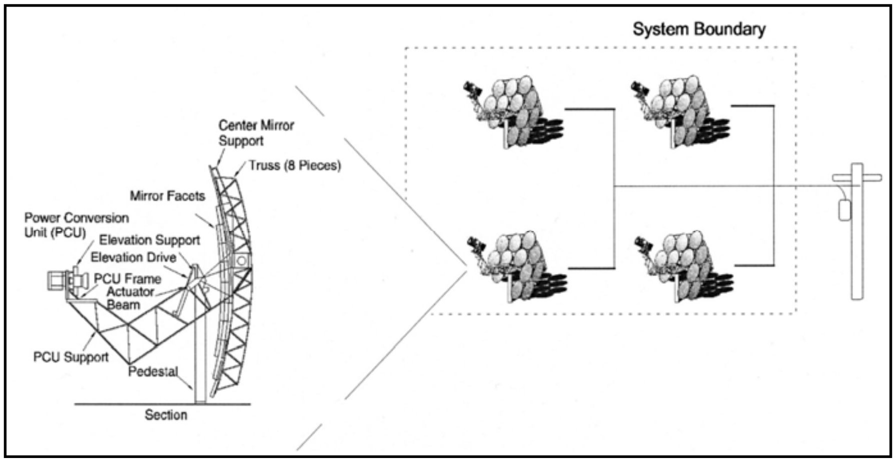
Concentrating Solar Power

Technology Description

Concentrating Solar Power (CSP) systems concentrate solar energy 50 to 10,000 times to produce high-temperature thermal energy, which is used to produce electricity for distributed or bulk generation process applications.

System Concepts



- In CSP systems, highly reflective sun-tracking mirrors produce temperatures of 400°C to 800°C in the working fluid of a receiver; this heat is used in conventional heat engines (steam or gas turbines or Stirling engines) to produce electricity at solar-to-electric efficiencies for the system of up to 30%.
- CSP technologies provide firm, nonintermittent electricity generation (peaking or intermediate load capacity) when coupled with storage.
- Because solar-thermal technologies can yield extremely high temperatures, the technologies could some day be used for direct conversion (rather than indirect conversion through electrochemical reactions) of natural gas or water into hydrogen for future hydrogen-based economies.

Representative Technologies

- A parabolic trough system focuses solar energy on a linear oil-filled receiver to collect heat to generate steam to power a steam turbine. When the sun is not shining, steam can be generated with a fossil fuel to meet utility needs. Some of the new trough plants include thermal storage. Plant sizes can range from 1.0 to 100 MW_e.
- A power tower system uses many large heliostats to focus the solar energy onto a tower-mounted central receiver filled with a molten-salt working fluid that produces steam. The hot salt can be stored extremely efficiently to allow power production to match utility demand, even when the sun is not shining. Plant size can range from 30 to 200 MW_e.
- A dish/engine system uses a dish-shaped reflector to power a small Stirling or Brayton engine/generator or a high-concentrator PV module mounted at the focus of the dish. Dishes are 2-25 kW in size and can be used individually or in small groups for distributed, remote, or village power; or in clusters (1-10 MW_e) for utility-scale applications, including end-of-line support. They are easily hybridized with fossil fuel.

Technology Applications

- Nine parabolic trough plants, with a rated capacity of 354 MW_e, have been operating in California since the 1980s. Trough system electricity costs of about 12¢-14¢/kWh have been demonstrated commercially.
- Solar Two, a 10-MW_e pilot power tower with three hours of storage, provided all the information needed to scale up to a 30-100 MW commercial plant, the first of which is now being planned in Spain.
- A number of prototype dish/Stirling systems are currently operating in Nevada, Arizona, Colorado, and Spain. High levels of performance have been established; durability remains to be proven, although some systems have operated for more than 10,000 hours.

Current Status

- New commercial plants are being considered for California, Nevada, New Mexico, Colorado, and Arizona. A 1MW power plant began operation in Arizona in 2005.
- The 10-MW Solar Two pilot power tower plant operated successfully near Barstow, California, leading to the first commercial plant being planned in Spain.
- Operations and maintenance costs have been reduced through technology improvements at the commercial parabolic trough plants in California by 40%, saving plant operators $50 million.

Technology History

Organized, large-scale development of solar collectors began in the United States in the mid-1970s under the Energy Research and Development Administration (ERDA) and continued with the establishment of the U.S. Department of Energy (DOE) in 1978.

Troughs:

- Parabolic trough collectors capable of generating temperatures greater than 500ºC (932 F) were initially developed for industrial process heat (IPH) applications. Acurex, SunTec, and Solar Kinetics were the key parabolic trough manufacturers in the United States during this period.
- Parabolic trough development also was taking place in Europe and culminated with the construction of the IEA Small Solar Power Systems (SSPS) Project/Distributed Collector System in Tabernas, Spain, in 1981. This facility consisted of two parabolic trough solar fields – one using a single-axis tracking Acurex collector and one the double-axis tracking parabolic trough collectors developed by M.A.N. of Munich, Germany.
- In 1982, Luz International Limited (Luz) developed a parabolic trough collector for IPH applications that was based largely on the experience that had been gained by DOE/Sandia and the SSPS projects.
- Southern California Edison (SCE) signed a power purchase agreement with Luz for the Solar Electric Generating System (SEGS) I and II plants, which came online in 1985. Luz later signed a number of Standard Offer (SO) power purchase contracts under the Public Utility Regulatory Policies Act (PURPA), leading to the development of the SEGS III through SEGS IX projects. Initially, the plants were limited by PURPA to 30 MW in size; later this limit was raised to 80 MW. In 1991, Luz filed for bankruptcy when it was unable to secure construction financing for its 10th plant (SEGS X).
- The 354 MWe of SEGS trough systems are still being operated today. Experience gained through their operation will allow the next generation of trough technology to be installed and operated much more cost-effectively.

Power Towers:

- A number of experimental power tower systems and components have been field-tested around the world in the past 15 years, demonstrating the engineering feasibility and economic potential of the technology.
- Since the early 1980s, power towers have been fielded in Russia, Italy, Spain, Japan, and the United States.
- In early power towers, the thermal energy collected at the receiver was used to generate steam directly to drive a turbine generator.
- The U.S.-sponsored Solar Two was designed to demonstrate the dispatchability provided by molten-salt storage and to provide the experience necessary to lessen the perception of risk from these large systems.
- U.S. industry is currently pursuing a subsidized power tower project opportunity in Spain. This project, dubbed "Solar Tres," represents a 4x scale-up of the Solar 2 design.

Dish/Engine Systems:

- Dish/engine technology is the oldest of the solar technologies, dating back to the 1800s when a number of companies demonstrated solar-powered steam Rankine and Stirling-based systems.

- Development of modern technology began in the late 1970s and early 1980s. This technology used directly illuminated, tubular solar receivers, a kinematic Stirling engine developed for automotive applications, and silver/glass mirror dishes. Systems, nominally rated at 25 kWe, achieved solar-to-electric conversion efficiencies of around 30%. Eight prototype systems were deployed and operated on a daily basis from 1986 through 1988.
- In the early 1990s, Cummins Engine Company attempted to commercialize dish/Stirling systems based on free-piston Stirling engine technology. Efforts included a 5 to 10 kWe dish/Stirling system for remote power applications, and a 25 kWe dish/engine system for utility applications. However, largely because of a corporate decision to focus on its core diesel-engine business, Cummins canceled their solar development in 1996. Technical difficulties with Cummins' free-piston Stirling engines were never resolved.
- Current dish/engine efforts are being continued by three U.S. industry teams – Science Applications International Corp. (SAIC) teamed with STM Corp., Boeing with Stirling Energy Systems, and WG Associates with Sunfire Corporation. SAIC and Boeing together have five 25kW systems under test and evaluation at utility, industry, and university sites in Arizona, California, and Nevada. WGA has two 10kW systems under test in New Mexico, with a third off-grid system being developed in 2002 on an Indian reservation for water-pumping applications.

Technology Future

The levelized cost of electricity (in constant 2003$/kWh) for three CSP configurations are projected at:

	2003	2007	2012	2025
Trough	11.3	6.4	5.4	N/A
Power Tower	12.0	5.7	4.0	N/A
Dish/Engine	40.0	20.0	N/A	6

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

- Parabolic troughs have been commercialized and nine plants (354 MW total) have operated in California since the 1980s.
- A 64-MW parabolic trough plant is under construction near Boulder City, Nevada. Nevada Power and Sierra Pacific Power will purchase the power to comply with the solar portion of Nevada's renewable portfolio standard.
- The World Bank's Solar Initiative is pursuing CSP technologies for less-developed countries. The World Bank considers CSP to be a primary candidate for Global Environment Facility funding.

Market Context

- There is currently 350 MW of CSP generation in the United States, all of it in Southern California's Mojave Desert.
- Power purchase agreements have been signed for 800 MW of new dish/engine capacity in California. The plants are anticipated to come on-line within the next several years. Significant domestic and international interest will likely result in additional projects.
- According to a recent study commissioned by the Department of Energy, CSP technologies can achieve significantly lower costs (below 6¢/kWh) at modest production volumes.
- At Congress' request, DOE scoped out what would be required to deploy 1,000MW of CSP in the Southwest United States. DOE is actively engaged with the Western Governors' Association to map a strategy to deploy 1-4 GW of CSP in the Southwest by 2015.
- A near-term to midterm opportunity exists to build production capacity in the United States for both domestic use and international exports.

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).

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Market Data

U.S. Installations (electric only)

Source: *Renewable Electric Plant Information System (REPiS)*, Version 7, NREL, 2003, and *Renewable Energy Technology Characterizations,* EPRI TR-109496.

Cumulative (MW)	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002
U.S.	0	24	274	354	364	364	364	364	354	354	354
Power Tower	0	10	0	0	10	10	10	10	0	0	0
Trough	0	14	274	354	354	354	354	354	354	354	354
Dish/Engine	0	0	0	0	0	0	0.125	0.125	0.125	0.125	0.125

Annual Generation from Cumulative Installed Capacity (Billion kWh)

Source: EIA, *Annual Energy Outlook* 1998-2006, Table A16, Renewable Resources in the Electric Supply, 1993, Table 4.

	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
U.S.	1*	0.82	0.90	0.89	0.89	0.87	0.49	0.54	0.54	0.57	0.58

* Includes both solar thermal and less than 0.02 billion kilowatthours grid-connected photovoltaic generation.

Annual U.S. Solar Thermal Shipments (Thousand Square Feet)

Source: EIA - *Annual Energy Review 2004,* Table 10.3 and *Renewable Energy Annual 2004* Table 30.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004[P]
Total[1]	19,398	NA	11,409	7,666	7,616	8,138	7,756	8,583	8,354	11,189	11,663	11,444	14,114
Imports	235	NA	1,562	2,037	1,930	2,102	2,206	2,352	2,201	3,502	3,068	2,986	3,723
Exports	1,115	NA	245	530	454	379	360	537	496	840	659	518	813

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

No data are available for 1985. [P] = Preliminary

Technology Performance

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

		2003	**2005**	**2007**	**2012**	**2018**	**2025**
Capacity Factor (%)	Power Tower	78	75	73	NA	72	NA
	Trough	28	39	56	56	NA	NA
	Dish	24	NA	24	NA	NA	50
Solar to Electric Eff. (%)	Power Tower	14	16	17	NA	18	NA
	Trough	13	13	16	17	NA	NA
	Dish	20	NA	23	NA	NA	26

Cost*		**2003**	**2005**	**2007**	**2012**	**2018**	**2025**
Total ($/kWe)	Power Tower	6800	4100	3500	NA	2500	NA
	Trough	2805	3556	3422	2920	NA	NA
	Dish	NA	NA	NA	NA	NA	NA
O&M ($/kWh)	Power Tower	.04	.01	.01	NA	.01	NA
	Trough	.02	.01	.01	.007	NA	NA
	Dish	NA	NA	NA	NA	NA	NA
Levelized Cost of Energy ($/kWh)	Power Tower	.12	.06	.06	NA	.04	NA
	Trough	.11	.10	.06	.05	NA	NA
	Dish	.40	NA	.20	NA	NA	.06