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11/02/08
Energy & The Environment

Solar Thermal Industry

Since the beginnings of time, humans have relied on heat from the sun as a source of energy. The solar thermal electricity industry in the United States has been trying to capitalize on solar radiation as a fuel source since the 1980s. However, the lack of technology combined with the low cost of conventional fuels such as crude oil and natural gas have created economic hurdles for the solar thermal industry in the past. With rising concerns over the emission of green house gasses and increased federal incentives, the market is ripe yet again for electricity derived from solar thermal power.

Solar power plants operate in a similar manner to traditional coal-powered steam plants. In a solar thermal power plant, a series of mirrors reflect heat and light from the sun to convert water into steam, which is then run through a turbine to generate electricity. The solar thermal electricity industry generated a total of .54 billion kWh in 2005 and .49 billion kWh in 2006.[1] This figure is expected to rise to 2.18 billion kWh in 2030, representing 6.4% annual growth.[2] In 2005, the electric power industry consumed .01 quadrillion BTU of all marketable solar thermal electricity, whereas the commercial sector consumed .02 quadrillion BTU of non-marketed renewable energy derived from solar thermal.[3]

The solar thermal industry exhibited steady growth over the past 10 years primarily driven by low-temperature solar thermal collector sales. In 1998, the Energy Information Administration reported shipments of 7,756 thousand sq feet of solar thermal collectors from 28 companies.[4] In 2007, 60 companies shipped a total of 15,153 thousand sq feet of solar thermal collectors.[5] Low-temperature solar collectors, commonly used to heat water, made up 75% of solar thermal shipments in 2006.[6] Due to the lack of recent solar thermal power plant construction, the shipment of high-temperature solar collectors has been negligible. However, solar thermal collector shipment peaked in 2006 at 20.7 million sq feet partially due to the increased demand for high-temperature collectors as a result of Nevada's 64 MW Solar One power plant.[7]

Large scale electricity generation from solar thermal was first introduced to the United States by Luz International Limited, an American/Israeli company. From 1984 to 1990, Luz built and sold a total of nine solar thermal parabolic trough plants in California's Mojave Desert. These plants, named SEGS I-IX, had operating capacities ranging from 14 MW (SEGS I) to 80

1 Energy Information Administration. “Energy Outlook 2008”. June 2008. Available at <http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2008).pdf>.
2 Ibid.
3 Ibid.
4 Energy Information Administration. “Solar Thermal”. Available at <http://www.eia.doe.gov/cneaf/solar.renewables/page/solarthermal/solarthermal.html>.
5 Ibid.
6 Energy Information Administration. “Solar Thermal Collector Shipments by Type, Quantity, Revenue, and Average Price, 2006 and 2007”. October 2008. Available at <http://www.eia.doe.gov/cneaf/solar.renewables/page/solarreport/table2_12.pdf>.
7 Energy Information Administration. “Solar Thermal and Photovoltaic Collector Manufacturing Activities 2006”. October 2007. Available at <http://tonto.eia.doe.gov/FTPROOT/renewables/017406.pdf>.

MW (SEGS IX) for a total of 354 MW.[8] The SEGS I plant generated electricity at a rate of $0.24/kWh when it was first introduced. However, Luz's experience and knowledge translated into SEGS IX operating at $0.08/kWh.[9] Despite having to file for bankruptcy in 1991 due to low energy prices along with "the phasing out of state and federal investment tax credits", Luz was successful in demonstrating that economies of scale would help the solar thermal industry compete with electricity generated by conventional sources.[10]

Almost all commercially operated solar thermal power plants in the United States rely on parabolic trough technology to generate electricity. Parabolic trough power plants have a network of pipes that run down the middle of the concave troughs. The troughs focus solar energy on the pipeline, which heats a fluid with a high heat capacity. As the fluid finishes its cycle through the parabolic trough piping system, its thermal energy is used to convert water into steam via a heat exchanger. The steam is then used to power a traditional steam turbine. To operate at low solar irradiance levels, solar thermal power plants rely on thermal storage units or burn natural gas in low quantities.

The SEGS power plants, all of which use parabolic trough technology, have provided California's grid with reliable power for the past 24 years. As a result, parabolic troughs are considered to be the most mature method with the lowest technical and financial risks required to generate electricity from solar energy.[11] In 2007, the real levelized cost of electricity from a parabolic trough power plant was $125/MWh including a 30 percent investment tax credit as mandated by the Energy Policy Act of 2005.[12] Parabolic troughs benefit from low capital costs and a high maximum conversion efficiency. In 2002, construction of a basic 100 MW solar thermal plant using parabolic trough technology was $1,956/kW.[13] The addition of a thermal storage unit resulted in a $103/kWh price increase, and a fossil fuel hybridization system augmented the costs by $196/kW.[14] Current parabolic trough power plants have an maximum conversion efficiency of 24 percent, but only operate at an annual average efficiency of 13 percent.[15] By upgrading heat collectors on certain SEGS power plants, operators increased heat collection efficiency by 18 percent.[16] The Sargent & Lundy consulting group claims technological improvements in regards to advanced thermal storage coupled with higher rated heat-transfer fluids and improved high-temperature solar collectors will all have a sizable impact on the solar thermal industry in the years to come.[17] By 2020, power plants that implement parabolic trough designs incorporating the technologies described above will generate electricity at the rate of $0.062/kWh-$0.043/kWh with a capacity factor as high as 56 percent.[18] As a result,

8 Henry W. Price. "Parabolic Trough Solar Power for Competitive U.S. Markets". National Renewable Energy Laboratory. November 1998. Available at <http://www.nrel.gov/csp/troughnet/pdfs/25798.pdf>.

9 Ibid.

10 Ibid.

11 Sargent & Lundy LLC Consulting Group. "Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts". NREL. October 2003. Available at <http://www.nrel.gov/csp/pdfs/35060.pdf>.

12 L. Stoddard, J. Abiecunas, and R. O'Connell. "Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California". NREL. April 2006. Available at <http://www.nrel.gov/docs/fy06osti/39291.pdf>.

13 Ibid.

14 Ibid.

15 Ibid.

16 Ibid.

17 Sargent & Lundy LLC Consulting Group. "Executive Summary: Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts". NREL. October 2003. Available at <http://www.nrel.gov/csp/pdfs/35060.pdf>.

18 Ibid.

parabolic trough design has an attractive future amongst solar thermal plants.

Power plants that incorporate parabolic trough technology must be constructed away from residential or commercial zones due to their environmental impact. Parabolic trough power plants require five acres per MW, and should be greater than 100MW to reach economies of scale.[19] Furthermore, the fluid used in the pipelines of parabolic trough power plants is a highly volatile and flammable organic compound.[20] The use of Caloria, a flammable mineral oil, for thermal storage at a SEGS power plant resulted in a fire that destroyed the storage unit.[21] As a safety and environmental precaution, molten salt has become a popular alternative for thermal storage due to its high heat capacity and non-toxic properties. Parabolic trough power plants rely on thermal storage systems to increase electricity generation at low solar irradiance levels, thus boosting their annual average capacity factor to 23 percent.[22] Vegetation growing below the parabolic troughs also poses a fire hazard.[23] Plant operators must invest in expensive forms of weed control, which could have negative impacts on the environment. Finally, solar trough power plants require significant amounts of cooling water, which is a scarce and valuable commodity in the desert environment where yields from solar thermal are greatest. Therefore, parabolic trough power plants place additional stress on water resources in fragile ecosystems.[24] To cope with all of these environmental factors, the annual estimated operations and maintenance costs for a 100 MW parabolic trough power plant developed in 2007 with 6 hours of storage developed was $1,678,250.[25] Solar field parts and materials account for the highest percentage of O&M costs, with the cost of fuel being negligible.[26]

In recent years, the solar thermal industry has shifted attention to solar power towers. In a tower design, large mirrors known as heliostats focus sunlight on a receiver containing molten salt located at the top of a tower. Heat from the molten salt is exchanged with water which forms steam that is used to drive a steam turbine.

Even though power towers are not commercially operated in the United States, they offer several improvements over parabolic through technology. Power towers operate at high thermal efficiency levels, which "lead to plant capacity factors of over 60 percent using solar energy alone".[27] Furthermore, capital costs related to heat storage for power towers are $27/kWh, which is significantly less than that of parabolic trough power plants.[28]

Despite their high efficiencies, power towers require more land and are far more visible than parabolic trough plants. Operators of power tower solar thermal plants must dedicate eight acres of land per plant MW, which makes them larger than parabolic trough power plants.[29] The capacity of power plant using tower technology is directly proportional to it's power tower's

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19 Arnold Leitner. "Fuel from the Sky: Solar Power's Potential for Western Energy Supply". NREL. July 2002. Available at <http://www.nrel.gov/csp/troughnet/pdfs/32160.pdf>.
20 Ibid.
21 Ibid.
22 Ibid.
23 Ibid.
24 Ibid.
25 L. Stoddard, J. Abiecunas, and R. O'Connell. "Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California". NREL. April 2006. Available at <http://www.nrel.gov/docs/fy06osti/39291.pdf>.
26 Ibid.
27 George Simons and Joe McCabe. "California Solar Resources". April 2005. Available at <http://www.energy.ca.gov/2005publications/CEC-500-2005-072/CEC-500-2005-072-D.PDF>.
28 Arnold Leitner. "Fuel from the Sky: Solar Power's Potential for Western Energy Supply". NREL. July 2002. Available at <http://www.nrel.gov/csp/troughnet/pdfs/32160.pdf>.
29 Ibid.

height. In the case of a 200 MW power plant, the power tower may reach heights of 640 feet.[30] As a result, power towers are considered an eye sore. Finally, power tower plants require the same amount of cooling water as parabolic trough plant.[31] Because the technology is not as tested as parabolic trough technology, electric utilities operating in the United States have been slow to adopt power tower designs.

The solar thermal industry has experimented with parabolic dish systems, another technology used to generate electricity, for over 17 years.[32] Parabolic dish systems are up to 45 feet tall and operate by concentrating solar thermal energy on a heat engine to produce electricity.[33] The Sterling heat engine is commonly used in parabolic dish systems due to its high thermal-to-electricity efficiency ranging from 38-42 percent.[34] The parabolic dish system is a modular technology that can be compared to wind turbines. The typical parabolic dish system's electrical peak output is only 25kW.[35] They are compact, requiring only four acres per installed MW, and can be erected in a matter of days.[36] Sterling-powered parabolic dish systems are the most efficient solar generating technology, and can ramp up to grid synchronization within a minute.[37] Since sunlight is free, they have no fuel cost. Their environmental impact is small due to the lack of a need for cooling water, since the Sterling engine is air-cooled.[38] However, parabolic dish systems have the highest initial capital costs out of all the other solar thermal technologies at $2,650/kW.[39] Because a single parabolic dish systems can be operated as a stand alone generating unit, power plant operators benefit from being able to assess performance prior to investing hundreds of millions of dollars to build out a solar thermal plant based on parabolic trough or power tower technologies.

The solar thermal industry's future is heavily dependent on federal and state government subsidies. The federal government currently provides a 10 percent permanent investment tax credit for solar power.[40] A study for the National Renewable Energy Laboratory from 2006 claimed that by extending the 30 percent investment tax credit, implemented by the Energy Policy Act of 2005, to 2017 and 10 percent thereafter would result in 55 GW of solar thermal power by 2050.[41] The failure to construct solar thermal plants from 1990 to 2005 was a result of "declining federal and state incentives combined with declining energy prices".[42] Fortunately for the solar thermal industry, the Energy Improvement and Extension Act of 2008 extended the 30

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30 George Simons and Joe McCabe. "California Solar Resources". April 2005. Available at <http://www.energy.ca.gov/2005publications/CEC-500-2005-072/CEC-500-2005-072-D.PDF>.

31 Arnold Leitner. "Fuel from the Sky: Solar Power's Potential for Western Energy Supply". NREL. July 2002. Available at <http://www.nrel.gov/csp/troughnet/pdfs/32160.pdf>.

32 Ibid.

33 George Simons and Joe McCabe. "California Solar Resources". April 2005. Available at <http://www.energy.ca.gov/2005publications/CEC-500-2005-072/CEC-500-2005-072-D.PDF>.

34 Ibid.

35 Arnold Leitner. "Fuel from the Sky: Solar Power's Potential for Western Energy Supply". NREL. July 2002. Available at <http://www.nrel.gov/csp/troughnet/pdfs/32160.pdf>.

36 Ibid.

37 Ibid.

38 Ibid.

39 Ibid.

40 N. Blair, M. Mehos, W.Short, and D. Heimiller. "Concentrating Solar Deployment Systems (CSDS) – A New Model for Estimating U.S. Concentrating Solar Power (CPS) Market Potential". NREL. April 2006. Available at: <http://www.nrel.gov/csp/troughnet/pdfs/39682.pdf>.

41 Ibid.

42 National Renewable Energy Laboratory. "Parabolic Trough FAQs". Available at <http://www.nrel.gov/csp/troughnet/faqs.html>.

percent federal investment tax credit for solar power until 2016. As a result, the solar thermal industry has solid potential for growth in the coming years.

Today's solar thermal industry lacks integration. Due to the government incentive programs, there are lots of parabolic trough and dish producers, as well as power tower producers. In October of 2008, Ausra launched the first solar thermal plant in California in the past 20 years.[43] Ausra developed the compact linear Fresnel reflectors, based off parabolic trough technology, and designed the plant, and then implemented it with a construction team. Aura considers themselves “a large-scale solar thermal energy developer and manufacture”.[44] However, Ausra must rely on PG&E to purchase their power and redistribute it through the transmission grid.

eSolar is a small manufacture of utility-scale power tower solar thermal plants. They recently signed a contract with Southern California Edision to build out 245 MW of concentrated solar power.[45] Like Ausra, eSolar only provides the plant and the technology needed to generate electricity from solar irradiance to a large-scale utilities.

Stirling Energy Systems has also developed a power purchase agreement with Southern California Edison for the next 20 years. Stirling Energy Systems will deploy 20,000-34,000 solar dish Stirling systems at the Solar One site in the Mojave Desert, and will sell off the generated electricity to SCE.[46] At their Solar Two site, they will construct between 12,000-36,000 solar dish Stirling systems and sell the electricity to San Diego Gas & Electric as a result of another 20 -year power purchase agreement.[47]

As more solar thermal power plants come online, the solar thermal industry will be able to reach economies of scale and drive down capital as well as O&M costs. With the addition of strong federal and state investment tax credits, the solar thermal industry is poised to make large gains in the coming years.

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43 Ausra. “Solar Power Company Ausra Launches First Solar Thermal Plant in California in Nearly 20 Years”. October 2008. Available at <http://www.ausra.com/news/releases/081023.html>.

44 Ibid.

45 eSolar. “eSolar and Southern California Edison to Produce 245 MW of Solar Power”. June 2008. Available at <http://esolar.com/news/press/2008_06_03>.

46 Stirling Energy Systems. “Solar One”. Available at <http://www.stirlingenergy.com/projects/solar-one.asp>.

47 Stirling Energy Systems. “Solar Two”. Available at <http://www.stirlingenergy.com/projects/solar-two.asp>.

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9. National Renewable Energy Laboratory. “Parabolic Trough FAQs”. Available at <http://www.nrel.gov/csp/troughnet/faqs.html>.
10. Price, Henry W. “Parabolic Trough Solar Power for Competitive U.S. Markets”. National Renewable Energy Laboratory. November 1998. Available at <http://www.nrel.gov/csp/troughnet/pdfs/25798.pdf>.
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12. Simons, George and McCabe, Joe. “California Solar Resources”. April 2005. Available at <http://www.energy.ca.gov/2005publications/CEC-500-2005-072/CEC-500-2005-072-D.PDF>.
13. Stirling Energy Systems. “Solar One”. Available at <http://www.stirlingenergy.com/projects/solar-one.asp>.
14. Stirling Energy Systems. “Solar Two”. Available at <http://www.stirlingenergy.com/projects/solar-two.asp>.
15. Stoddard, L., Abiecunas, J., and O'Connell, R. “Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California”. NREL. April 2006. Available at <http://www.nrel.gov/docs/fy06osti/39291.pdf>.

Table 5-2 Annual CSP O&M Cost Breakdowns, 2005 $1,000				
	2007 100 MW	2009 100 MW	2011 150 MW	2015 200 MW
Labor				
Administration	528	528	554	554
Operations	979	973	1,088	1,158
Maintenance	633	633	664	664
Total Labor	**3,018**	**2,984**	**3,517**	**3,926**
Miscellaneous	419	415	516	599
Service Contracts	263	259	352	435
Water Treatment	260	265	413	556
Spares and Equipment	669	651	870	1,040
Solar Field Parts and Materials	1,859	1,311	1,457	1,904
Annual Capital Equipment	226	218	320	418
Subtotal	**3,695**	**3,119**	**3,928**	**4,953**
Total	**6,713**	**6,104**	**7,445**	**8,879**
Source: NREL Excelergy Model.				

A summary of annual O&M costs for four solar thermal power plants in California.

Stoddard, L., Abiecunas, J., and O'Connell, R. “Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California”. NREL. April 2006. Available at <http://www.nrel.gov/docs/fy06osti/39291.pdf>.

Table 5-1 CSP Plant Capital Cost Breakdowns, 2005 $1,000				
	2007 100 MW*	2009 100 MW*	2011 150 MW*	2015 200 MW*
Site Work and Infrastructure	2,455	2,433	2,566	2,681
Solar Field	230,865	205,109	243,059	268,441
HTF System	10,009	9,895	11,896	13,542
Thermal Energy Storage	57,957	57,937	71,320	89,390
Power Block	38,754	38,754	48,899	56,818
Balance of Plant	22,533	22,533	28,432	33,036
Contingency	30,707	28,116	33,742	37,720
Total Direct Costs	**393,280**	**364,776**	**439,915**	**501,627**
Indirects	101,106	92,814	113,469	129,746
Total Installed Cost	**494,386**	**457,590**	**553,384**	**631,373**
Source: NREL Excelergy Model. *With 6 hours storage.				

A summary of capital cost for four solar thermal power plants in California.

Stoddard, L., Abiecunas, J., and O'Connell, R. “Economic, Energy, and Environmental Benefits of Concentrating Solar Power in California”. NREL. April 2006. Available at <http://www.nrel.gov/docs/fy06osti/39291.pdf>.

Exhibit 40: Cost and Performance of Thermal Concentrating Solar Power Plants

	Dish Stirling	Parabolic Trough	Power Tower
Standard Plant Size	2.5 MW/100 MW	100 MW	100 MW
Max Conversion Efficiency % (1)	30%	24%	22%
Generation Threshold W/m^2	200	300	300
Annual Average Efficiency (2)	21.40%	13.70%	16.00%
Annual Avg. Capacity Factor (2)			
Basic Plant	25.20%	23%	29%
With Thermal Storage (3)	N/A	33% (4 hrs, 1.8 x)	48% (8 hrs, 1.8 x)
With Fossil Fuel Hybridization	N/A	23-95%	29-95%
Equiv. Forced Outage Rate (EFOR) %	5 (estimate)	5	5 (estimate)
Off-Sun Generation	Fossil Hybrid	Heat Storage/Fossil Hybrid	Heat Storage/Fossil Hybrid
Acres/MW of Collectors	4	5	8
Construction Time (4)	3-4 days per unit; 35 days/6 months	12 months	12 months
Incremental Capital Cost			
Basic Plant $/kW	2,650	1,956	2,065
Heat Storage $/kWh	N/A	103	27
Additional Solar Field $/kW	N/A	510	540
Fossil Fuel Hybridization $/kW	Not commercial	196	196
Fossil Heat Rate (HHV) (4)	TBD	10,800	10,000
Incremental Fixed O&M $/kW-year			
Basic	40/2.5	33	30
Heat Storage	N/A	2	1.5
Additional Solar Field Only	N/A	2	1.5
Fossil Fuel Hybridization	N/A	–	–
Incremental Variable Non-fuel O&M $/MWh			
Basic	16.80/15	2	2
Heat Storage	N/A	–	–
Fossil Fuel Hybridization	N/A	–	–
RDI estimated new Capacity (MW) that could be built (5)			
2002	0.7		–
2003	3.1	30	–
2004	27.5	100	50
2005	75	200	50
2006	100	300	150
Total	206.3	630	250
Cumulative U.S. Installations	118 kW	354 MW	10 MW
Largest Unit in the U.S.	25 kW	80 MW	10 MW (decommissioned)
Demonstrated System Hours	80,000	300,000	2,000

A complete break down of the various solar thermal technologies.

Leitner, Arnold. "Fuel from the Sky: Solar Power's Potential for Western Energy Supply". NREL. July 2002. Available at <http://www.nrel.gov/csp/troughnet/pdfs/32160.pdf>.