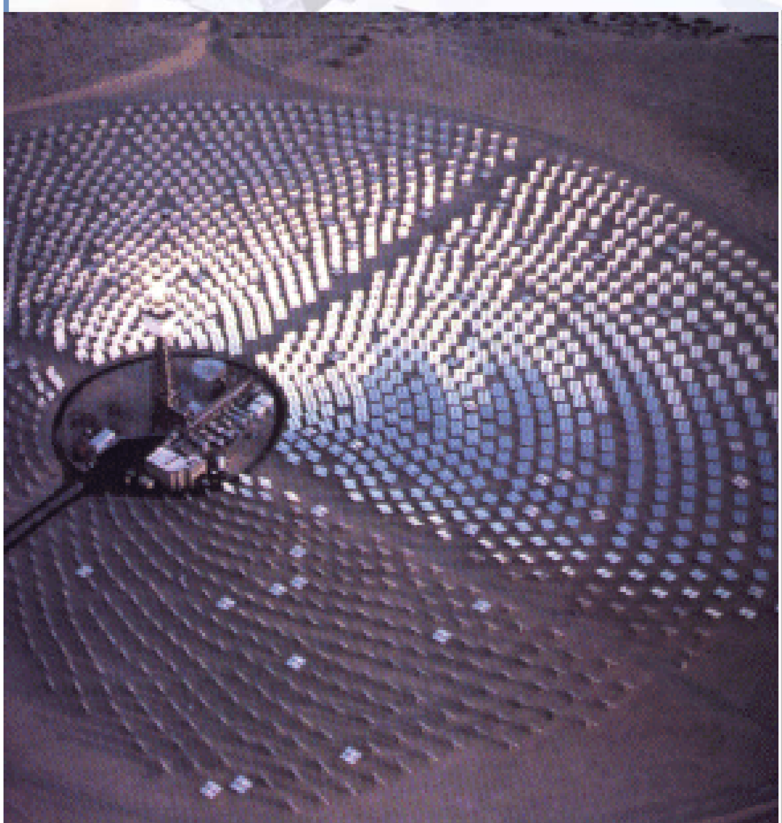
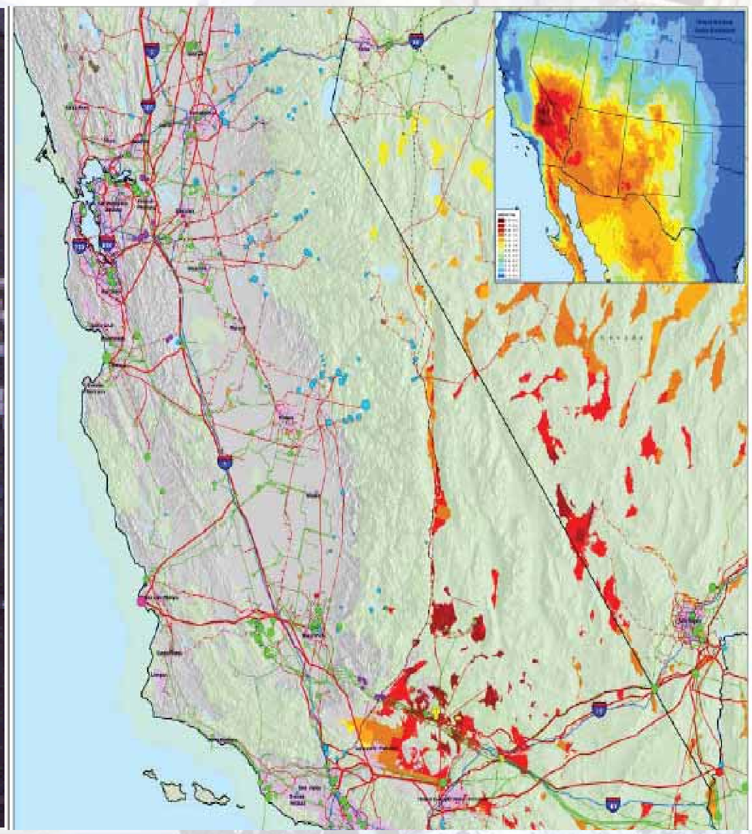
Concentrating Solar Power –Technology, Cost, and Markets

2008 Industry Report

A guide to the impact CSP technologies will have on the solar and broader renewable energy markets through 2020





Produced by the Prometheus Institute for Sustainable Development and Greentech Media

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Executive Summary

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Today, the Institute strives to be the world's leading source of publicly available primary data on the photovoltaic (PV) supply chain and end-markets through a series of data collection and outreach projects and the publication of the industry's oldest newsletter, *PVNews*™.

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Contents

FIGURES

TABLES

APPENDIX

Concentrating Solar Rising

SECTION 1

Concentrating the sun's rays in order to harness its great power for industrial purposes has a recorded history that dates back to Archimedes, but for thousands of years other sources of industrial energy have dominated the energy landscape. Just in the last hundred years, the development of industrial grids for the delivery of cheap electricity has relied on coal, oil, natural gas, hydro-electric dams, and nuclear reactors to power prime movers in a predominantly large, central station configuration that shipped electricity to users over transmission and distribution lines. Combined, such generators make up over 95% of modern electricity generation capacity. But pressures continue to mount on the electricity industry – including rising cost of fossil fuels and systemic pressure on the ability to deliver of fuel and power to where it is needed, and increasing realization of the environmental and national security repercussions of how energy is harnessed. These pressures are forcing modern industrial economies to look for additional sources of vital energy - and they are increasingly looking to the sun.

Today, a number of specific drivers are increasing the attractiveness of harnessing solar resources for electricity generation, and many approaches are being developed and commercialized. Benefits include:

- Solar electricity represents a highly popular form of new energy in studies of public perception and expectation of future contribution to the energy mix.

Figure 1-1: Markets and applications for solar power

Category	Small		Medium		Large	
Installation Size	< 10kW	10 to 100kW	100kW to 1 MW	1 to 10MW	10 to 100MW	> 100 MW
Technology Mix in Each Market	100% PV		99% PV, 1% CSP		20% PV, 80% CSP	
2007 Share of Worldwide Solar Market (Installed Capacity and % of Installed Capacity)	7GW (84%)		0.7 GW (9%)		0.5 GW (7%)	
Installation Type	Distributed Generation					
				Central Generation		
Markets Served	Residential					
		Commercial				
				Utility		
				Base (50%). Intermediate (40%), Peak (10%)		
PV Based – Non Dispatchable – Non-Tracking PV	best suited	best suited	best suited	best suited	suitable	
PV Based – Non Dispatchable – Tracking PV	suitable	suitable	best suited	best suited	best suited	
PV Based – Non Dispatchable – CPV	suitable	suitable	best suited	best suited	best suited	suitable
Thermal Based – Dispatchable (with storage) – Dish-Engine		suitable	best suited	best suited	best suited	best suited
Thermal Based – Dispatchable (with storage) – Trough		suitable	suitable	best suited	best suited	best suited
Thermal Based – Dispatchable (with storage) – Tower				suitable	best suited	best suited
Thermal Based – Dispatchable (with storage) – LFR					best suited	best suited
Installation Size	<10kW	10 to 100 kW	100kW to 1MW	1 to 10 MW	10 to 100 MW	> 100 MW

Legend: best suited; suitable

- Solar electricity is clean, often with very little environmental impact, particularly in the greenhouse gas emitting dimension that is driving much of the international debate on climate change.
- Solar electricity is local, allaying the risks of access to and physical and economic control over critical energy supplies.
- Solar electricity is available to nearly everyone worldwide at some cost and using some available technology – a statement that is not true of nearly every other renewable energy technology being pursued from wind to waves to geothermal.
- Finally, the available solar resources are thousands of times more than human society consumes each year, providing ample opportunity for increasing per capita energy use – even in a world of simultaneously increasing population and wealth.

Among solar electricity generation technologies, photovoltaic (PV) technologies have seen the largest growth in interest over the last few years. As shown in Figure 1-1, PV has emerged primarily at the very smallest type of deployment – often on the home or commercial building and providing power on the customer's side of the meter at a relatively high (retail) value. By 2008, PV has nearly eight GW of cumulative global grid-tied installations and is expected to grow by another three to four GW in 2008 - and growth should increase in subsequent years. Driven by various policy programs in Japan, Germany, the US, Spain, and many other countries, PV is increasingly seen as a viable alternative for electricity generation – growing in volume globally second only to wind power among renewable energy technologies and at a faster percentage.

Policy-led demand for solar energy and global growth rates of 40 to 50 percent each year has led to recent supply bottlenecks in PV manufacturing, most notably in the highly capital- and energy-intensive polysilicon feedstock needed for 90 percent of the PV produced today. Large scale utility and industrial users are increasingly interested in solar technologies that may be more useable in central station applications – including those that can be more rapidly scalable, inherently "dispatchable" or predictable, and possibly those generating heat versus direct electricity to supplement existing heat-driven power plants. Many potential concentrating solar technologies are being pursued in an attempt to meet these needs.

The two great challenges to using more solar electricity remain its perceived high cost and the nature of solar to be both periodic and not absolutely reliable, a characteristic that makes its use in conjunction with modern grids problematic. This report looks at all of the available concentrating solar power technologies in or near commercialization and the methods of storing and dispatching them, being driven by dozens of companies around the world. Using baseline PV installations and economics as a benchmark for evaluating performance and future economics, it shows how the different system characteristics create different value offerings for different customers. In the end, what this report finds is that each concentrating solar technology is suited to slightly different needs, but that many technologies have interesting market opportunities in the years ahead for those that can understand how this exciting market will develop over time.

Table 1-2: Complete CSP Systems

CSP Type	System	Concentrator Technology	Power Conversion
CST	Trough	Parabolic Trough	Rankine Cycle
	LFR	Linear Fresnel Reflector	Rankine Cycle
	Tower	Heliostat Solar Field	Rankine / Brayton Cycle
	Dish-Engine	Parabolic Dish	Stirling / Brayton Engine
CPV	Dish CPV	Parabolic Dish	Multi-Junction or Silicon PV
	Lens CPV	Lens of Fresnel Lens	Multi-Junction PV
	LCPV	Low Concentration Reflector	Silicon PV
	Non-Tracking PV	Non-Tracking Concentrator	Multi-Junction or Silicon PV

CSP systems can be made of any combination of concentrators and power converters. However, distinct combinations have emerged and are summarized in this table. These technologies are broken into the two main categories of Concentrating Solar Thermal (CST) and Concentrating Photovoltaic (CPV) technologies. While this table shows the degree of variation between CSP technologies, another level of variation exists within each of these technologies that will be explored in the following sections.

1.1 Technology

The technologies examined in this report include all current available and potential technologies near commercialization in concentrating solar power (CSP) for electricity generation. Looking at Table 1-1, these technologies break down into two general categories.

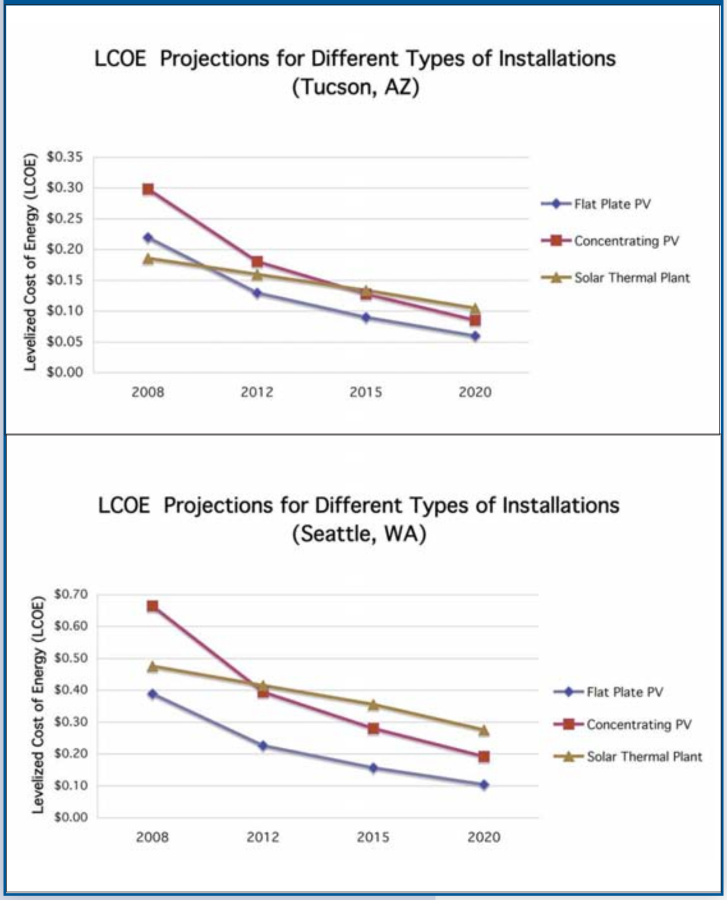
The first is Concentrating Solar Thermal (CST), which includes those concentrating the sun's energy on a thermal conductor and then using that heat to move an engine or turbine. These usually take the form of a large power plant and can concentrate using mirrors in a line or around a point. The mirror array can be concave or flat - concentrating from 80 suns for the linear arrays (including trough systems and LFR) to over 1500 suns on the point arrays (including tower and dish-engine systems), with corresponding temperatures and variations of technology components to convert the heat into useful electricity. Because they generate heat, CST systems have relatively more costs in the operation and maintenance versus PV systems, but create the advantage of potentially storing the heat or using it in a hybrid configuration to make the power dispatchable – a significant advantage in integrating the power into modern grid architectures.

Alternatively, Concentrating Photovoltaic (CPV) technologies concentrate the sun's energy directly onto high efficiency PV materials to directly create electricity. These technologies use both mirrors and lenses and can be deployed in configurations that range from large systems to mid-sized systems, with some technologies even able to be done at small modular scale similar to traditional PV modules. CPV technologies tend to have fewer, but often still meaningful, tracking and other moving parts than CST systems, reducing relative operating costs. However, the direct electricity generation complicates the harnessing and storage of electricity with today's electric storage technology and limits CPV's ability to be dispatchable. Still, substituting mirrors or lenses for expensive PV in systems has the potential to reduce the total system cost when scale and technology improve from today's levels.

1.2 Cost

Regardless of which CSP technology is chosen, correctly assessing the cost of solar electricity and further engineering to bring it down over time is their key challenge. The cost of solar electricity – measured using a standardized

Figure 1-2: LCOE trend over time at two different locations in United States



Levelized Cost of Electricity (LCOE) – is dependent on many variables related to the site and the technology chosen. These factors are all considered in determining relative economics herein.

In terms of the location, it turns out that latitude of where the installation exists matters a great deal. Latitude is important for two reasons. First, total available irradiance has a strong impact of the economics of all solar electricity generation, but particularly for concentrating solar where fixed costs and operation and maintenance is less scalable with the size of the system versus traditional PV. Second, the reliance of most CSP systems on tracking systems and the incident angle of light at different latitudes has a first order effect on the LCOE. Offsetting effects of atmospheric interference and optimal tracking configuration does more acutely limit the range of locations that CSP technologies can optimally use to high sun and middle latitude applications, but fortunately the power needs in those locations is vast compared to CSP's current penetration.

From a technology standpoint, the largest economic hurdle CSP technologies must overcome is their reliance on only the direct irradiation portion of the solar resource, or the part of the light that is perpendicular to the collector – known as Direct Normal Irradiation, or DNI. Depending on location, DNI can range from 60 to 80 percent of the total available light that is available to flat-plate PV, and maximizing its capture is what requires the use of complex and precise tracking systems for most CSP technologies. This penalty is offset by higher efficiency of conversion by both CST and CPV technologies, but has interesting ramifications on system design and technology choice across different locations and users.

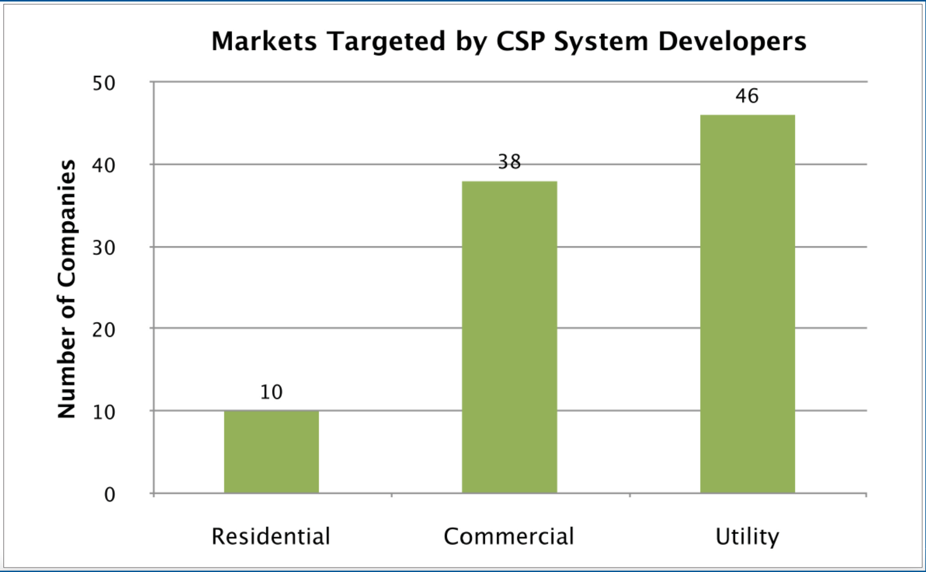
Regardless of the LCOE that the various technologies can achieve today, the most interesting analysis is how that will change over time with cost improvements and scale of production. Figure 1-2 shows how the cost for both CST and CPV - as well as traditional PV - will change through 2020, and it shows this comparison for two different locations in the US – Tucson and Seattle. The assumptions that go into these forecasts are expanded in the report, and alternative methods of calculation are provided.

In the end, however, scale of production matters to determine which technologies and companies will be best placed to take advantage of the markets. This is because LCOE will be a function of the cumulative deployment of a technology and the current scale of its installations and experience of its installers. Unfortunately for any emerging CSP technology, PV's dropping component and system prices and current scale advantages will create a declining hurdle that they will have to match in order to become viable.

1.3 Market

Understanding the cost of solar is not enough, the value of the electricity generated versus the cost is what will drive the market economics and technology adoption. Though often thought of as expensive to generate, solar electricity technologies do create electricity at the most valuable time of the day – during peak daylight hours. Therefore, solar energy is by its nature a high value electricity at both the wholesale and retail levels, displacing the need for expensive (often) natural gas fired intermediate power generators that are subject to substantial swings in fuel prices.

Figure 1-3: Number of CSP companies targeting each market segment



The utility market is the most popular market for CSP companies, for both technological and market-oriented reasons. While some technologies are confined to the utility market, modular technologies are not, but are mostly focusing on the utility market with plans to expand to distributed residential and commercial markets.

How the power is purchased is also important, and two methods have emerged – 1) retail/commercial customers who can buy power to replace the power they currently purchase from utilities, and (2) the utility themselves either directly or through wholesale power markets. Figure 1-3 shows the number of companies that this report tracks that are attempting to serve each of those markets.

The utility market is the most popular market for CSP companies, for both technological and scale reasons. Installations have recently been announced for thousands of MW of peak capacity of CSP, and many more are being considered. Utilities are looking to CSP to help them meet Renewable Portfolio Standards (RPS) set by states and nations, and CSP installations allow for a very rapid volume ramp to meet those goals. In such cases, utilities often plan to purchase the power directly under a Power Purchase Agreement, but longer term it is possible that CSP providers can sell directly into the wholesale power markets – particularly when storage allows for dispatchability and shifting of loads to the most valuable times of the day – a distinct advantage to today's CST technologies with thermal storage described in an Appendix to the report.

The changing policy landscape will also likely influence, and accelerate, the deployment of CSP. Changes and enhancements of RPS programs, rising value for carbon offsets, and increasing comfort with the reliability and efficacy of the technologies will combine to further support solar electricity in general and CSP in specific. One note of caution is that unpredictable changes or volatility in policy may have correspondingly volatile effects on CSP deployment over short time frames.

1.4 Conclusion

Our research has led to three main conclusions about the impact of CSP on the solar energy industry and the broader energy markets in the next decade.

CSP clearly has a role to play over the next decade

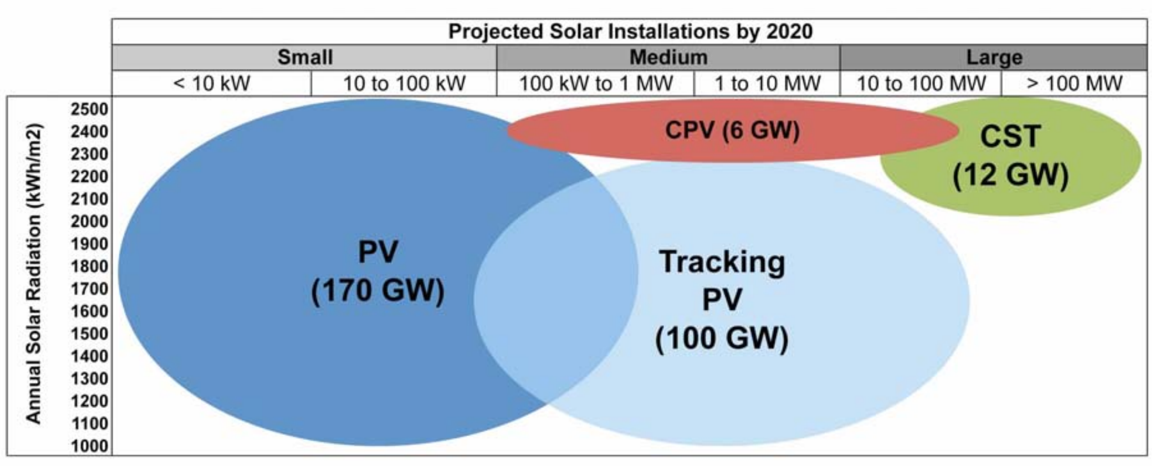
With the current plants, those in construction, those under consideration, and the pace of development, it is clear that some tens of GW of cumulative production over the next decade – possibly as much as 50 GW – of CSP capacity will be installed by 2020. This would represent somewhere between $80 Billion and $200 Billion of aggregate investment in the sector over the next 12 years. In just the last six months, over $30 Billion in new plants have been proposed, and many of these will be constructed in the next several years.

Although PV is projected to have a lower cost than CST in the medium to long term, CST will play a role in utility scale installations due to storage capabilities and other benefits to utilities and societies. Trough technologies will be implemented first and will experience incremental technical improvements and cost reductions. CPV technologies will suffer from slower ramping and scale, but should become competitive at the utility scale within the next decade, and some recently emerging non-tracking and low concentration CPV technologies may have an interesting impact at the distributed residential and commercial level as well.

PV will remain dominant in the distributed market

That said, flat plate PV for distributed applications and some fixed or single-axis tracking systems for central systems will remain economically competitive. PV has seen limited price declines for its components and systems in the last few years due to some feedstock constraints, but innovation and additional capital are going to remedy those problems soon. At the distributed level, low operating and maintenance costs will

Figure 1-4: Solar technology penetration based on location and market segments



likely be determinative. Unless CSP technologies can match those of PV, the distributed market will be tough for CSP technology to penetrate. And the PV industry's scale and ability to serve more markets than CSP will drive ongoing cost improvements for decades to come.

Centralized Generation Market up for Grabs

Figure 1-4 shows the base case forecast for the range of technologies, what markets they will serve, and what insolation conditions are optimal for each. While each of the technologies have core markets that they best serve, it is where the circles meet that is most interesting for evaluating competitive markets for solar technologies. The success of each will be determined by a number of things this report examines in detail including:

- Irradiance location and type
- Cost improvements over time
- Availability of components
- Need for and value of dispatchability
- Difficulty from and cost of transmission line upgrades
- Changes in policy - international, national, and local
- Emergence of low-cost grid electricity storage options

While future market share of the various technologies cannot be known, it is pretty clear that the collection of solar technologies described herein will soon be cheap enough to penetrate deeply into the need for expensive daytime power, and with storage, perhaps into base load and transportation energy as well.

Today, a number of solar energy technologies have arguably become cost effective. As a result, many should enjoy increasing market share and further price declines in the coming years. At the same time conventional sources of energy will have increasing difficulty in simply maintaining prices and production volumes in the face of fuel stock pressure and grid maintenance requirements. The combination will drive dominant solar electricity economics for decades to come, and CSP is poised to scale up quickly for the largest customers. Finally, the dawn of large scale concentrating solar power is here, and the forecast shows hardly a cloud in the sky.

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