Hawaii Renewable Energy Development Venture
Technology Assessment

Solar Thermal Power Plants

1. Overview:

Solar thermal power plants, also known as concentrating solar plants (CSP), use large arrays of mirrors to concentrate solar energy and produce high temperature heat. The heat is then used in a turbine or engine to generate electricity. The three solar thermal technologies in use today are parabolic trough, parabolic dish-engine, and central receiver. Parabolic troughs use long lines of u-shaped mirrors to focus solar energy on a tube containing a heat transfer fluid, which is typically oil. The heat transfer fluid is then used to produce steam and generate electricity in a traditional steam turbine and generator. Parabolic dish-engine plants arrange mirrors in a configuration similar to a satellite dish and concentrate solar energy on a power conversion unit. In this unit, solar energy heats a working fluid, which is usually hydrogen gas, and powers an engine with an electricity generator. High efficiency Stirling engines are typically used in these plants and the units are modular with capacities ranging from 10 to 25 KW. Central receiver plants use a large field of mirrors, known as heliostats, to focus energy on a centrally located tower. The tower contains a heat transfer fluid, which is usually molten salt, and the heat is then used to produce steam and generate electricity.

A limited number of power plants have been built and operated using each of three technologies, and the technologies are at different stages of commercial readiness. Currently, the solar thermal industry is growing rapidly and numerous proposals are in varying stages of development in the Southwest United States, Europe, Africa, and the Middle East that would significantly expand the installed capacity of these technologies. Because solar thermal plants utilize direct normal insolation and require large tracts of flat land for the mirrors, they have been primarily developed in desert areas. Solar thermal plants are currently less expensive than electricity produced from photovoltaic arrays and have estimated levelized costs of electricity (LCOE) that is competitive with electricity produced from natural gas-fueled combustion turbines (approximately 12-15 cents per kwh) (Stoddard et al., 2006). With ongoing expansions in installed capacity, the LCOE is expected to decline.

Many of the current solar thermal projects are proposing to include heat storage or “hybridize” with fossil fuel plants, and these options offer advantages over many other renewable technologies. Solar thermal plants that store heat for several hours can mitigate some of the intermittency problems associated with the variable solar resource. Heat storage can also help the power plant operator match plant output more closely with system peak demand in locations where the peak solar resource and electricity demand may differ by a few hours. Another option with solar thermal plants is to “hybridize” with fossil fuel plants to provide a more reliable power source in comparison to other renewable technologies. In current plants, hybrid plants use fossil fuel (typically natural gas) as a backup to produce heat during periods with low or no solar resource. New plants are proposing to add the steam from solar thermal plants directly into the steam cycle of a combined cycle plant. Current research is also analyzing the opportunities to add steam generated from solar thermal plants directly into the steam cycle of existing coal plants (EPRI, 2009).

2. Status of commercial readiness:

The three solar thermal technologies are at different stages of commercial readiness. Parabolic trough plants have the most extensive operating experience and are considered an early commercial technology (Black and Veatch, 2005). Beginning in 1984, the first parabolic trough plants were built in the Mojave Desert and are known as the Solar Electric Generating System (SEGS) project. A total of nine units were built between 1984 and 1991 with a combined nameplate capacity of 354 MW. These plants remain in operation today and in 2007 produced 675 GWh of electricity. From 1991 to 2007, average annual generation from these power plants averaged 775 GWh (California Energy Commission, 2009a). These plants do not utilize energy storage but do use natural gas as a backup energy source to produce steam. After completion of the SEGS plants in 1991, no new plants were built in the United States until the Sagauro Solar Generating Station in Tucson, AZ came online in 2006 (DOE Energy Efficiency and Renewable Energy, 2007). Given the continuous operating experience of the SEGS plants, parabolic trough plants are considered the most advanced of all the solar thermal power plants (Black and Veatch, 2005).

Parabolic dish-engine and central receiver power plants have been tested in the United States but have less extensive operating experience. Parabolic dish-engine technologies actually date back to the 1800's but modern technology development started in the late 1970's and early 1980's. Since that time, several prototype units have been tested and most recently a six dish test system was installed at the Sandia National Laboratory in 2005 (SolarPACES, 1997; Stoddard et al., 2006). No commercial power plants are currently using this technology and for this reason it is considered at a demonstration phase (Black and Veatch, 2005). Central receiver plants are at an even earlier stage of technological development. An experimental central receiver plant was first built and operated in California from 1982 to 1986 (known as Solar One) and it was later reopened in 1996 until 1999 (known as Solar Two) (California Energy Commission, 2009b). No central receiver power plants are currently in operation in the United States and this technology is still considered in research and development (Black and Veatch, 2005).

There is currently considerable commercial interest in new solar thermal plants in the United States, Europe, Africa, and the Middle East. In California, over 5 GW of new capacity is in various stages of permitting but not in operation yet, and over half of this proposed capacity is using parabolic trough technology (California Energy Commission, 2009b). Other regions of the world are also experiencing similar rapid growth in solar thermal capacity. In Spain, over 100 MW of new capacity recently began operation and several hundred more is under construction (Abengoa Solar, 2009; SolarPACES, 2007). Israel has committed to building a 100 MW plant with potential for expansion to 500 MW. The World Bank and Global Environment Facility (GEF) are supporting numerous hybrid solar thermal combined cycle power plants in developing countries (SolarPACES, 2007).

Most of this proposed new capacity is utilizing parabolic trough technology; however, a considerable amount of new capacity is expected to use both parabolic dish-engine and central receiver technologies. In California, solar developers are proposing over 1.5 GW of new capacity using parabolic dish plants with Stirling engines and over 500 MW of capacity using central receiver technology (California Energy Commission, 2009b). Additional plants using these technologies are proposed in Spain (Abengoa Solar, 2009).

A demonstration solar thermal power plant is also operating in Hawai‘i and a commercial pilot plant is under construction. Sopogy, Inc. has been testing a small-scale parabolic trough plant at the Natural Energy Laboratory of Hawai‘i Authority (NELHA) on the island of Hawai‘i and in 2008 began constructing a pilot micro-scale solar thermal plant.

With Hawaii’s substantial solar resource and the favorable economics of solar thermal relative to many other renewable technologies, solar thermal has considerable promise in Hawai‘i. However, several issues remain in successfully deploying the technology here. Some of these include high capital costs, the plants can be both land- and water-intensive, and the variability of the solar resource.

In a recent renewable energy technology assessment on Kaua‘i, the engineering firm Black and Veatch estimated the current LCOE for a parabolic trough plant at 13-16 cents per kwh with potential for future cost decreases. An important issue is that most new projects currently in development are achieving cost reductions by increasing the project size to capture economies of scale. Because of the limited land area suitable for solar thermal power and the high cost of land in Hawai‘i, large scale projects may be difficult to site and may not achieve cost reductions of similar magnitude to other locations.

Data on current projects shows that solar thermal plants are land intensive and may also require substantial freshwater sources. Black and Veatch estimated that a 228 MW plant without storage could meet all of Kauai’s current annual energy demand and would require approximately 1350 acres, which is a ratio of approximately 6 acres per MW of capacity. The SEGS projects in California have an average footprint of roughly 5 acres per MW of capacity. Given these values, even modest size solar thermal plants from 25-50 MW (most current proposals on the mainland are over 100 MW) could potentially require up to several hundred acres of land. Since the Leeward sides of the islands primarily have the land best suited for solar thermal plants and on many islands these areas are highly valued for residential and resort development, there may be a limited number of feasible sites for large-scale solar thermal plants.

The demand for water in these power plants may also be a concern. The plants use water primarily in the cooling cycle and some water is required to clean mirrors. The level of water consumption is highly dependent on the type of cooling system used in the steam cycle. A water-cooled plant consumes a considerable amount of water and is estimated at approximately 800 gallons per MWh. This rate is approximately 60% higher than the rate of water consumption in a coal or nuclear plant and over 4 times higher than a natural gas combined cycle plant. Water consumption in an air-cooled plant is estimated at 79 gallons per MWh but these cooling cycles have higher capital costs and lower efficiencies in producing electricity (DOE, 2008). Most of Hawaii's large power plants use once-through cooling with seawater, which could be costly and difficult to permit for an individual solar thermal plant. Although, a hybrid solar thermal plant built at an existing power plant could possibly utilize the existing cooling system. Finally, approximately 2% of total water consumption at solar thermal plants is used to clean mirrors (DOE, 2008).

Another technical issue with solar thermal plants is the variability of the solar resource. The current SEGS plants have a fossil fuel backup system to produce heat when the solar resource is unavailable or insufficient. Most current proposals include heat storage systems of varying time durations to mitigate intermittency and help the plant's output match peak electricity demand. While these options help the plants mitigate against highly variable output and provide a level of dispatchability adequate to provide power during periods of intermediate and peak demand, the plants are not designed to provide fully dispatchable, baseload power similar to a coal plant. The exception to this limitation is hybrid plants that are combined with combined cycle or coal plants.

Given some of the limitations noted above about conventional solar thermal plants, small-scale distributed solar thermal technology could be a game-changing technology with significant upside potential in Hawai'i. This could include the small-scale parabolic trough designs Sopogy is currently developing but also parabolic dish-engine plants that are modular in units less than 25KW. The technologies could be used as distributed generation resources and avoid the challenges of siting large-scale plants.

A second potential application of interest in Hawai'i is to hybridize existing or new steam plants with solar thermal technology. Some of Hawaii's current power plants are located in areas with good solar resources and may have enough land adjacent to the plant suitable for solar thermal collectors. New power plants that use a steam cycle could also be combined with a solar thermal plant, which would save fuel in plants supplied by fossil fuel, biofuel, or biomass. The potential for hybrid plants would be highly site specific because the solar thermal plant is most efficient when it is adjacent to the power plant.

3. Appropriateness to Hawai'i

With Hawaii's abundant solar resource and the relatively lower cost of solar thermal in comparison to other renewable technologies, solar thermal power could be highly appropriate to Hawai'i. Due to the limitations described earlier, the small-scale solar thermal technologies could be the most appropriate in Hawai‘i and could be used as distributed generation sources. In these applications, solar thermal power could to help facilitate other large-scale renewable energy projects. Solar thermal plants operating below full capacity could use some of the stored heat to increase output during critical situations, such as a rapid decline in wind power output. This resource when combined with other distributed generation sources and demand-reducing technologies could provide greater flexibility for system operators. The stored energy would not have the same rapid response time as some storage technologies, such as batteries. However, it could still prove useful as part of an array of strategies to manage large-scale intermittent renewable energy sources.

Hybrid solar thermal plants may also be appropriate for reducing fossil fuel consumption in some existing power plants where sufficient solar resource and land is available. This option could also be used as to save fuel in future firm power sources, as noted above. In these plants, adding the solar thermal heat would reduce the power plant's variable fuel cost (but increase the capital cost).

4. Considerations related to specific technologies and/or resources

For renewable energy resource technologies, availability of the resource in the state may be a significant assessment factor. For bioenergy technologies, for example, additional questions may include:

As noted earlier, Hawai‘i has significant solar resources on land that is suitable for solar thermal power plants. For example, Black and Veatch estimated that a 114 MW solar thermal plant with storage could provide enough energy generation to meet all of Kauai's current annual demand. While the solar resource in Hawai‘i is abundant, land is a valuable commodity and power generation would have to compete with other potential land uses, such as residential development and agriculture. For this reason, the number of suitable sites for large-scale solar thermal plants is probably limited. A solar thermal power plant is currently operating in Hawai‘i and further development of this resource could be available in the near term.

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