Through 1998 (Constant 1996 Dollars)



Source: Figure provided by DOE.

[16]The actual cost of electricity from a wind turbine depends on the abundance of usable wind (defined as steady and frequent). The more usable wind available, the more electricity the turbine can generate. This allows the fixed costs of the turbine to be spread across a larger amount of electricity generation, thus lowering the cost of generating per kWh.

As a result of these cost reductions, the cost of wind-generated electricity is more competitive in some markets,[17] but remains more expensive than the 2.5 to 4 cents per kWh cost to generate electricity for some new power plants in the United States.[18] According to industry representatives, greater opportunities exist for wind-generated electricity in some Asian, South American, and African markets.These are typically markets where new electric generation sources are needed quickly and access to fossil fuels is limited. In Europe, although higher costs for electricity make wind-generated electricity more competitive than in the United States, many countries use public initiatives to boost renewable energy. These public initiatives have included publicly funded wind turbine R&D, laws that provide higher prices for power produced using wind turbines, and laws that require power companies to generate a portion of their total power using renewable resources, such as wind. In the United States, where the cost of electricity is lower, industry representatives stated that direct public sector support programs, such as the federal Renewable Energy Production Incentive and state incentive programs,[19] are important in increasing the demand for wind turbines in the United States.

Photovoltaic Energy Technologies

During fiscal years 1978 through 1998, DOE was provided about $2 billion for R&D of photovoltaic energy technologies. DOE's objectives for this program have expanded from an initial emphasis on fundamental research in photovoltaic energy production to explicitly include sales targets for U.S. industry. The markets for photovoltaic technologies have grown in recent years, particularly for uses that are not connected to local electrical powerlines.

[17]Industry sources stated that, for the cost of wind-generated electricity to approach parity with that of traditional generation resources, the turbine must be installed in an area possessing predictable and strong winds, the turbine must be favorably financed, the electricity must be required in areas without immediate access to a nearby existing natural gas line or other fuel supply line, and the costs of connecting the turbine to the local transmission system must not be significant.

[18]This figure represents the average cost of generation for a combined-cycle natural gas power plant based on average regional costs of natural gas and existing technology.

[19]The federal Renewable Energy Production Incentive, which provides a tax credit for electricity generated by renewable energy sources such as wind turbines, was about 1.7 cents per kWh during 1998.

Photovoltaic Energy Technologies—DOE's Funding and Objectives

From fiscal year 1978 through fiscal year 1998, federal funding for DOE's photovoltaic energy R&D exceeded $2 billion,[20] and the objectives of the photovoltaic energy program have evolved over time. Federal funding of the program varied significantly over these years, and fiscal year 1999 funding is expected to equal $72.2 million. Early objectives of the photovoltaic energy program included fundamental research, while the most recent objectives include the increasing sales of photovoltaics by U.S. companies.

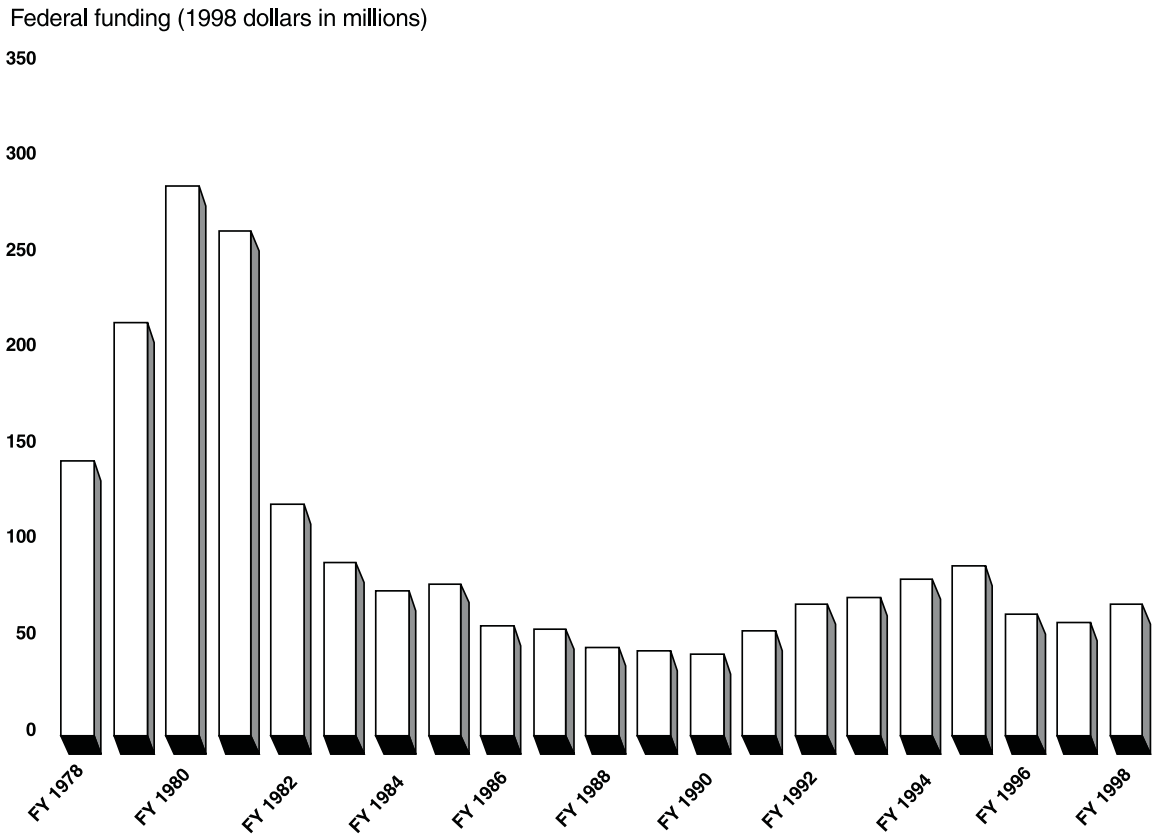
Historical Funding for Photovoltaic Energy Technologies Has Exceeded $2 Billion

During fiscal years 1978 through 1998, DOE was provided over $2 billion for R&D in photovoltaic energy technologies.[21] However, funding has been uneven over this period. As shown in figure 9, funding peaked during fiscal year 1980, reaching $286 million, and was followed by several years of annual decreases. Since reaching a low of $42 million during fiscal year 1990, funding has increased to about $60 million annually during each of the past 4 years.

[20]Research on photovoltaic energy has been funded by several federal agencies, including the National Aeronautical and Space Administration and DOE. This discussion only refers to federal spending through the DOE's Office of Energy Efficiency and Renewable Energy.

[21]Photovoltaic energy systems can consist of solar panels, energy conversion equipment, mounting equipment, and other specialized components. Typical photovoltaic solar panels consist of several photovoltaic solar cells, electrically interconnected and mounted within a glass-covered, sealed, and laminated sheet that is equipped with an electric junction box and placed inside a rigid mounting frame.

Figure 9: Federal (DOE's) **Funding for Photovoltaic Energy Systems, Fiscal Years 1978 Through 1998**

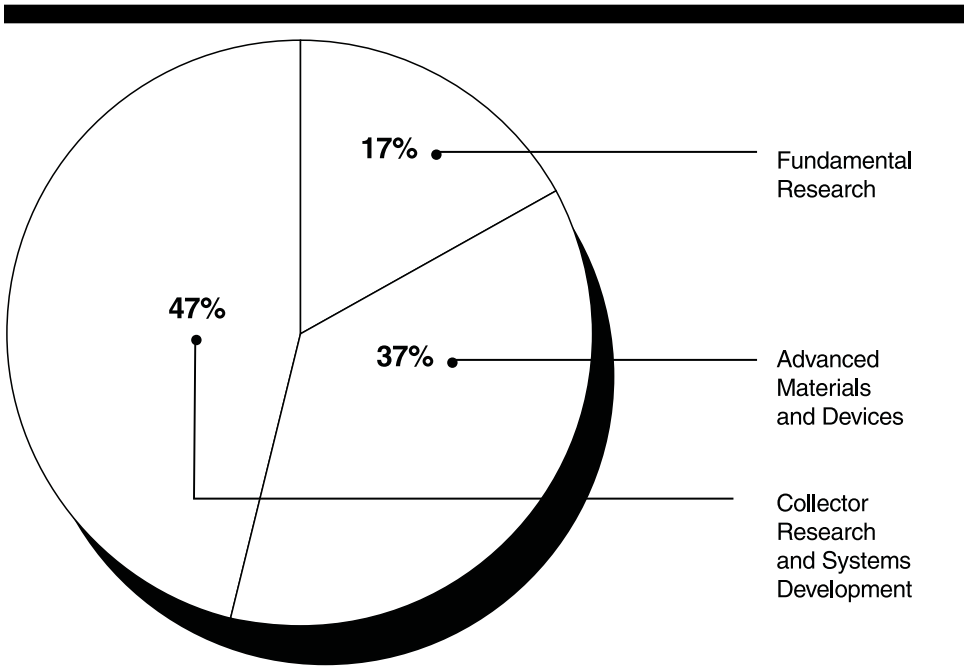


Source: Developed by GAO from data provided by DOE.

During fiscal year 1999, DOE has been provided $72.2 million in funding for research in photovoltaic energy. DOE has directed these funds toward three specific program areas, as figure 10 shows. The Collector Research and Systems Development program area ($34.2 million) supports activities to lower the cost of manufacturing photovoltaic panels, enhance the engineering and field testing of photovoltaic technologies, and develop innovative applications. The Advanced Materials and Devices program area ($27 million) is attempting to achieve technological advances that will enhance the commercial potential of the standard photovoltaic cell

primarily sold today as well as a more advanced photovoltaic technology[22] and products, such as embedding photovoltaic cells into roof shingles. The Fundamental Research program area ($11 million) includes DOE's basic and long-term research programs, unconventional technologies, and projects examining the fundamental properties of cells and cell materials.

Figure 10: Planned Funding for Photovoltaic Energy Systems, Fiscal Year 1999



Note: Total does not equal 100 percent due to independent rounding.

Source: Developed by GAO from data provided by DOE.

Objectives of the Photovoltaic Energy Program Have Changed

In its early years, the objectives of the federal photovoltaic program included fundamental research and emphasized research that industry was unlikely to undertake because of the costs and risks involved. In the first 5-year plan, issued in May 1983, DOE characterized the program's objectives as addressing widely applicable technical issues and developing a technology base from which private U.S. companies could choose to apply within domestic electricity markets. Since that time, DOE has

[22]The most commonly sold photovoltaic cell is made from wafers of crystalline silicon. The newer technology, known as "thin film," requires fewer steps in the manufacturing process, uses less of the expensive raw materials, and may offer significantly improved mass production economics than the silicon wafer technologies. As a result, thin-film technologies may be capable of producing electricity at a lower average cost than silicon wafer-based photovoltaic technologies.

expanded the objectives to explicitly include increasing sales in international markets by U.S. industry. More specifically, DOE's current objectives are to (1) increase efficiency of commercial modules; (2) reduce the retail sales price of modules; (3) increase the lifetime of photovoltaic systems; and, (4) increase the U.S. and international sales of photovoltaics made by U.S. industry.

Photovoltaic Energy Technologies—Characteristics of the Markets

The market for photovoltaic technologies is large and growing. World sales of photovoltaic technologies exceeded $1 billion in 1997 and increased by 16 percent annually from 1985 through 1997. Large multinational companies own photovoltaic-manufacturing subsidiaries that account for a large share of the total world sales. Despite dramatic reductions, the cost of generating electricity with photovoltaic technologies that connect to electrical powerlines remains substantially higher than the cost of traditional generation. However, for many applications not connected to electrical powerlines, such as communications towers, navigational buoys, and roadside signage, photovoltaic technologies can produce electricity at a lower cost than traditional sources of electricity.

Sales of Photovoltaic Technologies Are Large and Growing

The market for photovoltaic technologies has grown dramatically since its earliest beginnings. Although the market for photovoltaic cells once consisted almost solely of space applications such as satellites, a significant market for photovoltaics now exists on earth. In 1975, total sales of photovoltaic cells were less than 300 kW of generating capacity, or enough electricity to power approximately 100 houses.[23] By 1997, international sales of photovoltaic technologies had increased 380-fold to reach 114 MW,[24] and sales, according to an industry official, exceeded approximately $1 billion (see fig.11). [25] From 1985 through 1997, worldwide installed capacity grew an average of 16 percent per year.[26]

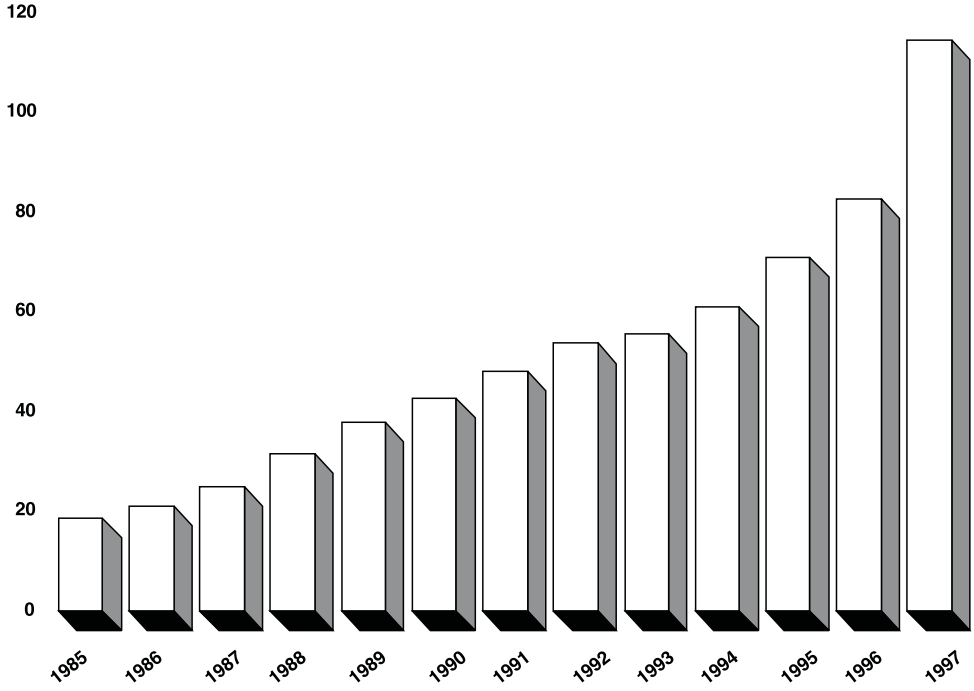
[23]The capability of photovoltaic technologies to supply a specific house varies based on the electricity usage, average annual sun exposure, and a system's efficiency. This figure is an estimate based on a home with relatively low electricity demand, location in an area with high annual solar availability, and assuming current photovoltaic technology.

[24]Data are reported as shipments of photovoltaic modules. In this report, we refer to them as sales.

[25]Total revenues from sales did not increase proportionally with sales because, according to a DOE official, the price of modules decreased significantly as R&D improved the technology.

[26]For uses connected to powerlines, solar technologies (including photovoltaics) generated 900 million kWh or approximately 0.0003 percent of total electricity in the United States. For uses not connected to powerlines, the amount of electricity generated by solar technologies (including photovoltaics) is unknown due to a lack of data.

Figure 11: Sales of Photovoltaic Modules, 1985 Through 1997

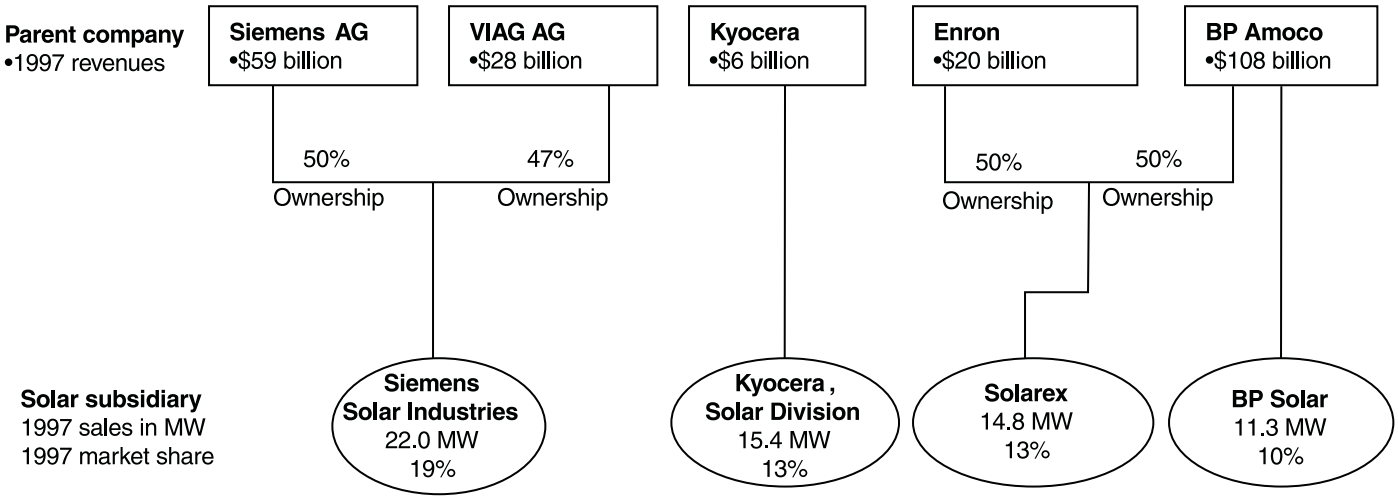


Source: Developed by GAO from data provided by Strategies Unlimited.

Large Multinational Companies Increasingly Dominate the Photovoltaic Industry

Over time, large multinational companies have entered the photovoltaic industry and now dominate the manufacturing portion of the business. In the early 1970s, only a few companies manufactured photovoltaic cells. Since then, several large multinational companies began to invest in the photovoltaic industry. As shown in figure 12, several large companies including Siemens AG, VIAG AG, Kyocera, Enron, and BP Amoco now own subsidiaries that manufacture photovoltaic cells. In 1997, revenues for these large companies from all lines of business, including photovoltaic cells, ranged from about $6 billion (Kyocera) to $108 billion (BP Amoco). Collectively, the subsidiaries accounted for approximately 55 percent of the total sales of photovoltaic cells during 1997.

Figure 12: Major Corporate Ownership of 4 Largest Photovoltaic Companies, With Total Corporate Revenue From All Sources for Corporate Owners



Notes: Information on corporate ownership represents status reported from company sources as of April 1, 1999. The 10 largest sellers of photovoltaic technologies also included Photowatt, Sharp, ASE, Solec International, Astropower, and Sanyo. In total, the 10 largest sellers accounted for approximately 79 percent of total sales in 1997.

The range of publicly available financial data for 1997 was not consistently reported across all companies. Revenue was available for BP Amoco and Enron. Siemens AG and VIAG AG reported sales in Deutsche Marks, which was converted to U.S. dollars. Kyocera reported net sales.

Ownership figures for Siemens Solar Industries do not add to 100 percent due to approximately 3 percent ownership by other entities.

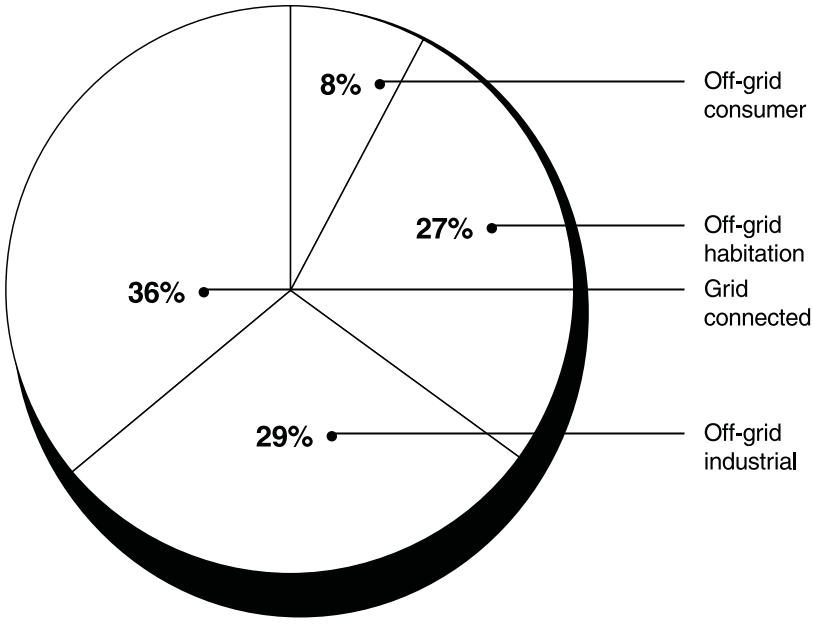
Source: Developed by GAO from data provided by BP Amoco, Enron, Kyocera, Siemens AG, Strategies Unlimited, and VIAG AG.

Connected or Unconnected: The Two Markets for Photovoltaic Technologies

The market for photovoltaic technologies now consists of two distinct types of uses: those that are connected to the local electricity grid (on-grid uses), and those that are not connected to the electricity grid (off-grid uses). Figure 13 shows that in 1997, off-grid applications accounted for about two-thirds of total sales. For either of these uses, DOE stated that photovoltaic cells currently produce electricity at about 25 cents per kWh.[27]

[27]Figure represents DOE's estimate and was not verified by GAO.

Figure 13: Sales of Photovoltaic Modules, by End Use, 1997



Source: Developed by GAO from data provided by DOE.

For on-grid uses, such as a photovoltaic powerplant or rooftop system supplying electricity through powerlines, photovoltaic technologies produce electricity at costs that are significantly higher than the 5 to 12 cents per kWh retail customers typically paid for electricity in 1998.[28] Figure 14—photos provided by the Sacramento Municipal Utility District—shows that there are many examples of on-grid uses of photovoltaic energy. To lower consumers' costs, several countries and some jurisdictions within the United States provide subsidies to those that purchase and install on-grid photovoltaic technologies. However, even with these subsidies, the costs remain above the average cost of power produced from traditional sources, such as coal and natural gas. As a result, photovoltaic industry representatives and government officials view

[28]These figures represent a range of average rates for residential, commercial, and industrial customers. We chose these rates because photovoltaic systems installed on buildings reduce the amount of electricity that would have been purchased by these customers at retail rates.

subsidies as an important way to increase the sales of photovoltaic technologies for on-grid applications.[29]

Figure 14: Examples of On-Grid Uses of Photovoltaic Technologies

A photovoltaic power plant located near the closed Rancho Seco nuclear generating station

A parking lot shaded with photovoltaic panels

A photovoltaic installation atop a church roof in Sacramento, California

A home in Sacramento, California with a rooftop photovoltaic system

[29]However, some industry representatives stated that tax incentives designed to increase the demand for, or production of, on-grid applications of photovoltaic technologies could increase the price of the materials used to make photovoltaic cells. This, in turn, could raise the price of cells and reduce the demand for off-grid applications. DOE officials note that the department's photovoltaic R&D program does not directly subsidize on-grid photovoltaic applications.

For off-grid uses, photovoltaic technologies can provide electricity at a lower cost than the traditional option of extending an electrical line and purchasing power from an electric company or relying on remote generating equipment. These off-grid uses can be located anywhere, even suburban and urban areas. As shown in figure 15, these applications include providing electricity for remote monitoring equipment, such as traffic monitors; roadside signage, such as warning lights; emergency callboxes; communications towers for cellular phones and other devices; as well as homes in remote areas. In these applications, photovoltaic technologies avoid the sometimes substantial costs of extending an electrical line, installing interconnection equipment (such as an electrical transformer), and purchasing the electricity delivered to the site or supporting a remote generator.[30] Several representatives of the photovoltaic industry stated that these markets would continue to grow without federal R&D funding or other assistance.[31]

[30]The cost of supplying electricity to an off-grid use varies significantly depending on a variety of factors, including access to fuel, proximity to existing electrical lines, and physical characteristics of the site.

[31]According to DOE, federal or other public subsidies were not generally available or used to subsidize off-grid installations of photovoltaic systems.

Figure 15: Examples of Off-Grid Uses of Photovoltaic Energy

Traffic monitoring station

School warning lights/signage

Agency Comments and Our Evaluation

We provided this report to DOE for its review and comment. We received comments from the Department, including the Assistant Secretary, Energy Efficiency and Renewable Energy, and have included these comments in appendix I. DOE expressed three major concerns about how we characterized the objectives of its wind energy and photovoltaic programs.

In its first concern, DOE states that we describe DOE's objectives for these programs as promoting sales by the domestic wind energy and photovoltaics industries rather than conducting R&D. We did not mean to suggest that DOE is promoting the domestic wind and photovoltaic industries by marketing or directly selling products. Nor did we mean to suggest that DOE no longer performs R&D. We explain in our report that DOE's recent program objectives include research to support industry by developing technologies that companies in the United States may apply to increase sales or shares in the marketplace. We modified the text to address DOE's concern by clarifying our characterization of DOE's support of industry R&D.

Second, DOE believes our report inaccurately concludes that the objectives for the wind energy and photovoltaic programs have moved away from the development of technologies. The Department then describes the research activities and performance measures that are included in its fiscal year 2000 budget proposals. We did not intend to suggest that DOE no longer develops technologies or performs R&D. We observe that, since the inception of the wind and photovoltaic programs, DOE's objectives have been expanded to include goals for market shares by wind turbine companies and sales by U.S. manufacturers of photovoltaics. In developing this view, we used documents provided by DOE, at our request, during our review. We maintain that the objectives of the programs, as specified in DOE's documentation, have expanded since the late 1970s. We modified the text to address DOE's concern by clarifying our characterization of DOE's prior and current objectives and by illustrating that DOE's objectives have expanded over time to include explicit goals for U.S. wind companies to attain a 25-percent market share and for U.S. photovoltaic companies to reach 1,000 MW in sales.[32]

Third, DOE maintains our assertion that the objectives for these programs have evolved from fundamental research to supporting U.S. industry is not reflected in the Department's fiscal year 2000 budget request. To make its case, the Department cites its fiscal year 2000 budget request to increase its funding for fundamental research on photovoltaics to $ 20.3 million. In response, our report refers to the evolution of DOE's stated objectives, not changes in funding allocations for research in photovoltaics. We did not examine the planned spending proposed in the fiscal year 2000 budget. We examined funding levels from fiscal year 1978 through fiscal year 1998. Nevertheless, although DOE's proposal to allocate $20.3 million for

[32]DOE officials told us that the goals stated in the fiscal year 2000 budget request are technical measures of success rather than program goals. However, since the budget request labels them as goals, we considered them to be goals for our report.

fundamental research in the photovoltaic program represents a significant increase in nominal terms, it represents a modest increase (17 percent in fiscal year 1998 to 22 percent in fiscal year 2000) as a percentage of the program's total spending. We made no change in response to this objection.

In addition, DOE believes that our decision to report DOE's funding of the wind energy and photovoltaics programs in constant 1998 dollars is inappropriate because it inflates the funding values in the initial years of the programs. We maintain our choice was sound. We chose to express DOE's spending in constant dollars because it ensures that a dollar DOE spent on research in wind energy or photovoltaics in 1978 equals a dollar it spent on this research in 1998. Economists generally believe this approach provides a better comparison of spending over time than reporting expenditures in nominal dollars because it adjusts for the general effects of inflation. We made no change in response to this comment.

DOE also provided technical and other editorial comments, which we incorporated as appropriate.

Scope and Methodology

We conducted this analysis from October 1998 through April 1999 in accordance with generally accepted government auditing standards. We reviewed DOE's budget history and other supporting documents as well as interviewed DOE officials in Washington, D.C. and at the National Renewable Energy Laboratory in Colorado. We interviewed representatives and reviewed documents from the wind and photovoltaic industries, the energy industry, the financial community, state and local officials, the wind and solar industry trade associations, as well as industry consultants. In addition, we also reviewed prior GAO analyses of renewable energy, and other studies of wind and solar energy.

As agreed with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 14 days from the date of this letter. At that time, we will send copies of this report to Representatives C.W. Bill Young and David R. Obey, Chairman and Ranking Minority Member, House Committee on Appropriations, respectively; Representatives Ken Calvert and Jerry F. Costello, Chairman and Ranking Minority Member, Subcommittee on Energy and Environment, House Committee on Science, respectively; Representatives Joe Barton and Ralph M. Hall, Chairman and Ranking Minority Member, Subcommittee on Energy and Power, House Committee on Commerce,

respectively; and Representatives Constance A. Morella and James A. Barcia, Chairwoman and Ranking Minority Member, Subcommittee on Technology, House Committee on Science, respectively. We will also send copies of this report to Senators Frank H. Murkowski and Jeff Bingaman, Chairman and Ranking Minority Member, Senate Committee on Energy and Natural Resources, respectively; Senators Pete V. Domenici and Frank R. Lautenberg, Chairman and Ranking Minority Member, Senate Committee on the Budget, respectively; Senators Fred Thompson and Carl Levin, Chairman and Ranking Minority Member, Senate Committee on Governmental Affairs, respectively; and Senators Don Nickles and Bob Graham, Chairman and Ranking Minority Member, Subcommittee on Energy Research, Development, Production, and Regulation, Senate Committee on Energy and Natural Resources, respectively.

If you have any questions or need additional information, please contact me on (202) 512-3841. Major contributors to the report were Daniel Haas, Daren Sweeney, Jon Ludwigson, and Michael Gilbert.

Susan D. Kladiva
Associate Director, Energy,
Resources, and Science Issues

Comments From the Department of Energy

Department of Energy
Washington, DC 20585

April 16, 1999

Ms. Susan Kladiva
Associate Director
Energy, Resource and Science Issues
U.S. General Accounting Office
Washington, DC 20548

Dear Ms. Kladiva:

The Department of Energy appreciates the opportunity to review the General Accounting Office draft report, GAO/RECD 99-130, "RENEWABLE ENERGY: DOE's Funding and Markets for Wind Energy and Solar Cell Technologies."

The report's primary conclusion (p. 2) for the wind and photovoltaic (solar cell) programs is "the objectives of DOE's investment efforts have changed over time moving from developing the technologies to currently promoting U.S. sales of these technologies throughout the world." We find that this conclusion is neither correct nor supported by the text of the report itself which describes the continuing research and development (R&D) activities of these programs.

The primary focus of both the wind and photovoltaic programs has been research and development to reduce the costs and improve the performance of these technologies. GAO itself reported in the report GAO/RECD-97-188, "DOE Solar and Renewable Resource Technologies Program," that funding for both the photovoltaic and wind energy programs is comprised of R&D activities as defined within that report by the following R&D categories: Basic Research, Applied Research/Exploratory Development, Advanced Development/Engineering Development, and Operational Tests/Field Validations. These research and development categories represent technology development efforts that are pre-commercial activities.

The GAO conclusion that the funding of the wind energy and photovoltaic programs has moved away from the development of technologies is not supported by the Department of Energy's FY 2000 Congressional Budget Request for Energy Supply/Solar and Renewable Resources Technologies. Our budget request for the photovoltaic and wind energy programs consists of pre-commercial research and development activities that focus on reducing the cost and improving the performance of these technologies. Our FY 2001- 2006 performance measures for each renewable energy program target planned reductions in the cost of electricity from continued investment in research and development efforts (p. 29). For example, the overall performance metric shown for the research and development efforts of wind energy program is "wind turbines capable of providing electricity at 2.5 cents per kilowatt-hour in good (15 mph) wind regions will be introduced commercially." The budget request provides detailed information on the goals, objectives, performance measures and research and development activities for the photovoltaic (solar cell) program (p. 51-63) and the wind energy program (p. 103-115).

A resulting objective of Federal investments in applied research programs is the subsequent commercialization and utilization of developed technologies by the private sector. It is through the subsequent widespread utilization of these technologies that the Nation derives benefit from Federal investments in research and development. A resulting program objective for Solar and Renewable Resources and Technologies (p. 28) is "to triple the U.S. electricity production capacity of non-hydopower renewable energy systems by 2010."

The achievement of these performance measures from our research and development programs will provide substantial economic, environmental and energy security benefits. The negative impact of the electricity sector on the environment will be reduced through the increased use of these clean power generation technologies. The U.S. economy will be enhanced through the production of renewable energy at a lower cost and the existence of vibrant domestic solar cell and wind energy industries that sell their products in both domestic and international markets. Finally, U.S. energy security will be enhanced through the development of secure domestic energy resources such as wind and solar power.

An additional example of the many inaccuracies and misinterpretations contained in the report is the statement on page 15 of this draft GAO report that "the objectives of the federal programs have evolved from fundamental research in photovoltaic energy to direct support of U.S. industry and specific commercial objectives." This statement is in clear conflict with the Department of Energy's FY 2000 Congressional Budget Request for Energy Supply/Solar and Renewable Resources Technologies, which shows a significant increase in the request for photovoltaic fundamental research for FY 2000 to $20.3 million (p. 55-57). Fundamental research continues to be a critical component of our balanced and integrated research and development efforts to decrease the cost of electricity produced by photovoltaic systems.

Another recurrent problem throughout the report is the mixing of actual historical appropriations for these programs with the historical appropriations adjusted to FY 1998 dollars. For example, the draft report (p. 3) states that from 1978 through 1998, the Department received "about $2 billion for photovoltaic technologies" and "over $967 million for research and development of wind energy technologies." However, the sum of the actual annual appropriations provided for this period of time was approximately $1.5 billion for the photovoltaic program and $673 million for the wind energy program. Therefore, the draft report misleads the reader by inflating past funding levels to 1998 dollars and implying that these funding levels represent the sum of the actual appropriations for this time frame.

We have already provided editorial comments on the draft report for your consideration in preparing the final report. We appreciate the opportunity to work with you on a resolution of these concerns.

Sincerely,

for Dan W. Reicher
Assistant Secretary
Energy Efficiency and Renewable Energy

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