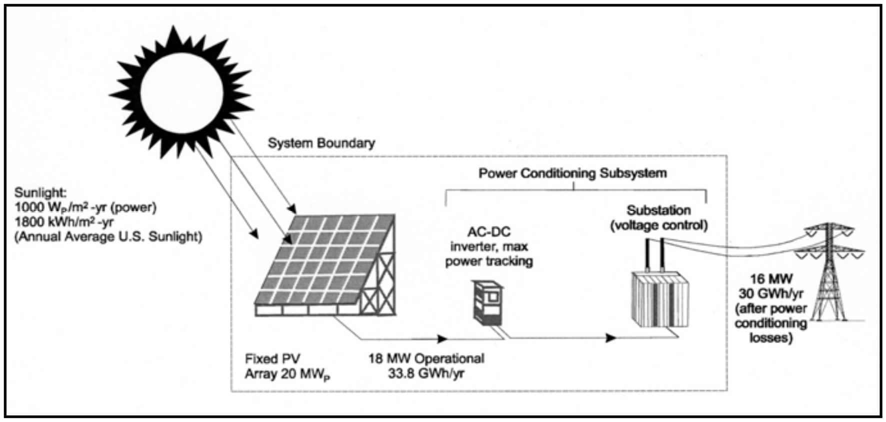
Photovoltaics

Technology Description



Solar photovoltaic (PV) arrays use semiconductor devices called solar cells to convert sunlight to electricity without moving parts and without producing fuel wastes, air pollution, or greenhouse gases. Using solar PV for electricity – and eventually using solar PV to produce hydrogen for fuel cells for electric vehicles, by producing hydrogen from water – will help reduce carbon dioxide emissions worldwide.

System Concepts

- Flat-plate PV arrays use global sunlight; concentrators use direct sunlight. Modules are mounted on a stationary array or on single- or dual-axis sun trackers. Arrays can be ground-mounted or on all types of buildings and structures (e.g., semitransparent solar canopy). The DC output from PV can be conditioned into grid-quality AC electricity, or DC can be used to charge batteries or to split water to produce hydrogen (electrolysis of water).
- PV systems are expected to be used in the United States for residential and commercial buildings, peak-power shaving, and intermediate daytime load. With energy storage, PV can provide dispatchable electricity and/or produce hydrogen.
- Almost all locations in the United States and worldwide have enough sunlight for cost-effective PV. For example, U.S. sunlight in the contiguous states varies by only about 25% from an average in Kansas. Land area is not a problem for PV. Not only can PV be more easily sited in a distributed fashion than almost all alternatives (for example, on roofs or above parking lots), a PV-generating station 140 km by 140 km sited at a high solar insolation location in the United States (such as the desert Southwest) could generate all of the electricity needed in the country (2.5×10^6 GWh/year, assuming a system efficiency of 10% and an area packing factor of 50% to avoid self-shading).

Representative Technologies

- Wafers of single-crystal or polycrystalline silicon – best cells: 25% efficiency; commercial modules: 12%-17%. Silicon modules dominate the PV market and currently cost about $2/$W_p$ to manufacture.
- Thin-film semiconductors (e.g., amorphous silicon, copper indium diselenide, cadmium telluride, and dye-sensitized cells) – best cells: 12%-19%; commercial modules: 6%-11%. A new generation of thin-film PV modules is going through the high-risk transition to first-time and large-scale manufacturing. If successful, market share could increase rapidly.
- High-efficiency, single-crystal silicon and multijunction gallium-arsenide-alloy cells for concentrators – best cells: 27%-39% efficient; precommercial modules: 15%-24%; prototype systems are being tested in high solar areas in the southwest United States.
- Grid-connected PV systems currently sell for about $6-$7/W_p (17¢-22¢/kWh), including support structures, power conditioning, and land.

Technology Applications

- PV systems can be installed as either grid-supply technologies or as customer-sited alternatives to retail electricity. As suppliers of bulk grid power, PV modules would typically be installed in large array fields ranging in total peak output from a few megawatts on up. Very few of these systems have been installed to-date. A greater focus of the recent marketplace is on customer-sited systems, which may be installed to meet a variety of customer needs. These installations may be residential-size systems of just 1 kilowatt, or commercial-size systems of several hundred kilowatts. In either case, PV systems meet customer needs for alternatives to purchased power, reliable power, protection from price escalation, desire for green power, etc. Interest is growing in the use of PV systems as part of the building structure or façade ("building integrated"). Such systems use PV modules designed to look like shingles, windows, or other common building elements.

- PV systems are expected to be used in the United States for residential and commercial buildings; distributed utility systems for grid support, peak power shaving, and intermediate daytime load following; with electric storage and improved transmission for dispatchable electricity; and H_2 production for portable fuel.
- Other applications for PV systems include electricity for remote locations, especially for billions of people worldwide who do not have electricity. Typically, these applications will be in hybrid minigrid or battery-charging configurations.
- Almost all locations in the United States and worldwide have enough sunlight for PV (e.g., U.S. sunlight varies by only about 25% from an average in Kansas).
- Land area is not a problem for PV. Not only can PV be more easily sited in a distributed fashion than almost all alternatives (e.g., on roofs or above parking lots), a PV-generating station 140 km-by-140 km sited at an average solar location in the United States could generate all of the electricity needed in the country (2.5×10^6 GWh/year), assuming a system efficiency of 10% and an area packing factor of 50% (to avoid self-shading). This area (0.3% of U.S.) is less than one-third of the area used for military purposes in the United States.

Current Status

- Because of public/private partnerships, such as the Thin-Film Partnership with its national research teams, U.S. PV technology leads the world in measurable results such as record efficiencies for cells and modules. Another partnership, the PV Advanced Manufacturing R&D program, has resulted in industry cost reductions of more than 60% and facilitated a sixteen-fold increase of manufacturing capacity during the past 12 years.
- A new generation of potentially lower-cost technologies (thin films) is entering the marketplace. A 30-megawatt amorphous silicon thin-film plant by United Solar reached full production in 2005. Two plants (First Solar and Shell Solar) using even newer thin films (cadmium telluride and copper indium diselenide alloys) are in first-time manufacturing at the MW-scale. Thin-film PV has been a focus of the federal R&D efforts of the past decade, because it holds promise for module cost reductions.
- During the past two years, record sunlight-to-electricity conversion efficiencies for solar cells were set by federally funded universities, national labs, or industry in copper indium gallium diselenide (19%-efficient cells and 13%-efficient modules) and cadmium telluride (16%-efficient cells and 11%-efficient modules). Cell and module efficiencies for these technologies have increased more than 50% in the past decade.
- A unique multijunction (III-V materials alloy) cell was spun off to the space power industry, leading to a record cell efficiency (35%) and an R&D 100 Award in 2001. This device configuration is expected to dominate future space power for commercial and military satellites. Recent champion cell efficiency has reached 39% under concentrated sunlight. DOE is interested in this technology (III-V multijunctions), as an insertion candidate for high efficiency terrestrial PV concentrator systems.

Technology History

- French physicist Edmond Becquerel first described the photovoltaic (PV) effect in 1839, but it remained a curiosity of science for the next three quarters of a century. At only 19, Becquerel found that certain materials would produce small amounts of electric current when exposed to light. The effect was first studied in solids, such as selenium, by Heinrich Hertz in the 1870s. Soon afterward, selenium PV cells were converting light to electricity at more than 1% efficiency. As a result, selenium was quickly adopted in the emerging field of photography for use in light-measuring devices.

- Major steps toward commercializing PV were taken in the 1940s and early 1950s, when the Czochralski process was developed for producing highly pure crystalline silicon. In 1954, scientists at Bell Laboratories depended on the Czochralski process to develop the first crystalline silicon photovoltaic cell, which had an efficiency of 4%. Although a few attempts were made in the 1950s to use silicon cells in commercial products, it was the new space program that gave the technology its first major application. In 1958, the U.S. Vanguard space satellite carried a small array of PV cells to power its radio. The cells worked so well that PV technology has been part of the space program ever since.
- Even today, PV plays an important role in space, supplying nearly all power for satellites. The commercial integrated circuit technology also contributed to the development of PV cells. Transistors and PV cells are made from similar materials and operate on similar physical mechanisms. As a result, advances in transistor research provided a steady flow of new information about PV cell technology. (Today, however, this technology transfer process often works in reverse, as advances in PV research and development are sometimes adopted by the integrated circuit industry.)
- Despite these advances, PV devices in 1970 were still too expensive for most "down-to-Earth" uses. But, in the mid-1970s, increasing energy costs, sparked by a world oil crisis, renewed interest in making PV technology more affordable. Since then, the federal government, industry, and research organizations have invested billions of dollars in research, development, and production. A thriving industry now exists to meet the rapidly growing demand for photovoltaic products.

Technology Future

The levelized cost of electricity (in constant 2003$/kWh) for PV are projected to be:

	2003	2007	2020	2025
Utility-owned Residential (crystalline Si)	0.25-0.40	0.22	0.8-0.10	NA
Concentrator	0.40	0.20	NA	0.04-0.06

Source: *Solar Energy Technologies Program Multiyear Technical Plan,* NREL Report No. MP-520-33875; DOE/GO-102004-1775.

- Worldwide, approximately 1,200 MW of PV were sold in 2004, with systems valued at more than $7 billion; total installed PV is more than 2 GW. The U.S. world market share fell to about 12% in 2004.
- Worldwide, market growth for PV has averaged more than 20%/year for the past decade as a result of reduced prices and successful global marketing. Worldwide sales grew 36% in 2001, 44% in 2002, 33% in 2003, and 60% in 2004.
- Hundreds of applications are cost-effective for off-grid needs. However, the fastest-growing segment of the market is battery-free, grid-connected PV, such as roof-mounted arrays on homes and commercial buildings in the United States. California is subsidizing PV systems to reduce their dependence on natural gas, especially for peak daytime loads that match PV output, such as air-conditioning.

Market Context

- Electricity for remote locations, especially for billions of people worldwide who do not have electricity.
- U.S. markets include retail electricity for residential and commercial buildings; distributed utility systems for grid support, peak-shaving, and other daytime uses (e.g., remote water pumping).
- Future electricity and hydrogen storage for dispatchable electricity, electric car-charging stations, and hydrogen production for portable fuel.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term.* DOE/PI-0002. November 2003 (draft update, September 2005).

Photovoltaics

Market Data

PV Cell/Module Production (Shipments) — Source: *PV News,* Vol. 15, No. 2, Feb. 1996; Vol. 16, No. 2, Feb. 1997; Vol. 20, No. 2, Feb. 2001; Vol. 22, No. 5, May 2003; and Volume 23, No. 4, April 2004. Paul Maycock, www.pvenergy.com

Annual (MW)	**1980**	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
U.S.	3	8	15	35	39	51	54	61	75	100	121	103
Japan	1	10	17	16	21	35	49	80	129	171	251	364
Europe	0	3	10	20	19	30	34	40	61	87	135	193
Rest of World	0	1	5	6	10	9	19	21	23	33	54	84
World Total	4	23	47	78	89	126	155	201	288	391	560	744

Cumulative (MW)	**1980**	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
U.S.	5	45	101	219	258	309	363	424	499	599	720	823
Japan	1	26	95	185	206	241	290	370	499	670	921	1,285
Europe	1	13	47	136	155	185	219	259	320	407	542	735
Rest of World	0	3	20	45	55	65	83	104	127	160	214	298
World Total	7	87	263	585	674	800	954	1,156	1,444	1,835	2,395	3,139

U.S. % of World Sales	**1980**	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Annual	71%	34%	32%	44%	44%	41%	35%	30%	26%	26%	22%	14%
Cumulative	75%	52%	39%	37%	38%	39%	38%	37%	35%	33%	30%	26%

Annual Capacity (Shipments retained, MW)* — Source: *Strategies Unlimited*

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
U.S.	1.4	4.2	5.1	8.4	9.2	10.5	13.6	18.4	21.3
Total World	3	15	39	68	79	110	131	170	246

*Excludes indoor consumer (watches/calculators).

Cumulative Capacity (Shipments retained, MW)* — Source: *Strategies Unlimited*

	1980	1985	1990	1995	1996	1997	1998	1999	2000
U.S.	3	23	43	76	85	96	109	128	149
Total World	6	61	199	474	552	663	794	964	1,210

*Excludes indoor consumer (watches/calculators).

U.S. Shipments (MW) — Source: *EIA, Annual Energy Review 2004,* DOE/EIA-0384(2004) (Washington, D.C., September 2004), Tables 10.5 and 10.6; and EIA, *Renewable Energy Annual 2003*, DOE/EIA-0603(2003) (Washington, D.C., December 2004) Table 26.

Annual Shipments	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total	5.8	13.8	31.1	35.5	46.4	50.6	76.8	88.2	97.7	112.1	109.4	181.1
Imports	0.3	1.4	1.3	1.9	1.9	1.9	4.8	8.8	10.2	7.3	9.7	47.7
Exports	1.7	7.5	19.9	22.4	33.8	35.5	55.6	68.4	61.4	66.8	60.7	102.8
Domestic Total On-Grid*	0.4	0.2	1.7	1.8	2.2	4.2	6.9	4.9	10.1	13.7	18.9	55.9
Domestic Total Off-Grid*	3.7	6.1	9.5	11.2	10.3	10.8	14.4	15.0	26.2	31.6	29.8	22.4

Cumulative Shipments (since 1982)	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Total	35.2	84.7	193.3	228.8	275.2	325.7	402.5	490.7	588.4	700.5	809.8	991.0
Imports	1.0	5.6	14.3	16.2	18	19.9	24.7	33.5	43.7	51.0	60.8	108.5
Exports	5.7	32.9	104	126.5	160.3	195.8	251.3	319.7	381.0	447.8	508.5	611.3
Domestic Total On-Grid*	2.9	4.7	8.2	10.0	12.2	16.5	23.3	28.2	38.3	52.0	70.9	126.9
Domestic Total Off-Grid*	26.6	47.2	81.1	92.3	102.7	113.5	127.9	142.8	169.0	200.6	230.4	252.8

* Domestic Totals include imports and exclude exports. Electricity generation only, excludes water pumping, communications, transportation, consumer goods, health, and original equipment manufacturers.

U.S. Shipments (MW) — Source: *Renewable Energy World*, July-August 2003, Volume 6, Number 4; and *PV News*, Vol. 23, No. 5, May 2004

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total				34.8	38.9	51.0	53.7	60.8	75.0	100.3	120.6	103.0
Imports								2.0	4.0	5.0	9.0	18.0
Exports				24.0	25.1	36.3	37.9	39.8	55.0	73.3	81.2	54.0

Annual U.S. Installations (MW)	Source: *The 2002 National Survey Report of Photovoltaic Power Applications in the United States*, prepared by Paul D. Maycock and Ward Bower, May 31, 2003, prepared for the IEA, Table 1. http://www.oja-services.nl/iea-pvps/nsr02/download/usa.pdf; and PV News, Vol. 23 No. 5.											
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Grid-Connected Distributed				1.5	2.0	2.0	2.2	3.7	5.5	12.0	22.0	32.0
Off-Grid Consumer				3.5	4.0	4.2	4.5	5.5	6.0	7.0	8.4	9.0
Government				0.8	1.2	1.5	1.5	2.5	2.5	1.0	1.0	1.0
Off-Grid Industrial/Commercial				4.0	4.4	4.8	5.2	6.5	7.5	9.0	13.0	16.0
Consumer (<40 w)				2.0	2.2	2.2	2.4	2.5	2.5	3.0	4.0	4.0
Central Station				0	0	0	0	0	0	0	0	5.0
Total				11.8	13.8	14.7	15.8	20.7	24.0	32.0	48.4	67.0

Cumulative U.S. Installations* (MW)	Source: *The 2002 National Survey Report of Photovoltaic Power Applications in the United States,* prepared by Paul D. Maycock and Ward Bower, May 31, 2003, prepared for the IEA, Table 1 http://www.oja-services.nl/iea-pvps/nsr02/usa2.htm.											
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Off-grid Residential				19.3	23.3	27.5	32.0	37.5	43.5	50.5		
Off-grid Nonresidential				25.8	30.2	35.0	40.2	46.7	55.2	64.7		
On-grid Distributed				9.7	11.0	13.7	15.9	21.1	28.1	40.6		
On-grid Centralized				12.0	12.0	12.0	12.0	12.0	12.0	12.0		
Total				66.8	76.5	88.2	100.1	117.3	138.8	167.8		

* Excludes installations less than 40kW.

Annual World Installations (MW)	Source: *Renewable Energy World,* July-August 2003, Volume 6, Number 4.										
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Consumer Products			16		22	26	30	35	40	45	60
U.S. Off-Grid Residential			3		8	9	10	13	15	19	25
World Off-Grid Rural			6		15	19	24	31	38	45	60
Communications/ Signal	N/A	N/A	14	N/A	23	28	31	35	40	46	60
PV/Diesel, Commercial			7		12	16	20	25	30	36	45
Grid-Conn. Res., Comm.			1		7	27	36	60	120	199	270
Central Station (>100kW)			1		2	2	2		5	5	5
Total			48		89	127	153	201	288	395	525

Annual U.S. Shipments by Cell Type (MW)

Source: *PV News,* Vol. 15, No. 2, Feb. 1996; Vol. 16, No. 2, Feb. 1997; Vol. 17, No. 2, Feb. 1998; Vol. 18, No. 2, Feb. 1999; Vol. 19, No. 3, March 2000; Vol. 20, No. 3, March 2001; Vol. 21, No. 3, March 2002; Vol. 22, No. 5, May 2003; and *Renewable Energy World*, July-August 2003, Volume 6, Number 4.

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Single Crystal				22.0	24.1	31.8	30.0	36.6	44.0	63.0	71.9
Flat-Plate Polycrystal (other than ribbon)				9.0	10.3	14.0	14.7	16.0	17.0	20.6	24
Amorphous Silicon				1.3	1.1	2.5	3.8	5.3	6.5	7.3	11
Crystal Silicon Concentrators				0.3	0.7	0.7	0.2	0.5	0.5	0.5	0.5
Ribbon Silicon	N/A	N/A	N/A	2.0	3.0	4.0	4.0	4.2	5.0	6.9	6.9
Cadmium Telluride				0.1	0.4	0	0	0	0	0.6	1.6
Microcrystal SI/Single SI											-
SI on Low-Cost-Sub				0.1	0.3	0.5	1.0	2.0	2.0	1.7	1.7
A-SI on Cz Slice									0	0	-
Total				34.8	39.9	53.5	53.7	64.6	75	100.6	120.6

Annual World Shipments by Cell Type (MW)

Source: *PV News,* Vol. 15, No. 2, Feb. 1996; Vol. 16, No. 2, Feb. 1997; Vol. 17, No. 2, Feb. 1998; Vol. 18, No. 2, Feb. 1999; Vol. 19, No. 3, March 2000; Vol. 20, No. 3, March 2001; Vol. 21, No. 3, March 2002; Vol. 22, No. 5, May 2003; and *Renewable Energy World*, July-August 2003, Volume 6, Number 4.

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998** 0	**1999**	**2000**	**2001**	**2002**
Single Crystal				46.7	48.5	62.8	59.8	73	89.7	150.41	162.31
Flat-Plate Polycrystal				20.1	24	43	66.3	88.4	140.6	278.9	306.55
Amorphous Silicon				9.1	11.7	15	19.2	23.9	27	28.01	32.51
Crystal Silicon Concentrators				0.3	0.7	0.2	0.2	0.5	0.5	0.5	0.5
Ribbon Silicon	N/A	N/A	N/A	2	3	4	4	4.2	14.7	16.9	16.9
Cadmium Telluride				1.3	1.6	1.2	1.2	1.2	1.2	2.1	4.6
Microcrystal SI/Single SI											3.7
SI on Low-Cost-Sub				0.1	0.3	0.5	1	2	2	1.7	1.7
A-SI on Cz Slice								8.1	12	30	30
Total				79.5	89.8	126.7	151.7	201.3	287.7	512.22	561.77

Annual U.S. Shipments by Cell Type (MW)	Source: EIA, Solar Collector Manufacturing Activity annual reports, 1982-1992; and EIA, *Renewable Energy Annual 1997,* Table 27; REA 2000, Table 26; REA 2002, Table 28; REA 2003, Table 28.											
	1985	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Single-Crystal Silicon			19.9	21.7	30	30.8	47.2	51.9	54.7	74.7	59.4	94.9
Cast and Ribbon Crystalline Silicon			9.9	12.3	14.3	16.4	26.2	33.2	29.9	29.4	38.6	64.2
Crystalline Silicon Total	5.5	12.5	29.8	34	44.3	47.2	73.5	85.2	84.7	104.1	98.0	159.1
Thin-Film Silicon	0.3	1.3	1.3	1.4	1.9	3.3	3.3	2.7	12.5	7.4	11.0	22.0
Concentrator Silicon			0.1	0.2	0.2	0.1	0.1	0.3	0.5	0.6	0.5	0
Other												
Total	5.8	13.8	31.2	35.6	46.3	50.6	76.8	88.2	97.7	112.1	109.5	181.1

Annual Grid-Connected Capacity (MW)	Source: *The 2002 National Survey Report of Photovoltaic Power Applications in the United States*, prepared by Paul D. Maycock and Ward Bower, May 31, 2003, prepared for the IEA, derived from Table 1 http://www.oja-services.nl/iea-pvps/nsr02/usa2.htm. Japan data from *PV News*, Vol. 23, No. 1, January 2004.								
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
U.S.		1.3	2.7	2.2	5.2	7.0	12.5		
Japan	3.9	7.5	19.5	24.1	57.7	74.4	91.0	155.0	168.0

Note: Japan data not necessarily grid-connected

Cumulative Grid-Connected Capacity (MW)	Source: *The 2002 National Survey Report of Photovoltaic Power Applications in the United States*, prepared by Paul D. Maycock and Ward Bower, May 31, 2003, prepared for the IEA, derived from Table 1 http://www.oja-services.nl/iea-pvps/nsr02/usa2.htm. Japan data from *PV News*, Vol. 23, No. 1, January 2004.								
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
U.S.	21.7	23.0	25.7	27.9	33.1	40.1	52.6		
Japan	5.8	13.3	32.8	56.9	114.6	189.0	280.0	435.0	603.0

Japan Grid-Connected Capacity (MW)	Source: IEA Photovoltaic Power Systems Program, *National Survey Report of PV Power Applications in Japan* 2002, http://www.oja-services.nl/iea-pvps/nsr02/jpn2.htm Table 1.							
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Annual	6.0	9.7	22.6	34.7	71.3	114.8	119.3	178.2
Cumulative	13.7	23.4	46.0	80.7	151.9	266.7	386.0	564.2

Annual U.S.-Installed Capacity (MW)	Source: *Renewable Electric Plant Information System (REPiS), Version 7, NREL, 2003.*											
Top 10 States	**1980**	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
California		0.034	0.016	0.720	0.900	0.606	0.577	2.993	5.833	7.236	16.072	7.452
Arizona		0.004		0.026	0.067	0.724	0.301	0.574	0.177	2.516	1.333	0.008
New York			0.013	0.067	0.425	0.021	0.246	0.041	0.377		1.078	
Ohio						0.001	0.001	0.010	0.144	0.004	1.986	
Hawaii				0.000	0.046	0.008	0.291	0.113	0.250	0.275		
Texas	0.006	0.015	0.002	0.008		0.010	0.133	0.248	0.089	0.028	0.020	
Colorado				0.018	0.100	0.006	0.132	0.344	0.137			
Georgia					0.352			0.019	0.221		0.003	0.032
Florida	0.009		0.008	0.018		0.036	0.047	0.106	0.202	0.031	0.050	
Illinois						0.002	0.005	0.034	0.043	0.449	0.044	
Total U.S.	0.015	0.078	0.049	1.029	2.131	1.670	1.899	5.140	8.244	10.807	21.251	8.008

2003 data not complete as REPiS database is updated through 2002.

Cumulative U.S.-Installed Capacity (MW)	Source: *Renewable Electric Plant Information System (REPiS), Version 7, NREL, 2003.*											
Top 10 States	**1980**	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
California	0.002	1.369	2.803	6.495	7.396	8.002	8.579	11.572	17.405	24.641	40.713	48.164
Arizona	0.008	0.032	0.048	0.097	0.164	0.888	1.190	1.764	1.941	4.457	5.790	5.798
New York	0	0	0.013	0.226	0.650	0.671	0.917	0.958	1.334	1.334	2.412	2.412
Ohio	0	0	0	0	0	0.001	0.002	0.012	0.155	0.159	2.145	2.145
Hawaii	0	0.014	0.033	0.033	0.079	0.087	0.378	0.491	0.741	1.016	1.016	1.016
Texas	0.006	0.021	0.366	0.437	0.437	0.446	0.579	0.828	0.917	0.945	0.965	0.965
Colorado	0	0	0.010	0.040	0.140	0.146	0.278	0.622	0.759	0.759	0.759	0.759
Georgia	0	0	0	0	0.352	0.352	0.352	0.371	0.592	0.592	0.595	0.627
Florida	0.009	0.093	0.117	0.135	0.135	0.171	0.218	0.325	0.527	0.558	0.609	0.609
Illinois	0	0	0.021	0.021	0.021	0.023	0.029	0.062	0.105	0.554	0.598	0.598
Total U.S. [1]	0.025	2.104	4.170	8.560	10.691	12.362	14.261	19.401	27.645	38.452	59.703	67.710

[1] There are an additional 3.4 MW of photovoltaic capacity that are not accounted for here because they have no specific online date.
2003 data not complete as REPiS database is updated through 2002.

Technology Performance

	Source: *Solar Energy Technologies Program Multiyear Technical Plan,* NREL Report No. MP-520-33875; DOE/GO-102004-1775.				
Efficiency		**2003**	**2007**	**2020**	**2025**
Cell (%)	Crystalline Silicon	NA	NA	NA	NA
	Concentrator	25	33	NA	40
Module (%)	Crystalline Silicon	14	15	15-20	NA
	Concentrator	NA	NA	NA	NA
System (%)	Crystalline Silicon	11.5	14	16	NA
	Concentrator	15	22	NA	33
Cost		**2003**	**2007**	**2020**	**2025**
Module ($/Wp)	Crystalline Silicon	4.80	2.50	1.00-1.50	NA
$(\$/m^2)$	Concentrator	160	90	NA	80
BOS ($/Wp)	Crystalline Silicon	0.85	0.60	0.40	NA
	Concentrator	0.60	0.30	NA	0.15
Total Installed System ($/Wp)	Crystalline Silicon *	6.20-9.50	5.20	2.30-2.80	NA
	Concentrator	NA	NA	NA	NA
O&M ($/kWh)	Crystalline Silicon	0.08	.0.02	0.005	NA
	Concentrator	0.02	0.01	NA	0.005