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ENERGY EFFICIENCY AND RENEWABLE ENERGY CLEARINGHOUSE

Concentrating Solar Power: Energy from Mirrors

Mirror mirror on the wall, what's the greatest energy source of all? The sun. Enough energy from the sun falls on the Earth everyday to power our homes and businesses for almost 30 years. Yet we've only just begun to tap its potential. You may have heard about solar electric power to light homes or solar thermal power used to heat water, but did you know there is such a thing as solar thermal-electric power? Electric utility companies are using mirrors to concentrate heat from the sun to produce environmentally friendly electricity for cities, especially in the southwestern United States.

The southwestern United States is focusing on concentrating solar energy because it's one of the world's best areas for sunlight. The Southwest receives up to twice the sunlight as other regions in the country. This abundance of solar energy makes concentrating solar power plants an attractive alternative to traditional power plants, which burn polluting fossil fuels such as oil and coal. Fossil fuels also must be continually purchased and refined to use.

Unlike traditional power plants, concentrating solar power systems provide an environmentally benign source of energy, produce virtually no emissions, and con-

Photo by Hugh Reilly, Sandia National Laboratories/PIX02186

This concentrating solar power tower system — known as Solar Two — near Barstow, California, is the world's largest central receiver plant.

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sume no fuel other than sunlight. About the only impact concentrating solar power plants have on the environment is land use. Although the amount of land a concentrating solar power plant occupies is larger than that of a fossil fuel plant, both types of plants use about the same amount of land because fossil fuel plants use additional land for mining and exploration as well as road building to reach the mines.

Individual trough systems currently can generate about 80 MW of electricity.

Other benefits of concentrating solar power plants include low operating costs, and the ability to produce power during high-demand energy periods and to help increase our energy security—our country's independence from foreign oil imports. Because they store energy, they can operate in cloudy weather and after sunset. When combined with fossil fuels as a hybrid system, they can operate around the clock regardless of weather. Concentrating solar power plants also create two and a half times as many skilled jobs as traditional plants.

Types of Systems

Unlike solar (photovoltaic) cells, which use light to produce electricity, concentrating solar power systems generate electricity with heat. Concentrating solar collectors use mirrors and lenses to concentrate and focus sunlight onto a thermal receiver, similar to a boiler tube. The receiver absorbs and converts sunlight into heat. The heat is then transported to a steam generator or engine where it is converted into electricity.

There are three main types of concentrating solar power systems: parabolic troughs, dish/engine systems, and central-receiver systems. These technologies can be used to generate electricity for a variety of applications, ranging from remote power systems as small as a few kilowatts (kW) up to grid-connected applications of 200-350 megawatts (MW) or more. A concentrating solar power system that produces 350 MW of electricity displaces the energy equivalent of 2.3 million barrels of oil.

Photo by Warren Gretz, NREL/PIX00033

Nine trough power plants in southern California, with a capacity of 354 MW, meet the energy needs of 350,000 people.

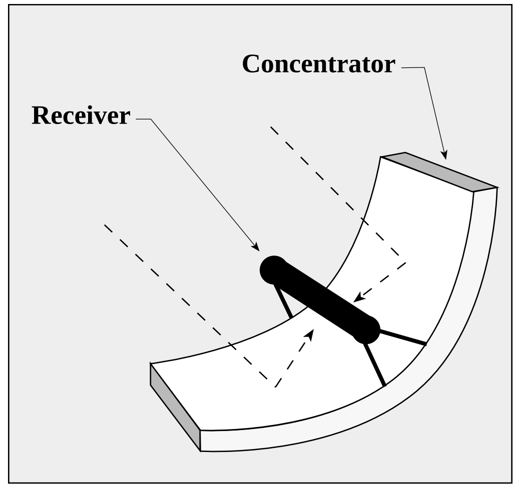

Fig. 1 A parabolic trough

Trough Systems

These solar collectors use mirrored parabolic troughs to focus the sun's energy to a fluid-carrying receiver tube located at the focal point of a parabolically curved trough reflector (see Fig.1 above). The energy from the sun sent to the tube heats oil flowing through the tube, and the heat energy is then used to generate electricity in a conventional steam generator.

Many troughs placed in parallel rows are called a "collector field." The troughs in the field are all aligned along a north-south axis so they can track the sun from east to west during the day, ensuring that the sun is continuously focused on the receiver pipes. Individual trough systems currently can generate about 80 MW of electricity. Trough designs can incorporate thermal storage—setting aside the heat transfer fluid in its hot phase—allowing for electricity generation several hours into the evening.

Currently, all parabolic trough plants are "hybrids," meaning they use fossil fuels to supplement the solar output during periods of low solar radiation. Typically, a natural gas-fired heat or a gas steam boiler/reheater is used. Troughs also can

Photo by Warren Gretz, NREL/PIX02342

This concentrating solar power system uses mirrors to focus highly concentrated sunlight onto a receiver that converts the sun's heat into energy.

be integrated with existing coal-fired plants.

Dish Systems

Dish systems use dish-shaped parabolic mirrors as reflectors to concentrate and focus the sun's rays onto a receiver, which is mounted above the dish at the dish center. A dish/engine system is a standalone unit composed primarily of a collector, a receiver, and an engine (see Fig.2 below). It works by collecting and concentrating the sun's energy with a dish-shaped surface onto a receiver that absorbs the energy and transfers it to the engine. The engine then converts that energy to heat. The heat is then converted to mechanical power, in a manner similar to conventional engines, by compressing the working fluid when it is cold, heating the compressed working fluid, and then expanding it through a turbine or with a piston to produce mechanical power. An electric generator or alternator converts the mechanical power into electrical power.

Dish/engine systems use dual-axis collectors to track the sun. The ideal concentrator shape is parabolic, created either by a single reflective surface or multiple reflectors, or facets. Many options exist for receiver and engine type, including Stirling cycle, microturbine, and concentrating photovoltaic modules. Each dish produces 5 to 50 kW of electricity and can be used independently or linked together to increase generating capacity. A 250-kW plant composed of ten 25-kW dish/engine systems requires less than an acre of land.

Individual dish/engine systems currently can generate about 25 kW of electricity.

Dish/engine systems are not commercially available yet, although ongoing demonstrations indicate good potential. Individual dish/engine systems currently can generate about 25 kW of electricity. More capacity is possible by connecting dishes together. These systems can be combined with natural gas, and the resulting hybrid provides continuous power generation.

Central Receiver Systems

Central receivers (or power towers) use thousands of individual sun-tracking mirrors called "heliostats" to reflect solar energy onto a receiver located on top of a tall tower. The receiver collects the sun's heat in a heat-transfer fluid (molten salt) that flows through the receiver. The salt's heat energy is then used to make steam to generate electricity in a conventional steam generator, located at the foot of the tower. The molten salt storage system retains heat efficiently, so it can be stored for hours or even days before being used to generate electricity. Therefore, a central receiver system is composed of five main components: heliostats, receiver, heat transport and exchange, thermal storage, and controls (see Fig. 3 on page 4).

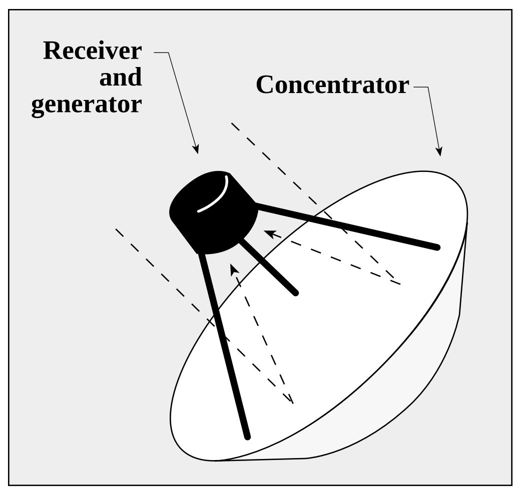

Fig. 2 A dish system

Solar One, Two, "Tres"

The U.S. Department of Energy (DOE), and a consortium of U.S. utilities and industry, built this country's first two large-scale, demonstration solar power towers in the desert near Barstow, California. Solar One operated successfully from

Power tower plants can potentially operate for 65 percent of the year without the need for a back-up fuel source.

Solar Two Power Tower

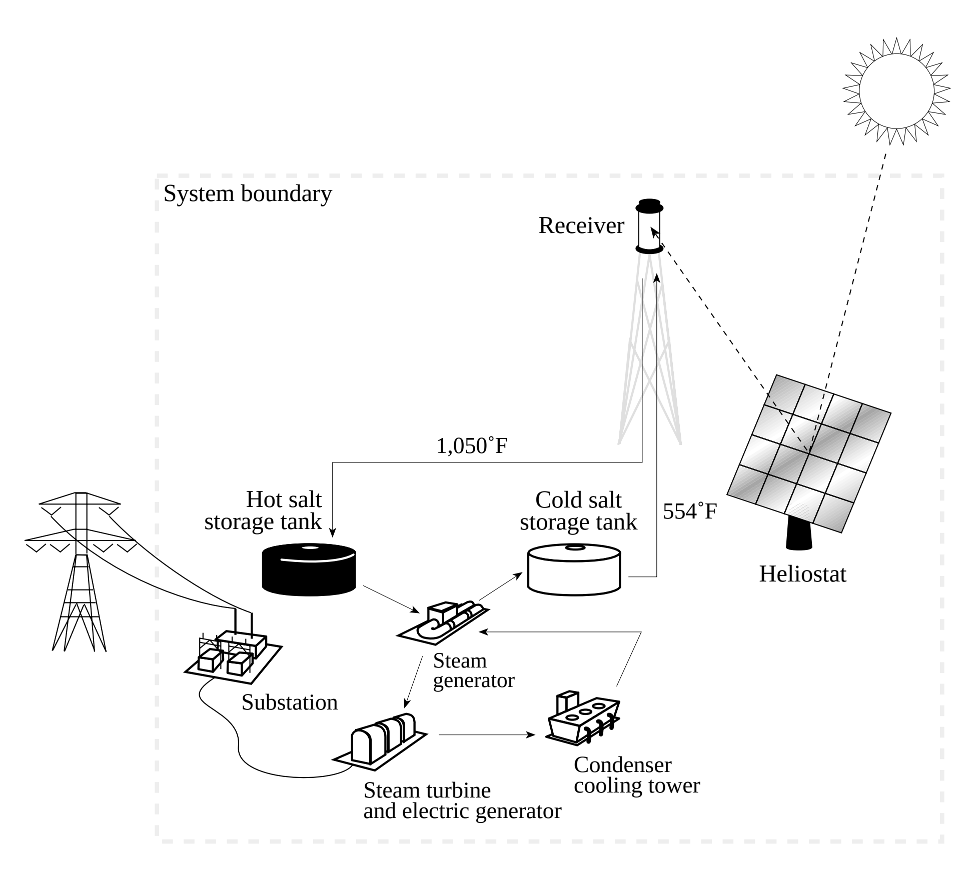

Fig. 3 Solar Two power tower system

Solar Two—a demonstration power tower located in the Mojave Desert—can generate about 10 MW of electricity. In this central receiver system, thousands of sun-tracking mirrors called heliostats reflect sunlight onto the receiver. Molten salt at 554ºF (290ºC) is pumped from a cold storage tank through the receiver where it is heated to about 1,050ºF (565ºC). The heated salt then moves on to the hot storage tank. When power is needed from the plant, the hot salt is pumped to a generator that produces steam. The steam activates a turbine/generator system that creates electricity. From the steam generator, the salt is returned to the cold storage tank, where it stored is and can be eventually reheated in the receiver.

By using thermal storage, power tower plants can potentially operate for 65 percent of the year without the need for a back-up fuel source. Without energy storage, solar technologies like this are limited to annual capacity factors near 25 percent. The power tower's ability to operate for extended periods of time on stored solar energy separates it from other renewable energy technologies.

Concentrating solar power technologies currently offer the lowest-cost solar electricity for large-scale power generation.

Photo by Warren Gretz, NREL/PIX 02156

Solar Two near Barstow, California.

1982 to 1988, proving that power towers work efficiently to produce utility-scale power from sunlight. The Solar One plant used water/steam as the heat-transfer fluid in the receiver; this presented several problems in terms of storage and continuous turbine operation. To address these problems, an upgrade of Solar One was planned — Solar Two. Solar Two operated from 1996 to 1999. Both systems had the capacity to produce 10 MW of power.

Solar Two demonstrated how nitrate salt (molten salt) could be used as the heat-transfer fluid in the receiver and as the heat storage media as well. At Solar Two, the molten nitrate salt reached approximately 1,050°F (565°C) in the receiver and then traveled to a storage tank, which had a capacity of 3 hours of storage. Solar Two demonstrated how solar energy can be stored efficiently and economically as heat in tanks of molten salt so that power can be produced even when the sun isn't shining. It also fostered commercial interest in power towers. Two of the project's key industry partners have been pursuing commercial solar power tower plant opportunities in Spain.

Solar energy premiums and other incentives under review in Spain create an attractive market opportunity, providing the economic incentives needed to reduce the initial high cost and risk of commercializing a new technology. The Spanish project, called "Solar Tres" or Solar Three, will use all the proven molten-salt technology of Solar Two, scaled up by a factor of three. Although Solar Two was a demonstration project, Solar Tres will be operated by industry as a long-term power production project. This utility-scale solar power could be a major source of clean energy worldwide, offsetting as much as 4 million metric tons of carbon equivalent through 2010.

Future Challenges

Solar technology has made huge technological and cost improvements, but more research and development remains to be done to make it cost-competitive with fossil fuels. Costs can be reduced by increasing demand for this technology worldwide, as well as through improved component design and advanced systems.

DOE estimates that by 2005, there will be as much as 500 MW of concentrating solar power capacity installed worldwide.

Photo by Warren Gretz, NREL/PIX 02334

A technician measures mirror surface quality on a dish concentrator.

Concentrating solar power technologies currently offer the lowest-cost solar electricity for large-scale power generation (10 MW-electric and above). Current technologies cost around $3 per watt or 12¢ per kilowatt-hour (kWh) of solar power. New innovative hybrid systems that combine large concentrating solar power plants with conventional natural gas combined cycle or coal plants can reduce costs to $1.5 per watt and drive the cost of solar power to below 8¢ per kWh. Advancements in the technology and the use of low-cost thermal storage will allow future concentrating solar power plants to operate for more hours during the day and shift solar power generation to evening hours. Future advances are expected to allow solar power to be generated for 4¢–5¢ per kWh in the next few decades.

Researchers are developing lower cost solar concentrators, high-efficiency engine/generators, and high-performance receivers. The goal is to further develop the technology to increase acceptance of the systems and help the systems penetrate growing domestic and international energy markets.

Future Opportunities

Developing countries in Asia, Africa, and Latin America—where half the population is currently without electricity and sunlight is usually abundant—represent the biggest and fastest growing market for power producing technologies. A number of projects are being developed in India, Egypt, Morocco, and Mexico. In addition, independent power producers are in the early stages of design and development for potential parabolic trough power projects in Greece (Crete) and Spain. If successful, these projects could open the door for additional project opportunities in these and other developing countries.

The southwestern United States can also benefit from the use of these systems. Because the Southwest gets up to twice as much sunlight as the rest of the country, many southwestern states (California, Nevada, Arizona, and New Mexico) are exploring the use of concentrating solar power, especially for use in public utilities.

One key competitive advantage of concentrating solar energy systems is their close resemblance to most power plants. Concentrating solar power technologies use many of the same technologies and equipment used by conventional power plants; they simply substitute the concentrating power of the sun for the combustion of fossil fuels to provide the energy for conversion into electricity.

DOE analysts predict the opening of specialized niche markets in this country for the solar power industry between 2005 and 2010. DOE estimates that by 2005, there will be as much as 500 MW of concentrating solar power capacity installed worldwide. By 2020, more than 20 gigawatts of concentrating solar power systems could be installed throughout the world.

Resources

The following are sources of additional information on concentrating solar power technologies. This list is not exhaustive, nor does the mention of any resource constitute a recommendation or endorsement.

Ask an Energy Expert
DOE's Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
1-800-DOE-EREC (363-3732)
TDD: 1-800-273-2957
Fax: (703) 893-0400
E-mail: doe.erec@nciinc.com
Online submittal form:
www.eren.doe.gov/menus/energyex.html
Consumer Energy Information Web site:
www.eren.doe.gov/consumerinfo/

Energy experts at EREC provide free general and technical information to the public on many topics and technologies pertaining to energy efficiency and renewable energy.

DOE's Energy Efficiency and Renewable Energy Network (EREN)
Web site: www.eren.doe.gov

Your comprehensive online resource for DOE's energy efficiency and renewable energy information.

Organizations

American Solar Energy Society (ASES)
2400 Central Avenue, Ste. G-1
Boulder, CO 80301
Phone: (303) 443-3130
Fax: (303) 443-3212
E-mail: ases@ases.org
Web site: www.ases.org

A national organization dedicated to advancing the use of solar energy for the benefit of U.S. citizens and the global environment.

DOE's Concentrating Solar Power Program

Web site: www.eren.doe.gov/csp/

Leads a national effort to develop clean, competitive, and reliable power options using concentrated sunlight.

DOE's SunLab
Web site: www.eren.doe.gov/sunlab/

Combines the expertise of Sandia National Laboratories and the National Renewable Energy Laboratory (NREL) to assist industry in developing and commercializing concentrating solar power technologies.

Solar Energy and Energy Conversion Laboratory
University of Florida
Mechanical Engineering
Box 116300
Gainesville, FL 32611-6300
Phone: (352) 392-0812
Fax: (352) 392-1071
E-mail: solar@cimar.me.ufl.edu
Web site: www.me.ufl.edu/SOLAR/

Performs fundamental and interdisciplinary engineering applications-oriented research in many areas of solar energy, energy conversion, energy conservation and space power systems.

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Solar Energy Industries Association (SEIA)
1616 H Street, NW 8th Floor
Washington, DC 20006
Phone: (202) 628-7979; (301) 951-3231
Fax: (202) 628-7779
Web site: www.seia.org/

A national trade association of solar energy manufacturers, dealers, distributors, contractors, and installers.

SolarPACES
International Energy Agency (IEA)
9 rue de la Fédération
75739 Paris Cedex 15
France
Phone: (+33) 140 57 65 51
Fax: (+33) 140 57 65 59
E-mail: info@iea.org
Web site: www.solarpaces.org/
IEA Web site: www.iea.org/

Provides a focus for the worldwide development of solar thermal power and solar chemical energy systems.

Web Sites

A Compendium of Solar Dish/Stirling Technology
Solstice
Web site: solstice.crest.org/renewables/dish-stirling/

Distributed Power Technologies—Concentrating Solar Power
DOE's Distributed Power Program
Web site: eren.doe.gov/distributedpower/pages/tech_csp.html

NREL Photographic Information eXchange (PIX)
Web site: www.nrel.gov/data/pix

Features a collection of photos on renewable energy and energy efficiency technologies.

Parabolic Troughs: Solar Power Today
EREN
Web site: www.eren.doe.gov/success_stories/opt_parabolic.html

TroughNet
DOE's SunLab
Web site: www.eren.doe.gov/troughnet/

Further Reading

Solar Trough Power Plants: Concentrating Power Plants Have Provided Continuous Generation Since 1984, produced by NREL for DOE, August 2000.
Available in HTML at
www.eren.doe.gov/power/success_stories/solar_troughs.html
and in PDF at
www.eren.doe.gov/power/success_stories/pdfs/solar_troughs.pdf.

Power Towers: Proving the Technical Feasibility and Cost Potential of Generating Large-Scale Electric Power from the Sun When It Is Needed, produced by NREL for DOE, August 2000. Available in HTML at
www.eren.doe.gov/power/success-stories/power_tower.html
and in PDF at
www.eren.doe.gov/power/success_stories/pdfs/power_tower.pdf.