



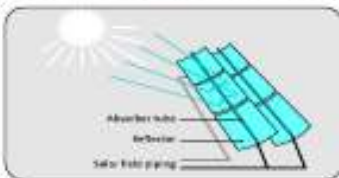
NEXT BIG THING: CONCENTRATING SOLAR THERMAL ELECTRICITY Time for India to Catch Up

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Solar thermal power generation using concentrating collectors, commonly referred to as concentrating solar power (CSP), involves the conversion of solar radiation to thermal energy, which is then used to run a conventional power system. Solar thermal is a viable alternative to conventional energy systems and depending on the particular technology, is suited to either distributed generation on the kW scale or to centralised power generation on scales up to several hundred MW. CSP systems use parabolic trough concentrating collectors, power tower/heliostat configurations, and parabolic dish collectors. An alternative system that uses Fresnel concentrators is also emerging. Parabolic trough, power tower and Fresnel systems typically run conventional power units, such as steam turbines. Parabolic dish systems power a small heat engine at the focal point of the collector.

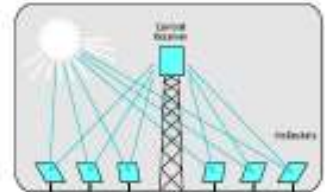
1. THE CSP TECHNOLOGY

Parabolic Trough: Parabolic trough-shaped mirror reflectors are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough's focal line. A thermal transfer fluid, such as synthetic thermal oil, is circulated in these tubes. Heated to approximately 400°C by the concentrated sun's rays, this oil is then pumped through a series of heat exchangers to produce superheated steam. The steam is converted to electrical energy in a conventional steam turbine generator, which can either be part of a conventional steam cycle or integrated into a combined steam and gas turbine cycle.

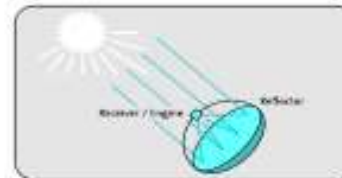


Central Receiver or Solar Tower: A circular array of heliostats (large individually tracking mirrors) is used to concentrate sunlight on to a central receiver mounted at the top of a tower. A heat-transfer medium in this central receiver absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy to be used for the subsequent generation of superheated steam for turbine operation. To date, the heat

transfer media demonstrated include water/steam, molten salts, liquid sodium, and air. If pressurised gas or air is used at very high temperatures of about 1000°C or more as the heat transfer medium, it can even be used to directly replace natural gas in a gas turbine, thus making use of the excellent cycle (60% and more) of modern gas and steam combined cycles.



Parabolic Dish: A parabolic dish-shaped reflector is used to concentrate sunlight on to a receiver located at the focal point of the dish. The concentrated beam radiation is absorbed into the receiver to heat a fluid or gas (air) to approximately 750°C. This



fluid or gas is then used to generate electricity in a small piston or Stirling engine or a micro turbine attached to the receiver.

Fresnel Collectors: A Linear Reflector (LFR) array is a line focus system similar to parabolic troughs in which solar radiation is concentrated on elevated inverted linear absorbers using an array of nearly flat reflectors. With the advantages of low structural support and reflector costs, fixed fluid joints, a receiver separated from the reflective system, and long focal lengths allowing the use of conventional glass, LFR collectors have attracted increasing attention. The technology is seen as a lower cost alternative to trough technology for the production of solar process heat and steam. For power generation, where higher steam temperatures are needed, LFR must still prove its cost effectiveness and system reliability.



Parabolic trough and power tower solar systems generate high-pressure steam to drive conventional steam turbine generators in sizes from 30 MWe to 200 MWe or can be used to



augment combined-cycle power plants. These systems achieve peak solar-to-net-electric system efficiencies of over 20% and use about 5 acres (or 2 hectares) of land for each MWe of capacity installed. One square kilometer of land is enough to generate as much as 100–120 gigawatt hour (GWh) of electricity per year. Power supply during a typical summer day remains constant from early morning to early evening. An important characteristic of trough and tower systems is their ability to dispatch power on demand by using a thermal storage system or augmenting solar energy with a fossil-fired boiler. Because time-of-use prices of electric power can be significantly higher at peak times, the value of the solar energy is enhanced, and the predictable output is better for planning and matching peak demand. Thus, solar thermal plants with cost-effective storage or natural gas hybridisation can deliver power to the utility grid when that power is most needed, not just when the sun is shining. The advantages and disadvantages of the three main technologies are given below in Table 1.

2. PROJECTS UNDER CONSTRUCTION & FUTURE

Solar thermal power plants have been considered to be a suitable commercial-scale technology for generating cost-

effective power plant electricity from solar energy, since the end of the 1980s. Since the beginning of the 1990s, solar power plants have been feeding 354 MW peak-load electricity originating from the Mojave Desert into the California grid, with power generation costs of less than 0.15 US\$/kWh. However, after the Israeli manufacturing company, LUZ International Limited went bankrupt at the end of the 1980s, not much was heard about this technology for a long time. It was only with the realisation that large amounts of CO₂-free electricity needs to be generated quickly to provide efficient climate protection that new opportunities opened up for solar thermal energy. Encouraged by various subsidy schemes, solar thermal power plants are again being built in different places throughout the world.

If the announcements of the relevant industries are anything to go by, such as those made at the CSP Industry Forum held during the International Solar Energy Conference 2005 in Florida, then these are just the tip of the iceberg of numerous solar thermal power projects that are about to be constructed around the world. The fact that this is no mere marketing gag is demonstrated by the long-term electricity supply agreements

Table 1: Comparison of Solar Thermal Power Technologies

	Parabolic Trough	Central Receiver	Parabolic Dish
Applications	Grid-connected plants, mid to high process heat (Highest single unit solar capacity to date: 80 MWe) Total capacity built: 354 MW.	Grid-connected plants, high temperature process heat (Highest single unit solar capacity to date: 10 MWe) Total capacity built: about 11 MW.	Stand-alone, small, offgrid power systems or clustered to larger grid-connected dish parks (Highest single unit solar capacity to date: 25 kWe; recent designs have about 10 kW unit size).
Advantages	<ul style="list-style-type: none"> ▶ Commercially available – over 12 billion kWh of operational experience; operating temperature potential up to 500°C (400°C commercially proven). ▶ Commercially proven annual net. ▶ Plant efficiency of 14% (solar radiation to net electric output). ▶ Commercially proven investment and operating costs. ▶ Modularity. ▶ Best land-use factor of all solar technologies. ▶ Lowest materials demand. ▶ Hybrid concept proven. ▶ Storage capability. 	<ul style="list-style-type: none"> ▶ Good mid-term prospects for high conversion efficiencies, operating temperature potential beyond 1000°C (565°C proven at 10 MW scale). ▶ Storage at high temperatures. ▶ Hybrid operation possible. 	<ul style="list-style-type: none"> ▶ Very high conversion efficiencies – peak solar to net electric conversion over 30%. ▶ Modularity. ▶ Hybrid operation possible. ▶ Operational experience of first demonstration projects.
Disadvantages	The use of oil-based heat transfer media restricts operating temperatures today to 400°C, resulting in only moderate steam qualities.	Projected annual performance values, investment and operating costs still need to be proven in commercial operation.	<ul style="list-style-type: none"> ▶ Reliability needs to be improved. ▶ Projected cost goals of mass production still need to be achieved.

that have already been concluded with electric utility companies along with the corresponding registration for feed-in compensation, purchase of lease of agreement on grid feed-in points, approval of environmental planning, and financing put in place. Table 2 below gives an indication of the numerous projects under construction or planned and their status of implementation in many countries.

Due to its commercial maturity, parabolic trough technology is the preferred choice of industrial developers and investors in large-scale CSP projects in Europe and the South-western United States. This also applies to Integrated Solar Combined Cycle (ISCC) projects in Algeria, Egypt, Iran, Mexico and Morocco. Recognising both the environmental and climatic hazards to be faced in the coming decades and the continued depletion of the world's most valuable fossil energy resources, Concentrating Solar Power can provide critical solutions to global energy problems within a relatively short timeframe and is capable of contributing substantially to carbon dioxide reduction efforts. Among all the renewable technologies available for large-scale power production today and for the next few

decades, CSP is one with the potential to make major contributions of clean energy because of its relatively conventional technology and ease of scale-up. Today, several scenarios exist describing the potential deployment of CSP systems. A typical example is the Athene Study that uses a scenario technique to quantify the world-wide deployment of CSP through 2025. This approach predicts a cost reduction down to 5 cents/kWh at a total installed capacity of 40 GW which will be achieved between 2020 and 2025 (see Fig.1). The European Union has realised the potential of this technology and currently supports the implementation of many pilot solar thermal power plants in Europe.

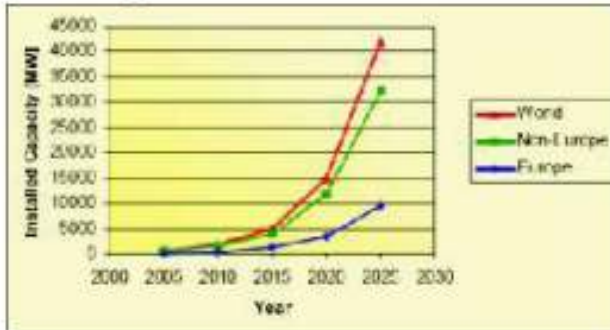
3. CSP COSTS

All new technologies such as gas turbines, nuclear power plants or wind power plants, cost more at their introduction relative to mature market prices. In order to become commercially viable, all energy technologies have initially received financial support from governments, based on the perceived benefits that would result if the technology were to

Table 2: CSP Projects Planned / Under Construction

Sr. No.	Company / Initiator	Location	Power Plant Type / Electrical Power	Date of Commissioning
1	ACS Cobra/ Solar Millennium	Marquesado de Zenete, near Grenada, Spain	Parabolic troughs / 2 x 50 MW	2008 / 2009
2	Solucar	Seville, Spain	Tower / 2 x 20 MW parabolic troughs 3 x 50 MW	11 MW in March 2007 Balance 2009 / 2010
3	Israel Electric Company	Ashrim, Israel	Parabolic troughs / 100 MW	Not specified
4	Iberdrola	11 locations in Spain	Parabolic troughs, each 50 MW. Total 550 MW	Not specified
5	SES	Southern California, USA	Dish-stirling / 850 MW	Up to 850 MW by 2010
6	Solargenix	Boulder City, Nevada, USA	Parabolic troughs / 65 MW	2007
7	Neal	Hassi R'Mel, Algeria	Parabolic troughs / 25 MW in combination with a 105 MW fossil fuel power plant	2008
8	Escom	Upington, South Africa	Tower / 100 MW (molten salt)	Not specified
9	Iranian Power Development Company	Yazd, Iran	Parabolic troughs / 67 MW in combination with a 363 MW fossil fuel power plant	2009
10	World Bank	Ain Beni Mathar, Morocco	Parabolic troughs / 30 MW in combination with a 210 MW fossil fuel power plant	2008
11	World Bank	Sonora, Mexico	Parabolic troughs / 30 MW in combination with a 470 MW fossil fuel power plant	2009
12	World Bank	Kuraymat, Egypt	Parabolic troughs / 30 MW in combination with a 120 MW fossil fuel power plant	2009
13	World Bank	Mathania, India	Parabolic troughs / 30 MW in combination with a 120 MW fossil fuel power plant	2009

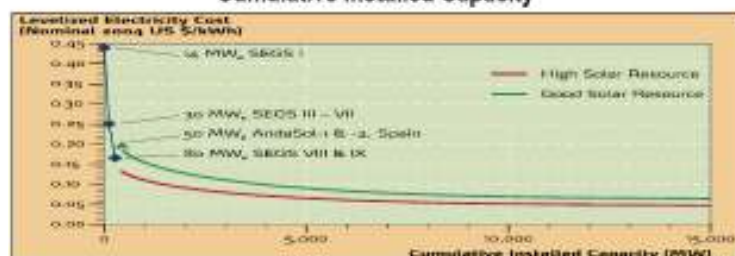
Fig.1: Athene Scenario on CSP Growth



become commercially widespread. For example, today's gas turbines, which were initially subsidised, are now significantly less costly due to advanced designs and mass production. The same principles apply to CSP, which has not yet achieved mass production or optimisation of its components. Many countries and states have solid experience in commercialising new energy technologies, and they have adopted proven approaches to lower their costs, enhance the businesses that produce and deliver them, and protect consumers by achieving greater reliability and better cost-effectiveness. The experience with the commercial implementation and operation of the parabolic trough project in the Mojave desert of California shows that power generation costs could be reduced, in nominal 2004 US dollars, from an initial US\$ 0.44/kWh for the first 14 MWe unit to just US\$ 0.17/kWh for the last 80 MWe unit in only seven years.

These factors were considered in recent independent and comprehensive evaluations of CSP trough and power tower technologies commissioned by the World Bank and the US Department of Energy. Both studies found that future plants have the potential to directly compete with fossil power. Fig.2 projects that a cost of US\$ 0.07–0.09/kWh will be achieved after installation of the first 5000 MW of CSP globally. Costs are expected to reach US\$ 0.05–0.07/kWh after 15,000 MW has been installed. This price would be competitive with the price of

Fig.2: CSP Electricity Cost as a Function of Cumulative Installed Capacity



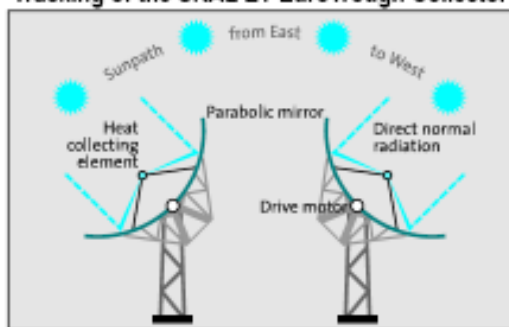
fossil power besides having numerous environmental and socio-economic benefits. Many factors affect the CSP electricity cost, like costs for grid connection and local infrastructure, project development costs, the rate of technology advancements and mass production. Scaling up plant size offers the easiest opportunity for reducing the cost of power. Besides R&D, the apparent financial cost of energy can be further reduced through preferential financing conditions and tax or investment incentives.

4. TECHNOLOGY DEVELOPMENTS

Parabolic trough systems represent the most mature solar thermal power technology, with 354 MWe connected to the Southern California grid since the 1980s. Supplying an annual 924 kWh at a generation cost of about 12 to 15 US cents/kWh, these plants have demonstrated a maximum summer peak efficiency of 21% in terms of conversion of direct solar radiation into grid electricity. Although successful, they by no means represent the end of the learning curve. A number of technology R&D advances have been identified that can also significantly reduce costs. These include increasing the collector size, improving the receiver efficiency and developing advanced thermal storage technologies, as well as advanced heat transfer fluids. Finally, increased commercial competition and volume production of solar field components and sub-systems will come into play to further reduce the cost of CSP generated electricity. Advanced structural design will improve optical accuracy and, at the same time, reduce weight and costs, thus resulting in higher thermal output. By increasing the length of the collector units, investment savings can be achieved in drive systems and connection piping. Next-generation receiver tubes will also further reduce thermal losses while, at the same time, improving reliability. Improvements to the heat transfer medium will increase operating temperature and performance. Low-cost thermal bulk storage will increase annual operating hours and thereby reduce generation costs. Most important for further significant cost reductions, however, is automated mass production in order to steadily increase market penetration. New structural collector designs have recently been developed in Europe and the USA and are currently in their test phase, whilst work in improved receiver tubes is under way in both Israel and Germany. What promises to be the next generation of parabolic collector technology has been under development at the European Solar Thermal Research Centre, the Plataforma Solar in Spain since 1998 by the European R&D

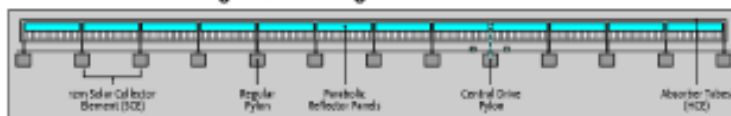
consortium. Known as 'EuroTrough', it aims to achieve better performance and lower costs by using the same well-tried key components – parabolic mirrors and absorber tubes – as in the commercially mature Californian plants, but significantly enhancing the optical accuracy by a completely new design for the trough structure (Fig.3). With funding from the European Union, both a 100m and a 150m prototype of the EuroTrough were successfully commissioned in 2000 and 2002 respectively at the Plataforma Solar.

Fig.3: Operating Principles and Daily Tracking of the SKAL ET-EuroTrough Collector



An extended 4360 m² loop of an advanced EuroTrough design, the SKAL ET collector loop has been built into and is in operation at the SEGS V plant in Kramer Junction, California, since spring 2003 and has operated continually ever since. The cost of this demonstration loop was shared between the German SKAL ET consortium and the German Federal Ministry for the Environment (Fig. 4).

Fig.4: EuroTrough ET 150 Collector



In the USA, an advanced-generation trough concentrator design that uses an all-aluminum space frame has recently been implemented in a 1 MW pilot plant in Arizona. The design is patterned on the size and operational characteristics of the LS-2 collector, but is superior in terms of structural properties, weight, manufacturing simplicity, corrosion resistance, manufactured cost, and installation ease. Also in Israel, an upgraded version of the LS2 parabolic trough has now become the fifth generation of this well-known and proven technology. The commercial plants in California use a synthetic oil as the heat transfer fluid, because of its low operating pressure and storage capacity. However, R&D efforts are under way at the Plataforma Solar – through the DISS (Direct Solar Steam) and

INDITEP project focused on increasing the steam temperature beyond 400°C. The issue of a cost-effective phase change storage medium for direct steam systems is at the focus of the European R&D project DISTOR. For the Spanish 50 MW and Sol 1, 2 and 3 projects, the German project developer Solar Millennium, in full collaboration with an American engineering company, designed a 6 to 12 full load hours thermal storage system operating with molten salt.

5. CSP GLOBAL MARKET INITIATIVE

Recent activities indicate that CSP technologies are poised at the threshold of extensive commercial deployment. There are currently about 13 CSP project locations under development around the world, totalling about 1000 MWe of new concentrating solar power capacity. One of the market barriers to further deployment is a lack of knowledge about the current technology and near-term potential of CSP on the part of energy policy makers, regulators, general contractors and would-be owners and users. With increased awareness of the numerous benefits of using the solar thermal energy resources around the world, and the necessary policy framework in place, it is anticipated that more CSP projects will come on line. And these projects would start faster and be more profitable if there was a forum for collaboration among interested countries and states. To create such a forum, an international public private CSP partnership (recognised as a UNEP Market Facilitation WSSD Type-II Partnership for Concentrating Solar Power Technologies) was established at the World Environmental Summit in Johannesburg, South Africa, in September 2002.

The goal of this coordinated action, called the CSP Global Market Initiative (GMI), is to facilitate and expedite the building of 5000 MWe of CSP power worldwide by 2014 (Fig.5). Participation is open to all governments in countries or states with adequate solar thermal resources, to countries that have an industrial capability in CSP technologies, but lack the appropriate solar resources, and to others who contribute to establishing the framework proposed below. If the benefits of CSP are to be spread globally, it is essential that participating industrial countries outside the sun-belt either support investments in sun-belt countries and/or allow import of solar power at cost-covering rates, thereby stimulating investment in CSP plants.

Fig.5: Anticipated Market for CSP



A visible, reliable and growing market for solar thermal power with normal risk levels must be established in order for project developers and CSP equipment suppliers to make the needed long-term investments to achieve acceptable investment costs, and hence competitive rates. Policy areas that will have the greatest impact on the use of concentrating solar power are given below.

6. POLICY AREAS & MEASURES

Each country or state participating in the CSP GMI will contribute with the following policy measures:

Targets: As the overall goal of the CSP GMI is 5000 MWe to reach cost competitiveness by 2015, national and/or regional targets will be set for CSP capacity. These targets may be a specific number of MW over a certain period of time, or may be a percentage of CSP within the new capacity to be built over a certain period of time, as in Renewable Portfolio Standards.

Tariffs: The level of revenue for CSP projects needs to be adequate to encourage private sector investment and provide a stable investment climate. This can be achieved by feed-in tariffs, production tax credits, or public benefit charges specific for CSP. These supports will be designed to reduce over time as the CSP technology becomes competitive in the power market after 5000 MWe of CSP has been built by 2015. The use of long-term power purchase agreements or similar long-term contracts with credit-worthy off-takers, or equity ownership by public organisations will build confidence of investors and financial institutions.

Financing: Cooperating bilateral and/or multilateral financial institutions will ensure that project-related flexible Kyoto instruments such as Clean Development Mechanisms and Joint Implementation Actions become applicable to CSP and

ensure that the mechanisms are bankable. The establishment of national or regional loan guarantee programmes via existing windows at multilateral banks, national lending programmes and global environmental programmes such as GEF, UNEP, and UNDP will further reduce the inherent risk of introducing new technology for private sector banking institutions. **Investment tax credits**, which stimulated the first 354 MWe of CSP plants in the United States, should be maintained and **production tax credits** similar to those that have stimulated the growth of wind power in the United States should be made available to CSP plants.

Regulation: Limitations on CSP plant capacity or operating strategies that make the technology introduction more costly need to be avoided. Legal restrictions and barriers to allow more cost-effective connections of CSP plants to the electric grid at the end-user (customer), distribution and/or transmission points shall be identified and eliminated.

7. WHAT INDIA CAN DO TO CATCH UP

Solar Resource Assessment: On 30 March 2007, the European Commission published a map of the solar power potential of Europe. The map is produced by the Photovoltaic Geographical Information System of the Joint Research Centre, which also includes an interactive service allowing users to calculate the solar power potential of any location in Europe. The information in the map shows that an identical solar system will generate twice as much energy in sunny areas of Europe, such as Malta and Southern Spain, than in areas such as Scotland or northern Scandinavia. The interactive information service map allows very specific calculation of the amount of energy that can be generated in any given location in Europe and its neighbouring regions. This calculation is based on knowledge of the sun's energy, geographic distribution, the different terrain across Europe and detailed technological analysis of the available photovoltaic technologies. The map shows that considerable potential exists in Europe for greater use of solar energy. The EU is seeking to increase the share of renewable energies in its consumption to 20 percent in 2020.

A similar effort was completed in the United States also. Direct-normal solar radiation values can be derived from satellite data. Geostationary weather satellites, such as GOES, continuously monitor the Earth's cloud on a time and location basis. This information can be used to generate solar irradiance



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data that are time and site specific, leading to the generation of high-resolution maps of solar radiation. Not all the land area with solar radiation are suitable for large-scale CSP plants, because such plants require relatively large tracts of nearly-level open land with economically attractive solar resources. To address this issue, Geographical Information System (GIS) data can be applied on land type (e.g. urban, agriculture), ownership (e.g., private, state, federal), and topography. The study showed that even if only the high-value resources are considered, nearly 7000 GW of solar generation capacity exists in the U.S. Southwest.

India has the technological capabilities to undertake such an assessment. It needs to be done on a war footing with the co-operation of all agencies like MNRE, ISRO, IMD etc. Many parts of India would emerge as potential sites for power generation through the CSP route.

Technology Development in the Mission Mode: Through public-private partnerships and by creating global alliances, India should develop cost-effective technologies. A specific Technology Mission could be set up to develop implementable plans by 2012. We could develop the systems much cheaper than western countries. Besides, a huge export market is waiting to be tapped.

A Proactive Policy, Financing & Regulatory Framework: In Section 5 of this essay, we saw that the GMI for CSP has presented a set of measures to be put in place by participating countries. This includes binding targets, adequate feed-in tariffs, tax credits, viable financing schemes, and an enabling regulatory framework.

Join the Global Market Initiative: As per guidelines of the GMI, India qualifies to be a member. We feel that India should join the Global Market Initiative and take full advantage of the technology transfer mechanisms.

(Compiled from various reports and studies)