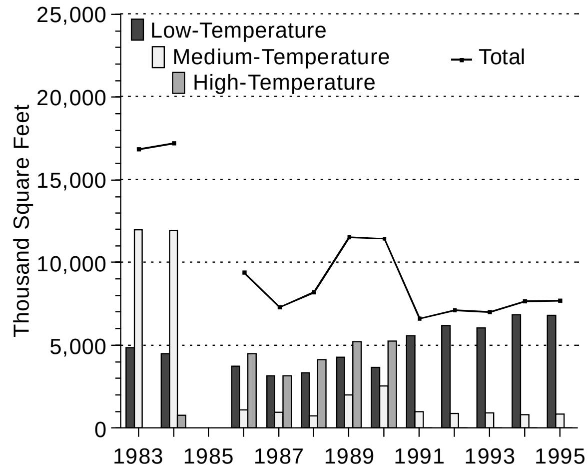
6. Solar Industry Profile

Introduction

The modern solar industry began with the oil embargo of 1973-74 and was strengthened with the second embargo in 1979. The growth of the solar industry during the period of fuel shortages and high prices (1974-1984) soared from 45 solar collector manufacturing firms to 225 firms and from 1.3 million square feet to 17.2 million square feet of production annually. The solar market was helped during this period by government assistance, both Federal and State, mainly in the form of tax credits.

From 1984 to 1986, the number of manufacturing firms in the solar industry declined by 127,[109] probably due to the expiration of the 40-percent residential and 15-percent business energy tax credits. The decline in industrial companies intensified with the drop in oil prices in 1986. The reinstatement of the business energy tax credit at the 15-percent level for 1986, at the 12-percent level for 1987 through 1991, and at the 10-percent level in 1992 and increasing oil prices after 1986 appear to have had little effect on drawing investors and companies into manufacturing solar thermal collectors. Since 1990, the rate of growth of solar collector shipments has stabilized at about 4 percent per year (Table 16 and Figure 18).

Figure 18. Solar Thermal Collector Shipments by Collector Type, 1983-1995



Note: Data for 1985 are incomplete and are not shown.
Sources: **1981-1984:** Energy Information Administration, Form EIA-63, "Annual Solar Thermal Collector and Photovoltaic Module Manufacturers Survey." **1986-1995:** Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Table 16. Annual Shipments of Solar Thermal Collectors, 1986-1995

Year	Number of Companies	Collector Shipments (thousand square feet)[a] Total	Imports	Exports
1986	98	9,360	473	224
1987	59	7,269	691	182
1988	51	8,174	814	158
1989	44	11,482	1,233	461
1990	51	11,409	1,562	245
1991	48	6,574	1,543	332
1992	45	7,086	1,650	316
1993	41	6,968	2,039	411
1994	41	7,627	1,815	405
1995	36	7,666	2,037	530

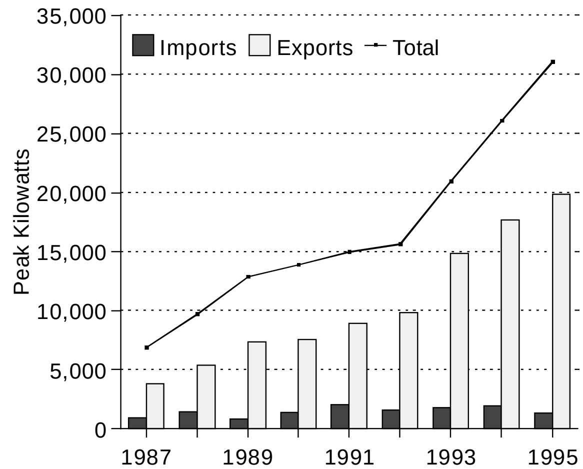
[a]Includes imputation of shipment data to account for nonrespondents.
Note: Total shipments as reported by respondents include all domestic and export shipments and may include imported collectors that subsequently were shipped to domestic or foreign customers.
Source: Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey."

The author of this chapter is Peter Holihan, Renewable Industry Specialist, Energy Information Administration.
[109]Energy Information Administration, *Renewable Energy Annual 1995*, DOE/EIA-0603(95) (Washington, DC, December 1995).

The "solar cell" or photovoltaic cell was discovered in 1954 by Bell Telephone researchers examining the sensitivity of a properly prepared silicon wafer to sunlight. Beginning in the late 1950s, photovoltaics were used to power U.S. space satellites. The success of photovoltaics in space generated commercial applications for photovoltaic technology that continue to be used and developed today.

Export sales continue to drive the expansion of the photovoltaic industry. Total shipments of photovoltaic cells and modules reached 31 peak megawatts in 1995, a 19-percent increase from 1994 (Table 17 and Figure 19). Exports accounted for 64 percent of total shipments in 1995. The value of photovoltaic cell and module shipments grew by 12 percent in 1995 to $118 million, although prices for modules stabilized and prices for cells fell by 17 percent (see Appendix F, Table F18). Shipments for grid-interactive electricity generation doubled, to 4.6 peak megawatts, making 1995 the second straight year in which shipments for this end use have doubled.

Figure 19. Import and Export Shipments of Photovoltaic Cells and Modules, 1987-1995



Note: Total shipments as reported by respondents include all domestic and export shipments and may include imports that subsequently were shipped to domestic or foreign customers.

Source: Energy Information Administration, Form EIA-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Solar Energy Data

Solar Thermal Collectors

Since 1974, approximately 233 million square feet of solar thermal collectors have been shipped for eventual installation in the United States (Table 18). Solar thermal collectors are grouped into three categories: low-temperature, medium-temperature, and high-temperature. Assuming an overall efficiency of 50 percent for all three categories and an average of 1,500 Btu per square foot of daily insolation (solar energy received at the Earth's surface), the potential thermal energy production from the 233 million square feet of solar thermal collectors shipped since 1974 can be estimated at 0.064 quadrillion Btu in 1995. However, this is a simplified approach to the energy calculation. A mildly cloudy day produces about 1,500 Btu of insolation onto an area 1 square foot, but the amount of

Table 17. Annual Shipments of Photovoltaic Cells and Modules, 1985-1995

Year	Number of Companies	Photovoltaic Cell and Module Shipments (Peak Kilowatts)[a]		
		Total	Imports	Exports
1985	15	5,769	285	1,670
1986	17	6,333	678	3,109
1987	17	6,850	921	3,821
1988	14	9,676	1,453	5,358
1989	17	12,825	826	7,363
1990	[b]19	[b]13,837	1,398	7,544
1991	23	14,939	2,059	8,905
1992	21	15,583	1,602	9,823
1993	19	20,951	1,767	14,814
1994	22	26,077	1,960	17,714
1995	24	31,059	1,337	19,871

[a]Does not include shipments of cells and modules for space/satellite applications.
[b]Includes imputed data for one nonrespondent which exited the industry during 1990.
Note: Total shipments as reported by respondents include all domestic and export shipments and may include imported collectors that subsequently were shipped to domestic or foreign customers.
Source: Energy Information Administration, Form EIA-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

Table 18. Annual Photovoltaic and Solar Thermal Shipments, 1974-1995

Year	Domestic Shipments[a]	
	Photovoltaic Cells and Modules (Peak Kilowatts)	Solar Thermal Collectors (Thousand Square Feet)
1974	—	1,274
1975	—	3,743
1976	—	5,801
1977	—	10,312
1978	—	10,020
1979	—	13,396
1980	—	18,283
1981	—	19,362
1982	6,897	18,166
1983	10,717	16,669
1984	7,759	16,843
1985	4,099	[b]19,166
1986	3,224	9,136
1987	3,029	7,087
1988	4,318	8,016
1989	5,462	11,021
1990	6,293	11,164
1991	6,035	6,242
1992	5,760	6,770
1993	6,137	6,557
1994	8,363	7,222
1995	11,188	7,136
Total	**89,281**	**233,386**

[a]Total shipments minus export shipments.
[b]Estimated data.
— = Not available.

Sources: **1974-1977:** Federal Energy Administration telephone survey. **1978-1984:** Energy Information Administration, Form EIA-63, "Annual Solar Thermal Collector and Photovoltaic Module Manufacturers Survey." **1985-1995**: Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey," and Form EIA-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey."

energy received varies with the changing weather conditions. Retirements are taken into account based on a 20-year average life for collectors, but their impact is minimal because few installed collectors have been in service for 20 years.

U.S. nonutility power producers reported installed capacity of 354 megawatts in 1995, with gross electricity generation of 824 million kilowatthours (equivalent to 0.8 trillion Btu of thermal energy) from solar thermal electric systems.[110] Nine operating Solar Electric Generating System (SEGS) plants in southern California—SEGS I through IX—accounted for 98 percent (347 megawatts) of the total nonutility solar generating capacity. Nine separate SEGS plants have been constructed by Luz International, Ltd., since 1984. In 1991 Luz ran into financial trouble and filed for Chapter 7 bankruptcy, and the operation of the SEGS plants was taken over by an investor group. A tenth SEGS plant, planned in 1991, was never constructed.

During Luz's existence, the cost of solar electricity was cut from 25 cents per kilowatthour to less than 8 cents per kilowatthour.[111] SEGS failed economically because: (1) natural gas prices and electricity costs did not rise as expected; (2) operating and maintenance costs for the station did not decline as rapidly as had been expected; and (3) key tax incentives were expiring or uncertain.

The newly renovated Solar Two solar thermal electric generating station, located in California's Mojave

[110]Energy Information Administration, Form EIA-867, "Annual Nonutility Power Producers Report."
[111]D. Escobedo, "Luz Blames Government for Bankruptcy Filings," *Public Utilities Fortnightly*, Vol. 129, No.2 (January 15, 1992).

Desert, consists of 1,900 motorized mirrors surrounding a generating station with 10 megawatts of capacity, which began operation in early 1996. It is part of an effort to build a commercially viable 100-megawatt solar thermal system by 2000 (see box).

Solar Two Solar Thermal Generating Station

The 10-megawatt Solar Two solar thermal electric plant near Barstow, CA, began operation in early 1996 on the site of the Solar One plant. Solar Two differs from Solar One primarily in that it includes a molten-salt storage system, which allows for several hours of baseload power generation when the sun is not shining. The molten salt (an environmentally benign combination of sodium nitrate and potassium nitrate) allows a summer capacity factor as high as 60 percent, compared with 25 percent without storage. The plant consists of 1,926 motorized mirrors focused on a 300-foot-high central receiver generating station rated at 10 megawatts. Molten salt from the "cold" salt tank (at 550°F) is heated to 1,050°F and stored in the "hot" salt tank. Later the hot salt is passed through a steam generator to produce steam for a conventional steam turbine.

A consortium comprising the U.S. Department of Energy, seven electric utilities (led by Southern California Edison), and several other companies and energy organizations is financing the demonstration. The cost of the plant is approximately $40 million for construction and $9 million for 3 years of testing and operation (1996-1998). In addition, land and reused structures from the Solar One facility, estimated to have a value of $140 million, are part of the project.

Photovoltaic Cells and Modules

Since 1982, approximately 89 peak megawatts of photovoltaic cells and modules have been shipped for eventual installation in the United States (Table 18).[112] Assuming a 27.5-percent capacity factor,[113] the potential energy production in 1995 from the 89 peak megawatts was about 214,400 megawatthours of electricity, which is equivalent to 0.001 quadrillion Btu of thermal energy. Retirements had no impact since data collection began in 1984.

U.S. electric utilities reported 3.9 million kilowatthours of net electricity generation from photovoltaic modules in 1995 (Table 19).[114] Of this total, 93 percent was generated in California (70 percent from a single plant). Estimated U.S. total electricity generation was 968.8 million kilowatthours in 1995, and overall estimated energy production in the United States was 71.23 quadrillion Btu (Table 20).

Federal and State Incentives

The Energy Policy Act of 1992 (EPACT), Section 1916, provides a permanent extension of the energy investment tax credit for solar property retroactive to June 30, 1992. Investors in or purchasers of qualified solar energy property can take the credit on up to 10 percent of the investment or purchase price and installment amount. Section 1212 applies an electricity production incentive of 1.5 cents per kilowatthour for solar energy generation sold by municipal electric utilities, rural cooperative utilities, and other public agencies.

At the end of 1995, approximately 30 States had official policies encouraging the development of solar energy and provided financial incentives for investment in the use of solar thermal collectors and photovoltaic modules and cells.[115] Three States—Hawaii, Iowa, and Washington—approved financial incentives during 1996. The legislative actions were passed to encourage the use of an environmentally clean source of energy, to promote energy conservation through the use of renewable energy technologies, and to promote energy efficiency. Among the most common incentives were property tax exemptions and income tax credits for both the residential and business sectors.

Technology Characterization

Solar energy technologies are separated into two major classifications by type of energy used: solar thermal devices, which use the sun's heat, and photovoltaic cells and modules, which use the energy inherent in solar photons and convert it directly to electricity.

[112]Energy Information Administration, *Renewable Energy Annual 1995*, DOE/EIA-0603(95) (Washington, DC, December 1995).
[113]US Department of Energy, "The Potential of Renewable Energy: An Interlaboratory White Paper" (Washington, DC, March 1990), p. G-5.
[114]Net generation is gross generation minus plant use.
[115]M.H. Brown and B. Foster, *State Incentives for Renewable Energy Resources that Generate Electricity* (Draft) (Denver, CO: National Conference of State Legislatures, August 7, 1996).

Table 19. U.S. Utility Net Electric Generation from Solar Energy, 1995
(Thousand Kilowatthours)

Utility	Plant (State)	Net Generation
Sacramento Municipal Utility District	Solar (California)	2,753
Austin Electric	Decker Creek (Texas)	253
Pacific Gas & Electric	PVUSA 1 (California)	900
Virginia Electric Power	North Anna (Virginia)	3
Total		**3,909**

Source: Energy Information Administration, *Electric Power Monthly,* DOE/EIA-0226(93/04) (Washington, DC, April 1996), Table 58.

Table 20. Estimated U.S. Solar and Total Energy Production, 1995
(Quadrillion Btu)

Activity, Production Sector, and Solar Energy Resource	Energy Production
Solar Energy Production To Generate Electricity	
Electric Utilities: Photovoltaic	<0.005
Nonutility Power Producers: Solar Thermal-Electric	0.01
End Users: Photovoltaic	<0.005
Solar Energy Production To Generate Thermal Energy	
End Users: Solar Thermal	0.06
Estimated Total U.S. Solar Energy Production	**0.07**
Adjusted Total U.S. Energy Production Estimate[a]	**71.23**

[a]Adjusted total is the sum of EIA's total energy production data of 71.16 quadrillion Btu (*Annual Energy Review 1995*, Table 1.2) and estimated solar energy production of 0.07 quadrillion Btu.

Source: Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey," Form EIA-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey," Form EIA-759, "Monthly Power Plant Report," and *Annual Energy Review 1995*, DOE/EIA-0384(95) (Washington, DC, July 1995), Tables 1.2 and 8.12.

Solar Thermal

Solar thermal systems collect the thermal energy in solar radiation for direct use in low- to high-temperature thermal applications. High-temperature solar thermal electric technologies work by concentrating large amounts of sunlight onto a smaller area to achieve high temperatures, which are then converted to electricity by various means, including conventional steam-cycle technology. High-temperature applications operate at temperatures above 180°F.

The leading solar thermal electric technology is the parabolic trough, which focuses sunlight on a tube that carries a heat-absorbing fluid, usually oil. The fluid is circulated through a boiler, where its heat is used to boil water to steam, and the steam is routed to a turbine to generate electricity. More than 350 megawatts of parabolic-trough electric generating capacity, connected to the Southern California Edison Company (SCE) utility grid, is operating in California's Mojave Desert.

Central-receiver technology plants use a field of mirrors to focus the sun's energy on a central receiver, which is mounted on a tower. An experimental 10-megawatt central receiver power plant, Solar One, was built and operated in Barstow, California, during the 1980s by a government-industry team. A newly refurbished plant, Solar Two, with an improved conversion technology, began operations in early 1996. Improvements in Solar Two relative to Solar One include a higher efficiency receiver system and high efficiency/low cost thermal energy storage. The receiver transfers the solar energy to a molten-salt liquid, which flows through tubes located in the receiver and then either directly to a tank located at the bottom of the tower for storage or to a heat exchanger to produce steam for electric output. Storage greatly enhances the attractiveness of this technology, in that it allows utilities to schedule electricity at times when the sun is not shining and eliminates disruptions in the plant output due to temporary cloud conditions. Solar Two is designed as a pilot-scale proof of concept, not a cost-competitive prototype (see box on page 52).

The third solar thermal electric technology, the dish/engine system, comprises a parabolic concentrator (dish), a thermal receiver, and a heat engine/generator. The system operates by tracking the sun and reflecting the solar energy to the focus of the dish, where it is

Solar Two, the Nation's second pilot power tower, located near Barstow, CA.

absorbed by the receiver. The absorbed heat is then transferred by the receiver working fluid (often liquid sodium) to the engine/generator. The typical engine used in these systems is the Stirling engine. Dish/engine modules can range in size from about 5 to 40 kilowatts; multiple dishes can be used to form power plants of any size. Dish/engine technology has been demonstrated in a variety of complete systems over the past dozen years, and may move into early commercial applications in the next few years.

Low-temperature solar collectors provide heat up to 110°F through either metallic or nonmetallic absorbers. Low-temperature solar applications include the heating of water for swimming pools.

Medium-temperature collectors provide heat greater than 110°F (usually 140 to 180) through glazed flat-plate collectors that use air either or liquid as the heat transfer medium. Medium-temperature collectors are used for water, space, and process heating. Evacuated tube collectors are included in this category.

Photovoltaic Cells and Modules

Photovoltaic energy technology involves the direct conversion of light into electricity by means of a solid-state device, the photovoltaic cell, which converts sunlight into electricity. Sunlight is composed of photons, infinitesimally small packets of radiant energy. When photons strike a photovoltaic cell, some packets are absorbed, generating electricity. The energy of a photon is transferred to an electron in an atom of the semiconductor device. The cell is composed of thin layers of semiconductor material that produce electricity when exposed to light. When electrical contacts are attached to the layers and the circuit is completed, an electrical current flows. To protect them from the environment, cells are linked together and encapsulated in modules, which are used in various applications.

Photovoltaic technology options can be divided into two categories: cell technology and module/array technology. Photovoltaic cell technologies include single-crystal Czochralski silicon, semicrystalline silicon, polycrystalline thin-film, and amorphous silicon. Photovoltaic module/array technologies include flat-plate and concentrator modules. The most common photovoltaic cells are made from single crystal silicon wafers. During 1995. U.S. shipments of single-crystal silicon cells and modules amounted to 19.9 million peak kilowatts, or a 63-percent market share, up from a 54-percent market share in 1990. Polycrystalline silicon cells are made by cast and ribbon production techniques. In 1995 they garnered a 31-percent market share, down from 36 percent in 1990. Amorphous silicon cells are based on amorphous silicon thin film, made from layers of randomly arranged noncrystalline silicon material deposited on a glass or other substrate, through a continuous and inexpensive process. U.S. shipments of amorphous silicon cells in 1995 were 1.3 million peak kilowatts or 4 percent of total shipments.

Photovoltaic modules are composed of an integrated array of photovoltaic cells assembled into a flat panel. The cell surface is encapsulated with a transparent covering that transmits sunlight to the cell and protects the cell from water and dirt damage. Concentrator arrays consist of one or more lenses that focus and concentrate incident sunlight on one or more photovoltaic cells.

Industry Activity in 1995

The following paragraphs present a summary of 1995 activity in the U.S. solar energy industry, based on data collected by the Energy Information Administration on Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey," and Form EIA-63B, "Annual Photovoltaic Module/Cell Manufacturers Survey." Detailed data from the surveys are presented in Appendix F, "Additional Solar and Photovoltaic Data Tables." The tables in Appendix F are referenced below.

Solar Thermal Collectors

In 1995, 36 companies were active in the solar thermal collector manufacturing industry, a decline of 12 percent from 1994. They shipped collectors totaling approximately 7.7 million square feet during the year (Table 16), a 1-percent increase from 1994. Six companies were planning to introduce new low-temperature collectors, 13 were planning new medium-temperature collectors, and 6 were planning to introduce new high-temperature collectors in 1996 (Appendix F, Table F1).

Since 1987, the 10 largest U.S. companies that shipped solar thermal collectors have supplied not less than 95 percent of all solar thermal collectors manufactured in or imported into the United States (Table F2). In 1995, 96 percent of the approximately 7.7 million square feet of total shipments were supplied by the 10 largest companies. In the period 1982 to 1984, the average share of the 10 largest companies was 50 percent of total shipments.

In 1995 employment in solar-thermal-related activities decreased to 386 person-years, a 4-percent drop from the 1994 employment level of 402 person-years. Industry employment data for 1992 through 1995 are as follows:

Year	Person-Years Expended
1992	449
1993	392
1994	402
1995	386

Most of the 36 reporting companies in 1995 combined manufacturing and related activities with imports of solar thermal collectors:

- A total of 28 companies were involved in design of collectors or systems, 17 were developing prototype collectors, and 13 were developing prototype systems (Table F3).
- There were 24 wholesale companies and 16 retail companies. Of the 36 companies, 15 offered installation of their collectors.

Solar-related sales represented 90 to 100 percent of total company sales for 22 companies in 1995, up from 24 companies in 1994 (Table F4). Solar-related sales made up less than 10 percent of total sales for 4 companies in 1995, compared with 3 companies in 1994.

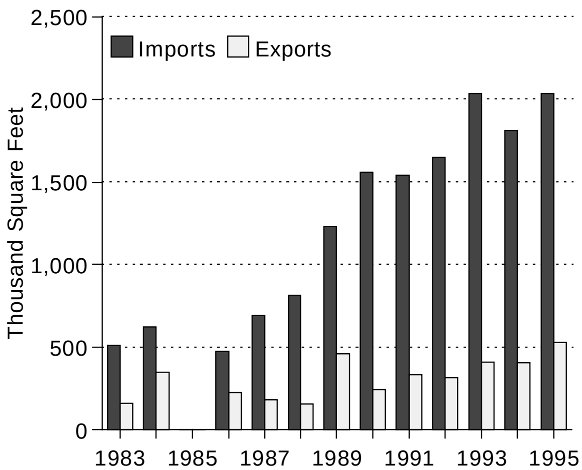
Shipments

Solar thermal collector shipments totaled approximately 7.7 million square feet in 1995, a 1-percent increase from the 1994 level of approximately 7.6 million square feet (Table 16). Import shipments totaled 2.0 million square feet and export shipments were 0.5 million square feet in 1995 (Figure 20). Shipments of low-temperature solar thermal collectors were roughly constant in 1994 and 1995 at about 6.8 million square feet (Figure 18 and Table F5). Shipments of medium-temperature collectors increased by 5 percent to 0.84 million square feet in 1995 from 0.80 million square feet in 1994. Shipments of high-temperature collectors increased from 2,000 square feet in 1994 to 13,000 square feet in 1995 (Table F5).

Origins

U.S. manufacturers in California, New York, New Jersey, Florida, and Puerto Rico produced 89 percent of

Figure 20. Import and Export Shipments of Solar Thermal Collectors, 1983-1995



Notes: Total shipments as reported by respondents include all domestic and export shipments and may include imports that subsequently were shipped to domestic or foreign customers. Data for 1985 are incomplete and are not shown.

Sources: **1981-1984:** Energy Information Administration, Form EIA-63, "Annual Solar Thermal Collector and Photovoltaic Module Manufacturers Survey." **1986-1995:** Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey."

U.S.-manufactured collectors in 1995, the same as in 1994. California continued to lead the Nation in 1995 with 32 percent of total domestic shipments. Shipments of U.S.-manufactured solar thermal collectors in 1995, which totaled 4.9 million square feet, originated from 17 States and Puerto Rico. Florida received the largest number of collectors, 50 percent of shipments (Table F6). New York, New Jersey, and Puerto Rico shipped a combined 2.7 million square feet in 1995.

Distribution

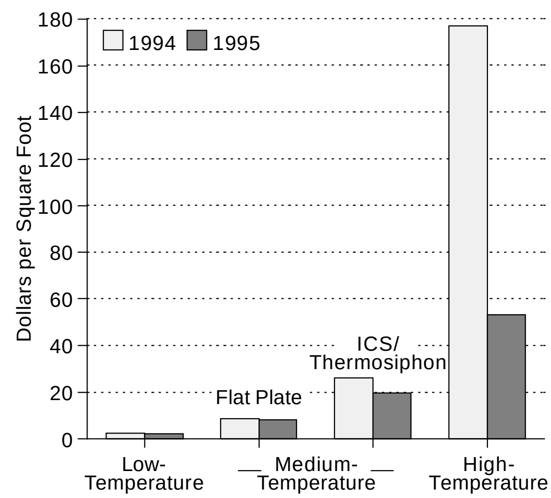
Of total shipments in 1995, 69 percent were sent directly to wholesale distributors and 22 percent were sent to retail distributors (Table F7). Of export shipments, 53 percent were sent directly to exporters. Direct shipments to installers, end users, and others accounted for 6 percent of total shipments in 1995.

Quantity, Values, and Prices

Low-temperature collectors dominated the solar thermal industry in 1995, accounting for 89 percent of total shipments (Table F5). Medium-temperature collectors accounted for 11 percent of total collector shipments in 1995. Flat-plate (medium-temperature) collectors represented 9 percent of total shipments. High-temperature collectors, shipped primarily for research and demonstration projects, represented less than 1 percent of total shipments in 1995.

The total value of solar thermal collector shipments was $25.2 million in 1995, an 11-percent decrease compared with 1994 (Table F8). The average price of low-temperature collectors decreased to $2.31 from $2.53 (dollars per square foot), and the average price of internal collector storage (ICS) and thermosiphon collectors decreased to $19.73 in 1995 from $26.10 in 1994 (Figure 21). This decrease was due primarily to decreased material costs. The average price for flat-plate collectors in 1995 decreased to $8.09 from the corresponding 1994 level of $8.79 per square foot.[116]

Figure 21. Average Price of Solar Thermal Collector Shipments by Collector Type, 1994 and 1995



Note: See Appendix F, Table F6, for data values.

Source: Energy Information Administration, Form EIA-63A, "Annual Solar Thermal Collector Manufacturers Survey."

Markets

In 1993, the residential sector was the largest market for solar thermal collectors. Solar thermal collectors shipped to the residential sector in 1995 totaled 7.0 million square feet, 91 percent of total shipments (Table F9). This market sector primarily involves the use of low-temperature solar collectors for heating swimming pools and medium-temperature collectors for water heating in residential buildings. The residential sector was also the largest market in 1994. The second-largest

[116]The value of shipments includes charges for advertising and warranties. Excise taxes and the cost of freight or transportation for the shipments are excluded.

market for solar thermal collectors in 1995 was the commercial sector, which accounted for 8 percent of total shipments.

Uses

The largest end use for solar thermal collectors shipped in 1995 was for heating swimming pools, representing 88 percent of the total square feet shipped, or 6.8 million square feet (Table F9). This application usually involves the use of low-temperature collectors. A common low-temperature pool-heating solar collector is a black plastic or rubber-like sheet with tubing through which water is circulated. The heat of the sun is transferred directly from the black absorbing material to the water circulating through the tubing to supply heat to the pool. Shipments for pool heating decreased by 1 percent in 1995 from the level reported in 1994.

The second-largest end use in 1995 was for domestic hot water systems, which accounted for 10 percent of the total square feet shipped, or 0.8 million square feet. Typical solar water-heating systems feature flat-plate collectors or collectors installed in an ICS or thermosiphon system. Unlike pool-heating systems, domestic solar water-heating systems nearly always have a conventional backup (i.e., gas or electric). Shipments in 1995 for hot water systems decreased by 4 percent from the 1994 level. Medium-temperature collectors also were shipped for space heating, and for installation into systems that provide both space and water heating and process heating. High-temperature parabolic dish and trough collectors were shipped for electricity generation and other end uses in 1995.

Destinations

Domestic. Solar thermal collectors were shipped to 41 States, Puerto Rico, and the U.S. Virgin Islands in 1995 (Table F10). In 1994, 42 States received collector shipments. The four States and one U.S. territory that received the largest amounts of solar thermal collectors in 1995 were Florida (50 percent), California (20 percent), Arizona (4 percent), Hawaii (3 percent), and Puerto Rico (2 percent) (Table F6). All of the collectors manufactured in Puerto Rico remained on the island. The U.S. market for solar thermal collectors continued to be highly concentrated in a few States and Puerto Rico. Factors favorable for solar energy use that these States and Puerto Rico have in common are: (1) good solar insolation; (2) high electricity costs; (3) solar-promoting incentives, such as tax credits or exemptions; and (4) a demand for low-technology solar pool heaters and solar domestic hot water systems.

Exports. Exports accounted for 7 percent of total shipments in 1995. A total of 19 companies exported solar thermal collectors in 1995, compared with 16 companies in 1994. Low-temperature collectors accounted for 24 percent and medium-temperature collectors 73 percent of 1995 exports. By region, the largest percentages of shipments were to the Americas (52 percent), followed by Asia and the Middle East (19 percent) and Europe (23 percent) (Table F11). Trading countries that received export shipments were Taiwan (15 percent), Japan (10 percent), Australia (9 percent), Mexico (9 percent), Austria (8 percent), Canada (7 percent), and France (6 percent) (see Chapter 12 of this report).

Systems

Of the 36 companies reporting shipments of solar thermal collectors in 1995, 31 reported shipments of 14,121 complete solar thermal collector systems.[117] This was an 11-percent decrease compared with 1994 (Table F12). The 14,121 complete systems accounted for 1.6 million square feet of collectors, an decrease of 44 percent in square feet shipped from the 1994 level. The total value for the systems shipped in 1995 was $17.8 million, compared with $19.4 million in 1994.

Photovoltaic Cells and Modules

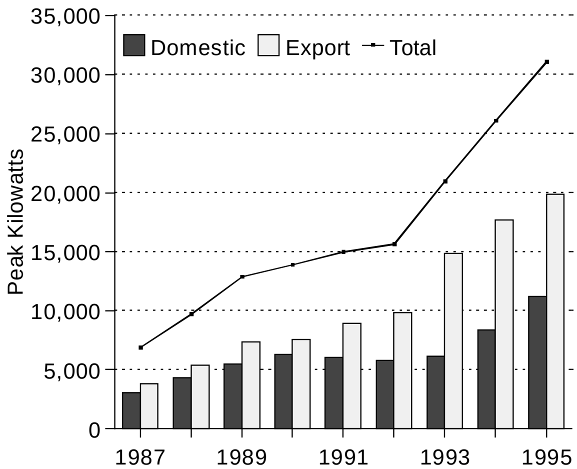
Manufacturing Activities

Photovoltaic cells are typically classified as, crystalline "thick-film" cells, thin-film cells, and concentrator cells. The last type is used in conjunction with a lens or focusing mirror that concentrates the sunlight on a small area. The majority of today's power applications are crystalline "thick-film" cell technology. Three types of the cells are now in production: the original single-crystal wafer, polycrystalline cells, and cells from "sheet" technology.

Photovoltaic cell and module shipments totaled 31.1 peak megawatts in 1996 (Table 17 and Figure 22). These shipments were reported by 24 companies, an increase of two companies from 1994. Four companies expect to introduce new crystalline-silicon module products, while eight companies reported plans to introduce new thin-film products to the industry during 1996 (Table F13). Two companies reported plans to produce new photovoltaic concentrator products and two planned new nonmodule system components during 1996.

[117] A complete system is a unit with a collector and all the necessary functional components, except for installation materials. Included are thermosiphon systems, integral collector storage systems, packaged systems, and system kits.

Figure 22. Domestic and Export Shipments of Photovoltaic Cells and Modules, 1987-1995



Notes: Total shipments as reported by respondents include all domestic and export shipments and may include imports that subsequently were shipped to domestic or foreign customers. See Table 17 for data values.

Source: Energy Information Administration, Form EIA-63B, "Annual Photovoltaic Cell/Module Manufacturers Survey."

Employment in photovoltaic-related activities totaled 1,578 person-years in 1995 (Table F14), an increase of 266 person-years from the 1994 level of employment. The average employment per company was 66 person-years in 1995, compared with 60 person-years in 1994.

Many companies that are engaged in manufacturing and/or importing photovoltaic cells and modules reported in the 1995 survey that they also were involved in other related activities. Nineteen companies were involved in module or system design, 17 were active in development of module prototypes, and 14 were active in development of system prototypes (Table F15). Fourteen companies sold wholesale and 6 companies sold at retail. Eight companies, two less than in 1994, installed photovoltaic cells or modules.

Shipments

Of the 31.1 peak megawatts of photovoltaic cell and module shipments in 1995 (Table F16), module shipments accounted for 19.6 peak megawatts and cell shipments accounted for 11.4 peak megawatts. Total shipments in 1995 increased by 19 percent from the 1994 level. Total shipments have increased by 538 percent since 1985 (Table 17). Data for cells and modules for terrestrial use only (i.e., excluding space applications) have been reported each year since 1985.

Imports

Eight companies reported import shipments of photovoltaic cells and modules in 1995 totaling 1.3 peak megawatts, or 4 percent of total shipments. The predominant type of imported cells and modules was crystalline silicon. Ninety-nine percent of the imports originated in Japan.

Distribution

In 1995, photovoltaic cell and module shipments totaling 16.4 peak megawatts (53 percent of total shipments) were sent directly to wholesale distributors (Table F17). Installers and end users combined received 4.6 peak megawatts (15 percent of total shipments). Cell manufacturers shipped 5.8 peak megawatts (19 percent of total shipments) to other companies that manufacture (assemble) cells into modules.

Cell and Module Types

Photovoltaic shipments are divided into three categories by product type: (1) crystalline silicon cells and modules (includes single-crystal, cast silicon, and ribbon silicon); (2) thin-film cells and modules (made from a number of layers of photosensitive materials such as amorphous silicon); and (3) concentrator cells and modules (in which a lens is used to gather and converge sunlight onto the cell or module surface).

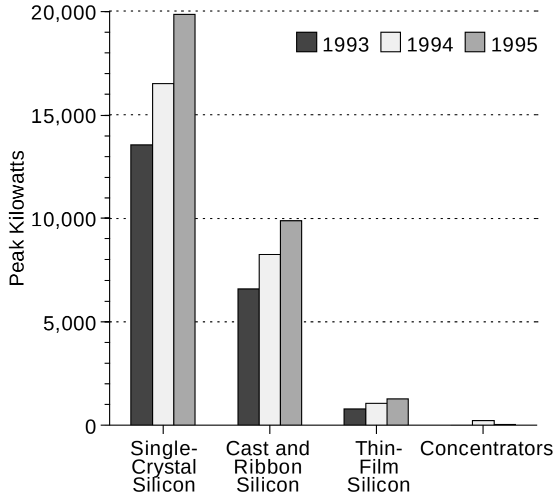
Crystalline silicon cells and modules continued to dominate the industry in 1995, accounting for 96 percent of total shipments (Table F16). In particular, single-crystal silicon shipments totaled 19.9 peak megawatts, an increase of 20 percent compared with corresponding 1994 shipments (Figure 23). Together, cast and ribbon silicon shipments totaled 9.9 peak megawatts in 1995, a 20-percent increase from the corresponding 1994 shipments. From 1994 to 1995, thin-film shipments increased by 19 percent (Table F16). Thin-film shipments represented 4 percent of total shipments in 1995.

Values and Prices

The total value of photovoltaic cell and module shipments was $118 million in 1995, a 12-percent increase over the 1994 value of $106 million (Table F18).[118] The total value of crystalline silicon (single-crystal, cast, and ribbon) shipments was $109.5 million in 1995, a 15-percent increase compared with the corresponding 1994 value. The value of thin-film shipments in 1995 was $8.8 million, 19 percent more than in 1994. The average price of crystalline silicon modules in 1995 was $4.39 per peak watt, a 4-percent increase from the 1994 price

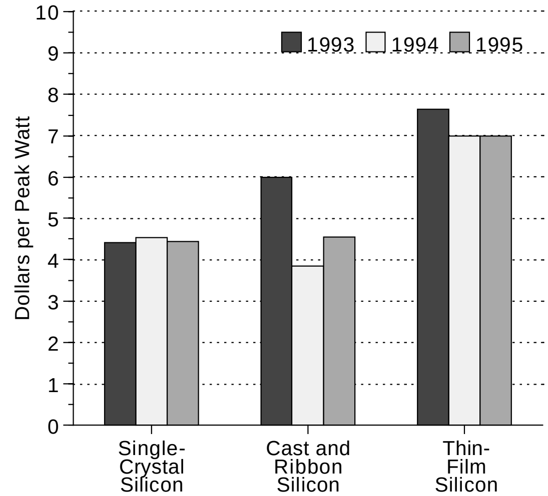
[118]The total value includes charges for advertising and warranties, but does not include excise taxes and the cost of freight or transportation for the shipments.

Figure 23. Photovoltaic Cell and Module Shipments by Type, 1993-1995



Source: Energy Information Administration, Form EIA-63B, "Annual Photovoltaic Cell/Module Manufacturers Survey."

Figure 24. Average Price of Photovoltaic Cell and Module Shipments by Type, 1993-1995



Source: Energy Information Administration, Form EIA-63B, "Annual Photovoltaic Cell/Module Manufacturers Survey."

of $4.22 (Figure 24). The average price for thin-film modules was $7.00 per peak watt, the same as in 1994.

Uses

The largest end-use application of photovoltaic cells and modules in 1995 was for electricity generation (combined grid-interactive and remote), which represented 41 percent of total shipments (Table F19). Of the 12.8 peak megawatts represented by this end use, 97 percent involved crystalline silicon cells and modules. Grid-interactive and remote (i.e., standalone) power generation uses included applications for grid distribution and general remote uses, such as residential power and power for mobile homes.

The second-largest end use in 1995 was in the communication sector, which accounted for 5.2 peak megawatts. Transportation end-use application accounted for 4.2 peak megawatts, or 14 percent of total shipments. In 1995, use of photovoltaics in the transportation sector increased by almost 98 percent from 1994. End uses related to water pumping and original equipment manufacturers accounted for 2.7 peak megawatts and 3.2 peak megawatts, respectively, in 1995 and involved primarily the use of crystalline silicon cells and modules.

Sales for consumer goods accounted for 1.0 peak megawatts in 1995, a decline of 68 percent from 1994. Cells and modules used for health and medical purposes—e.g., to power refrigerators, medical equipment, and water purifiers—totaled 0.8 peak megawatts in 1995, a tenfold increase over the 1994 level. End uses reported as "Other" for 1995 totaled 1.2 peak megawatts, 5 times as much as 1994.

Destinations

Domestic. The commercial sector was the largest market for photovoltaic cells and modules in 1995, accounting for 26 percent of total shipments, or 8.1 peak megawatts (Table F19). These cells and modules were shipped to provide power for commercial establishments such as office buildings, retail establishments, private hospitals, and schools (publicly owned hospitals and schools are listed under the government sector). In 1995, 96 percent were crystalline silicon and 4 percent were thin-film silicon cells and modules.

The industrial sector represented the largest market for photovoltaic shipments in 1994, whereas the use of cells and modules in grid-connected and remote systems to provide power for the industrial sector was the second-largest market in 1995, accounting for 23 percent of total shipments. The residential market was the third-largest market in 1995, accounting for 20 percent of total shipments in 1995. In 1994, the residential sector was the second-largest market at 25 percent of total shipments.

Photovoltaic cells and modules for the transportation sector, which were used to produce power on boats, in cars, in recreational vehicles, and to power transportation support systems, amounted to 2.4 megawatts. The transportation sector accounted for 8 percent of total shipments in 1995, the same as in 1994. Shipments to the utility sector, where cells and modules were used to produce power at utility-owned systems including central stations, decentralized systems, and experimental applications, amounted to 3.8 peak megawatts in 1995, a 59-percent increase from 1994.

Shipments of cells and modules used to produce power at installations of Federal, State, or local governments (excluding military) totaled 2.0 peak megawatts in 1995, compared with 2.1 peak megawatts shipped to the government sector in 1994. The “Other” sector (Table F19) in 1995 consisted of 1.3 peak megawatts shipped to foreign governments or used for specialty purposes, an increase of 164 percent from 1994.

Exports. Export shipments totaled 20 peak megawatts in 1995 (Table F20), an increase of 12 percent from the 1994 level. (Export shipments to individual countries are listed in Chapter 12.) Generally, export shipments since 1990 have paralleled total shipments because of the continued search for new markets outside the United States (Figure 22). A total of 18 companies reported exports of cells and modules in 1995, as exports accounted for 64 percent of total shipments. Of all types of cells and modules exported in 1995, 98 percent were crystalline silicon. Almost one-half (49 percent) of the photovoltaic cells and modules exported were shipped to Asia, and 28 percent were shipped to European countries (Table F21).

Systems

Of the 24 companies that reported shipments of photovoltaic systems in 1995, 15 reported shipments of 1,077 complete systems,[119] less than one-half the number shipped in 1994 (Table F22). Some complex, large-scale systems use concentrators to focus incident insolation onto small photovoltaic cells and tracking systems to track the sun. In this report, installation materials such as the support frame and concrete foundations are not considered as part of a system. The value of systems reported in Table F22 excludes excise taxes and charges for freight, transportation, and installation. The total value of complete systems shipped in 1995 was $6.4 million. Complete-system shipments in 1995 accounted for 0.9 peak megawatts, or 3 percent of total module shipments.

Activities in 1996

The following paragraphs summarize major activities in the U.S. solar power industry in 1996.

The National Renewable Energy Laboratory (NREL) in Golden, CO, set a world record sunlight-to-energy efficiency of 17.7 percent in 1996 for thin-film photovoltaics using copper indium gallium diselenide (CIGS). The achievement in this next-generation replacement for existing photovoltaic technologies is about 60 percent higher than the equivalent efficiency of commercial thin-film photovoltaics made from amorphous silicon. Amorphous silicon has been getting considerable attention as new production facilities are being opened in the United States, and power purchase agreements are being signed between U.S. companies and foreign governments.

Amoco/Enron Solar Power Development signed a 25-year power purchase agreement with the Rajasthan (India) State Electricity Board for the sale of up to 50 megawatts of electricity generating capacity from what is expected to be the world’s largest photovoltaic power plant, to be built in the Thar desert near Jaisalmer in Rajasthan state. The accord was signed 3 months after the two parties signed a letter of intent calling for the power to be bought on an escalating scale beginning at about 8 cents per kilowatthour. The same kind of modules will also be used to build a Hawaiian power plant in 1997, which is expected to be at full capacity by the middle of the year.

Helicol Corporation of Clearwater, FL, in late March 1996 completed the installation of a solar pool-heating system spanning more than 10,000 square feet at the aquatic center of the Georgia Institute of technology, where the 1996 summer olympic swimming and diving competitions were held. Because of the natatorium’s unique type of standing-seam, rib-roofing construction, no roof penetrations were used on most of the panels. A special roof clip was used for flush mounting, and special aluminum racks were built for 72 HC-50 panels. The 50-meter competition pool contained 1 million gallons of water, which was pumped through the Helicol collectors at 600 gallons per minute by a 40-horsepower three-phase pump. The pool water was kept within a margin of 1 degree during the competition. Richard Long, architect at Georgia Tech, estimated that the system would save $12,000 per year in utility bills.

Amoco/Enron Solar in Frederick, MD, was also expected to be selected to provide a polycrystalline building-integrated photovoltaic array with a capacity of approximately 312 peak kilowatts at the olympic natatorium—the largest such array in the United States. A second project, with a capacity of 9 kilowatts featuring new 240-watt Solarex architectural modules, was

[119]A complete photovoltaic system is defined as a power supply unit that satisfies all the power requirements of an application. Such a system is generally made up of one or more modules, a power conditioning unit to process the electricity into the form needed by the application, wires and other electrical connectors, and sometimes batteries for back-up power supply.

The swimming complex built on the campus of the Georgia Institute of Technology for the 1996 Summer Olympic Games features a large-scale solar electric (PV) system that supplies about 30 percent of the total electricity needs at the complex.

slated for the roof covering the walkway to the main entrance of the athletic center. Funding for the project was provided by the U.S. Department of Energy, Georgia Tech, and the Georgia Power Corporation, with design assistance from Solar Design Associates of Harvard, MA.

Four projects were selected in 1996 for immediate development of up to 270 megawatts of renewable energy in the southern Nevada Solar Enterprise Zone (SEZ). The Corporation for Solar Technology and Renewable Resources (CSTRR) of Las Vegas, NV, the agent for finding the projects, selected the following developers: Amoco/Enron Solar Power Development; Cummins Power Generation; a combined effort by Kenetech Corporation, Photovoltaics International, and Solar Cells, Inc.; and a combined effort by Nevada Power, Entech, and Science Applications International Corporation.

Farmers and herdsmen in Gansu Province, China, will receive 800 solar electric home lighting systems from the nonprofit Solar Electric Lighting Fund (SELF) in Washington, DC, under contract with NREL. The project will build on the existing 1,000-house photovoltaic rural electrification program in the province, which was initiated by SELF in 1993. It is part of a larger protocol agreement signed in 1995 between the U.S. Department of Energy and the Chinese State Council on Science and Technology, to provide cooperation on a variety of renewable energy efforts. NREL and the Chinese government will share hardware and project management costs.

Arizona's 25-percent solar tax credit entered its second year, with no indication of price increases for solar water heaters (as were seen when Federal and State credits were in effect), according to the Arizona Department of Commerce. The State credits apply to the first $4,000 spent for purchases of domestic solar hot water systems and solar daylighting. The State also has a sales tax exemption for purchases of solar goods.

At the Florida Solar Energy Center (FSEC) in Cocoa, FL, a year-long trial was started for a residential photovoltaic-powered water heater. The system, built by the National Institute of Standards and Technology in Gaithersburg, MD, uses computer technology to maximize the conversion of sunlight to electricity. Transfer of the system from NIST laboratories to the FSEC solar experimental station for field tests represented the latest advance for what NIST believes is a system with the potential to replace solar thermal water heating systems. Future field tests of the technology are expected to be held at the Kadena Air Force Base in Okinawa, Japan, and at a site selected by the Tennessee Valley Authority.

Also in 1996, ECO and Uni Solar unveiled two new roofing products that will be commercially produced. The solar shingle for residential rooftops and a solar metal battenseam product for commercial rooftops can be integrated into traditional roofs without additional supporting structures and can be installed by commercial roofing companies. Uni Solar also announced the achievement of stable cell efficiency of 11.8 percent for its thin-film amorphous silicon alloy multiproduction modules, surpassing its earlier world record of 11.1 percent. The new stabilized module efficiency is expected to be 9 percent (for 4- to 8-foot square panels), eventually improving to about 10 percent.