OVERVIEW OF SOLAR THERMAL TECHNOLOGIES

Introduction

There are three solar thermal power systems currently being developed by U.S. industry: parabolic troughs, power towers, and dish/engine systems. Because these technologies involve a thermal intermediary, they can be readily hybridized with fossil fuel and in some cases adapted to utilize thermal storage. The primary advantage of hybridization and thermal storage is that the technologies can provide dispatchable power and operate during periods when solar energy is not available. Hybridization and thermal storage can enhance the economic value of the electricity produced and reduce its average cost. This chapter provides an introduction to the more detailed chapters on each of the three technologies, an overview of the technologies, their current status, and a map identifying the U.S. regions with best solar resource.

Parabolic Trough systems use parabolic trough-shaped mirrors to focus sunlight on thermally efficient receiver tubes that contain a heat transfer fluid (Figure 1). This fluid is heated to 390°C (734°F) and pumped through a series of heat exchangers to produce superheated steam which powers a conventional turbine generator to produce electricity. Nine trough systems, built in the mid to late 1980's, are currently generating 354 MW in Southern California. These systems, sized between 14 and 80 MW, are hybridized with up to 25% natural gas in order to provide dispatchable power when solar energy is not available.

Cost projections for trough technology are higher than those for power towers and dish/engine systems due in large part to the lower solar concentration and hence lower temperatures and efficiency. However, with 10 years of operating experience, continued technology improvements, and O&M cost reductions, troughs are the least expensive, most reliable solar technology for near-term applications.

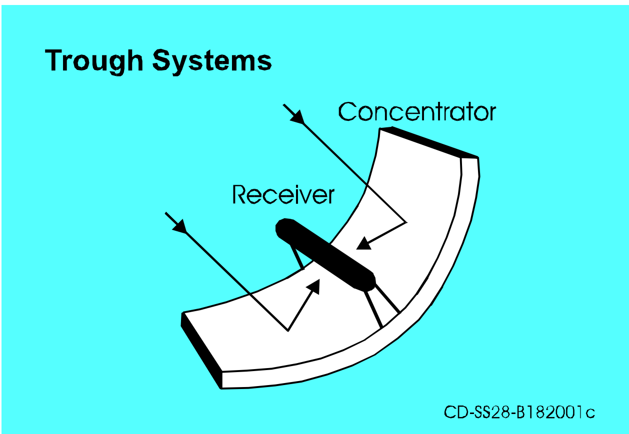

Figure 1. Solar parabolic trough.

Power Tower systems use a circular field array of heliostats (large individually-tracking mirrors) to focus sunlight onto a central receiver mounted on top of a tower (Figure 2). The first power tower, Solar One, which was built in Southern California and operated in the mid-1980's, used a water/steam system to generate 10 MW of power. In 1992, a consortium of U.S. utilities banded together to retrofit Solar One to demonstrate a molten-salt receiver and thermal storage system.

The addition of this thermal storage capability makes power towers unique among solar technologies by promising dispatchable power at load factors of up to 65%. In this system, molten-salt is pumped from a “cold” tank at 288°C

(550°F) and cycled through the receiver where it is heated to 565°C (1,049°F) and returned to a "hot" tank. The hot salt can then be used to generate electricity when needed. Current designs allow storage ranging from 3 to 13 hours.

"Solar Two" first generated power in April 1996, and is scheduled to run for a 3-year test, evaluation, and power production phase to prove the molten-salt technology. The successful completion of Solar Two should facilitate the early commercial deployment of power towers in the 30 to 200 MW range.

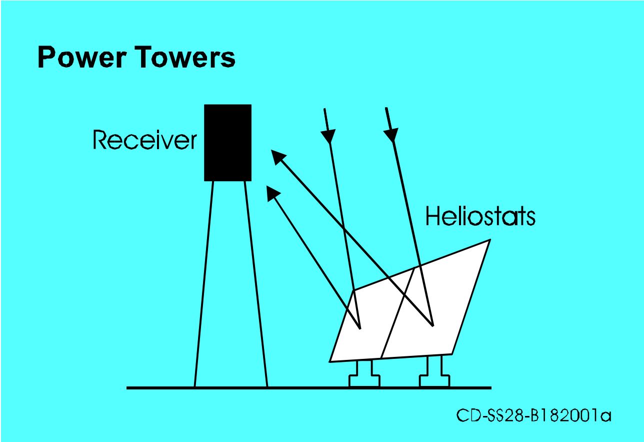

Figure 2. Solar power tower.

Dish/Engine systems use an array of parabolic dish-shaped mirrors (stretched membrane or flat glass facets) to focus solar energy onto a receiver located at the focal point of the dish (Figure 3). Fluid in the receiver is heated to 750°C (1,382°F) and used to generate electricity in a small engine attached to the receiver. Engines currently under consideration include Stirling and Brayton cycle engines. Several prototype dish/engine systems, ranging in size from 7 to 25 $kW_{e,}$ have been deployed in various locations in the U.S. and abroad.

High optical efficiency and low startup losses make dish/engine systems the most efficient (29.4% record solar to electricity conversion) of all solar technologies. In addition, the modular design of dish/engine systems make them a good match for both remote power needs in the kilowatt range as well as hybrid end-of-the-line grid-connected utility applications in the megawatt range. If field validation of these systems is successful in 1998 and 1999, commercial sales could commence as early as 2000.

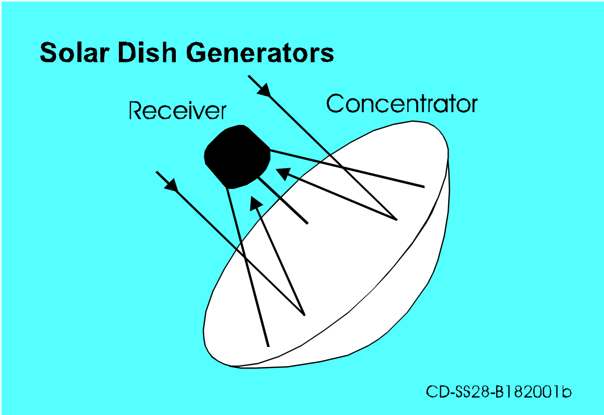

Figure 3. Solar dish/engine system.

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Technology Comparison

Table 1 below highlights the key features of the three solar technologies. Towers and troughs are best suited for large, grid-connected power projects in the 30-200 MW size, whereas, dish/engine systems are modular and can be used in single dish applications or grouped in dish farms to create larger multi-megawatt projects. Parabolic trough plants are the most mature solar power technology available today and the technology most likely to be used for near-term deployments. Power towers, with low cost and efficient thermal storage, promise to offer dispatchable, high capacity factor, solar-only power plants in the near future. The modular nature of dishes will allow them to be used in smaller, high-value applications.

Towers and dishes offer the opportunity to achieve higher solar-to-electric efficiencies and lower cost than parabolic trough plants, but uncertainty remains as to whether these technologies can achieve the necessary capital cost reductions and availability improvements. Parabolic troughs are currently a proven technology primarily waiting for an opportunity to be developed. Power towers require the operability and maintainability of the molten-salt technology to be demonstrated and the development of low cost heliostats. Dish/engine systems require the development of at least one commercial engine and the development of a low cost concentrator.

Table 1. Characteristics of solar thermal electric power systems.

	Parabolic Trough	Power Tower	Dish/Engine
Size	30-320 MW*	10-200 MW*	5-25 kW*
Operating Temperature (ºC/ºF)	390/734	565/1,049	750/1,382
Annual Capacity Factor	23-50%*	20-77%*	25%
Peak Efficiency	20%(d)	23%(p)	29.4%(d)
Net Annual Efficiency	11(d')-16%*	7(d')-20%*	12-25%*(p)
Commercial Status	Commercially Available	Scale-up Demonstration	Prototype Demonstration
Technology Development Risk	Low	Medium	High
Storage Available	Limited	Yes	Battery
Hybrid Designs	Yes	Yes	Yes
Cost			
$/m^2	630-275*	475-200*	3,100-320*
$/W	4.0-2.7*	4.4-2.5*	12.6-1.3*
$/W$_p$ †	4.0-1.3*	2.4-0.9*	12.6-1.1*

* Values indicate changes over the 1997-2030 time frame.

† $/W$_p$ removes the effect of thermal storage (or hybridization for dish/engine). See discussion of thermal storage in the power tower TC and footnotes in Table 4.

(p) = predicted; (d) = demonstrated; (d') = has been demonstrated, out years are predicted values

Cost Versus Value

Through the use of thermal storage and hybridization, solar thermal electric technologies can provide a firm and dispatchable source of power. Firm implies that the power source has a high reliability and will be able to produce power when the utility needs it. Dispatchability implies that power production can be shifted to the period when it is needed. As a result, firm dispatchable power is of value to a utility because it offsets the utility's need to build and operate new power plants. This means that even though a solar thermal plant might cost more, it can have a higher value.

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Solar Thermal Power Cost and Development Issues

The cost of electricity from solar thermal power systems will depend on a multitude of factors. These factors, discussed in detail in the specific technology sections, include capital and O&M cost, and system performance. However, it is important to note that the technology cost and the eventual cost of electricity generated will be significantly influenced by factors "external" to the technology itself. As an example, for troughs and power towers, small stand-alone projects will be very expensive. In order to reduce the technology costs to compete with current fossil technologies, it will be necessary to scale-up projects to larger plant sizes and to develop solar power parks where multiple projects are built at the same site in a time phased succession. In addition, since these technologies in essence replace conventional fuel with capital equipment, the cost of capital and taxation issues related to capital intensive technologies will have a strong effect on their competitiveness.

Solar Resources

Solar resource is one of the most important factors in determining performance of solar thermal systems. The Southwestern United States potentially offers the best development opportunity for solar thermal electric technologies in the world. There is a strong correlation between electric power demand and the solar resource due largely to the air conditioning loads in the region. Figure 4 shows the direct normal insolation for the United States.

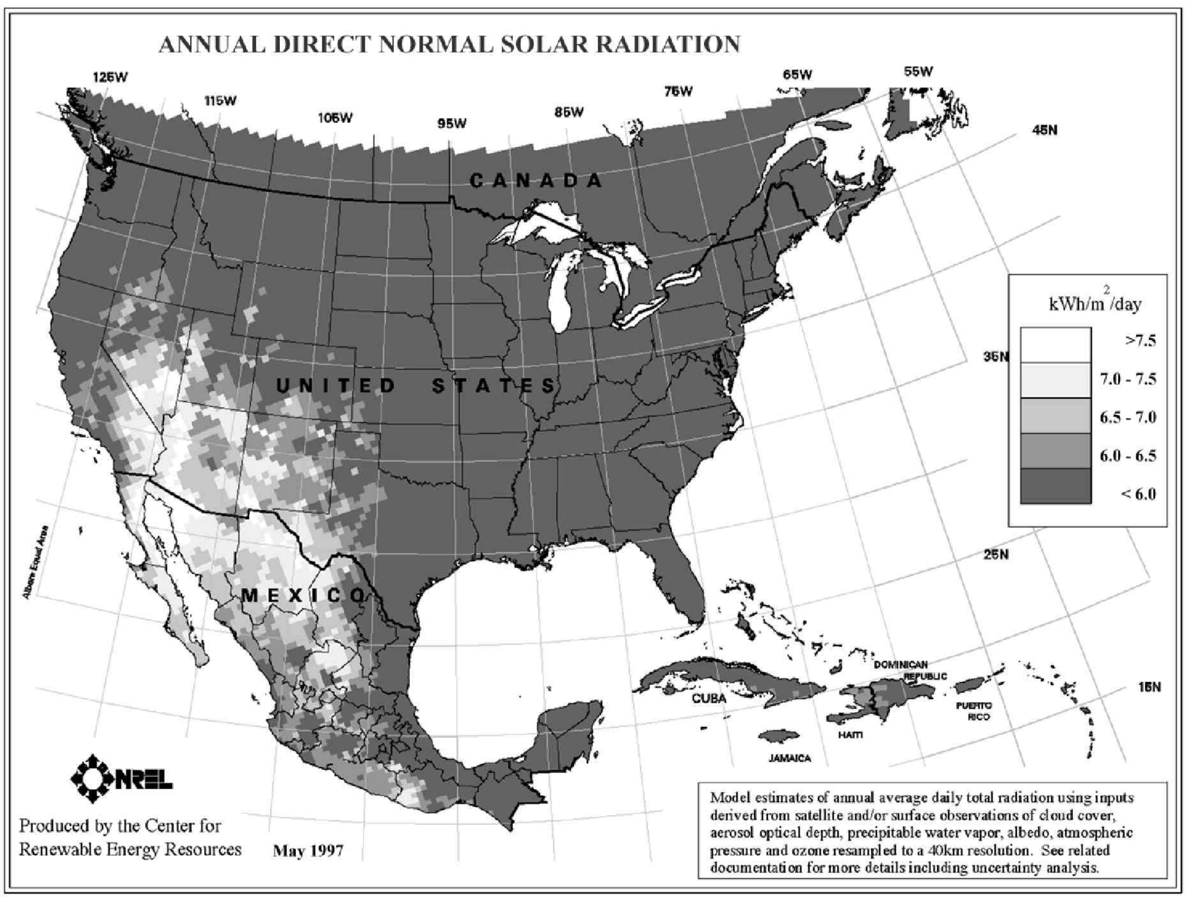

Figure 4. Direct normal insolation resource.

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Summary

Solar thermal power technologies are in different stages of development. Trough technology is commercially available today, with 354 MW currently operating in the Mojave Desert in California. Power towers are in the demonstration phase, with the 10 MW Solar Two pilot plant located in Barstow, CA., currently undergoing at least two years of testing and power production. Dish/engine technology has been demonstrated. Several system designs are under engineering development, a 25 kW prototype unit is on display in Golden, CO, and five to eight second-generation systems are scheduled for field validation in 1998. Solar thermal power technologies have distinct features that make them attractive energy options in the expanding renewable energy market worldwide. Comprehensive reviews of the solar thermal electric technologies are offered in References 1 and 2.

References

1. Status Report on Solar Thermal Power Plants, Pilkington Solar International: 1996. Report ISBN 3-9804901-0-6.

2. Holl, R.J., Status of Solar-Thermal Electric Technology, Electric Power Research Institute: December 1989. Report GS- 6573.

3. Mancini, T., G.J. Kolb, and M. Prairie, “Solar Thermal Power”, Advances in Solar Energy: An Annual Review of Research and Development, Vol. 11, edited by Karl W. Boer, American Solar Energy Society, Boulder, CO, 1997, ISBN 0-89553-254-9.