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EMERGING TECHNOLOGY OPTION FOR CLEAN POWER GENERATION - CONCENTRATED SOLAR POWER (CSP)

S.K. Sarangi, Barun Barpujari and Rohit Dawar
Indian Oil Corporation Limited, Corporate Planning & Economic Studies, 3079/3, Sadiq Nagar, J.B. Tito Marg, New Delhi – 110049, India

E-mail: sarangisk@iocl.co.in

ABSTRACT

This paper attempts to bring forward the concept of concentrated solar power (CSP), its relevance and importance in today's context, the various solar field technologies being practiced and solar projects being established worldwide. The paper also examines its economics, Governments intervention to promote CSP and present and future developments of technology. It also scans the Indian environment for identifying the potential and future of CSP in India.

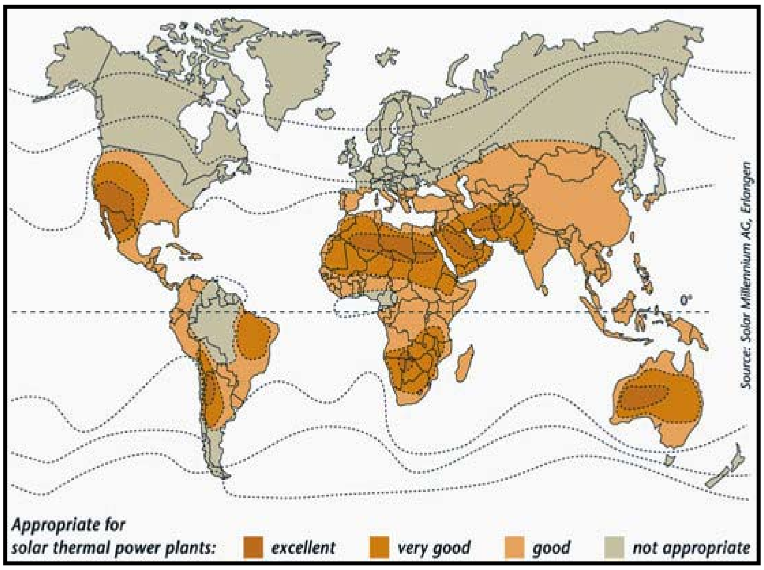
Introduction

Every year, each square kilometer of hot desert receives solar energy equivalent to 1.5 million barrels of oil and also enough to generate as much as 100-120 gigawatt hours of electricity per year using solar thermal technology. This is equivalent to the annual production of a 50 MW conventional coal or gas-fired mid-load power plant.

Solar thermal power is a relatively new technology which has already shown tremendous potential. With few environmental impacts and a massive resource, it offers a comparable opportunity to the sunniest countries of the world as offshore wind farms are currently offering to European nations with the windiest shorelines. The benefits of solar power are compelling: environmental protection, economic growth, job creation, diversity of fuel supply and rapid deployment. The underlying advantage of solar energy is that the fuel is free, abundant and inexhaustible and no attendant geo-political risks as in case of oil & gas, uranium, etc.

On climate change, a solid international consensus is to swiftly move towards a clean energy economy, and solar thermal power can be a prime choice in developing an affordable, feasible global energy source, that can be substitute fossil fuels in the sun belts around the world.

Solar thermal power can only use direct sunlight, called 'beam radiation' or Direct Normal Insolation (DNI), i.e. that fraction of sunlight which is not deviated by clouds, fumes or dust in the atmosphere and that reaches the earth's surface in parallel beams for concentration. Hence, it must be sited in regions with high direct solar radiation. Suitable sites should receive at least 2,000 kilowatt hours (kWh) of sunlight radiation per m^2 annually, whilst best site locations receive more than 2,800 $kWh/m^2/year$. Typical site regions, where climate and vegetation do not produce high levels of atmospheric humidity, dust and fumes, include steppes, bush,



savannas, semi-deserts and true deserts, ideally located within less than 40° of latitude north or south. Among the most promising areas of the world are the South-Western USA, Central and South America, North and Southern Africa, Mediterranean countries of Europe, Middle East, Iran, and desert plains of India, Pakistan, former Soviet Union, China and Australia.

Turning solar heat into electricity

The sun is a much larger practical energy resource than any non-direct solar resource. Consequently, solar electricity is the most likely means to nearly eliminate contributions to global warming from electricity generation by mid-century. Furthermore, with thermal storage much cheaper than electrical, mechanical or hydrogen storage, solar electricity will probably be predominantly in the form of solar thermal electricity with thermal storage, rather than photovoltaic solar electricity with electrical storage.

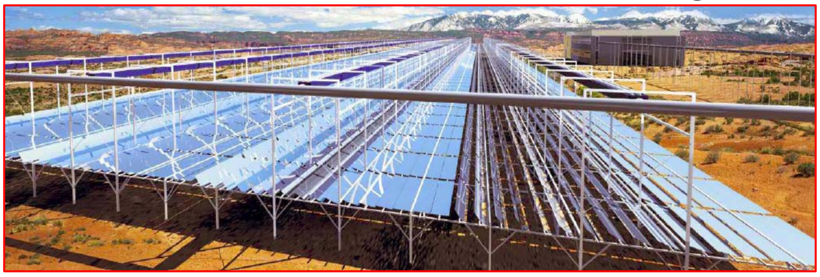
Producing electricity from the energy in the sun's rays is a straightforward process. Direct solar radiation can be concentrated and collected by a range of Concentrating Solar Power (CSP) technologies to provide medium to high temperature heat. CSP is also referred as Concentrated Thermal Electricity. This heat is then used to operate a conventional power cycle, for example through a steam turbine or a Stirling engine. Solar heat collected during the day can also be stored in steam, liquid or solid media like molten salts, ceramics, concrete or, in the future, phase-changing salt mixtures. At night, it can be extracted and, thus, extends turbine operation beyond sunset.

Technology and Costs

Power tower

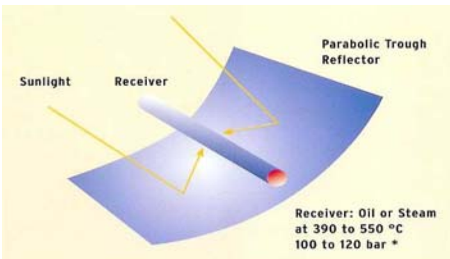
Parabolic trough

Dish/engine

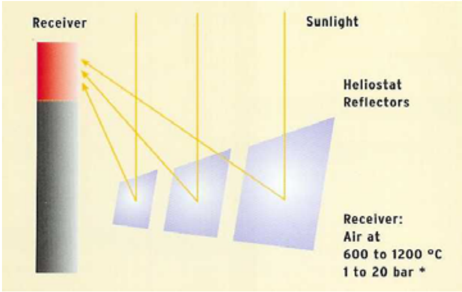


Compact Linear Fresnel Reflector (CLFR)

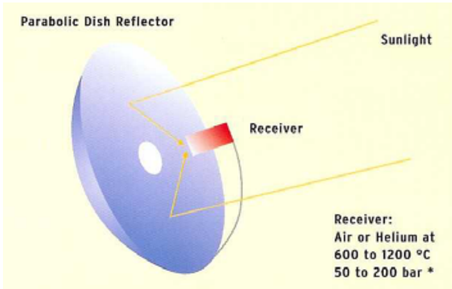
Four main elements are required to produce electricity from solar thermal power: a concentrator, a receiver, some form of transport or storage, and power conversion. The four most promising solar thermal technologies are the parabolic trough, the central receiver or solar tower, the parabolic dish and Compact Linear Fresnel Reflector.



Parabolic trough systems use trough-shaped mirror reflectors to concentrate sunlight on to receiver tubes through which a thermal transfer fluid is heated to roughly 400°C which then is used to produce superheated steam. They represent the most mature solar thermal power technology, with 354 MWe of plants connected to the Southern California grid since the 1980s using more than 2 million square metres of parabolic trough collectors. These plants supply 800 million kWh annually at a generation cost of about 14-17 US cents/kWh. Further advances are now being made in the technology, with utility-scale projects planned in Spain, Nevada (USA), Morocco, Algeria, Israel, Egypt, Iran, South Africa and Mexico. Cost of electricity from trough plants is thus expected to fall to 7-8 € cents/kWh in the medium term. Combined with gas-fired combined cycle plants, power generation costs are expected to be 6-7 € cents/kWh in medium term.

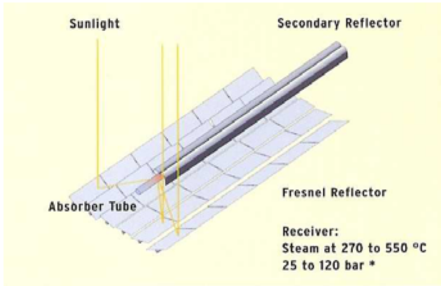


Central receiver (solar tower) systems use a circular array of large individually tracking plain mirrors (heliostats) to concentrate sunlight on to a central receiver mounted on top of a tower, with heat transferred for power generation through a choice of transfer media. Following the completion of the first 11 MWe PS10 commercial tower plant, solar tower developers feel confident that grid connected tower power plants can be built up to a capacity of 200 MWe solar-only units with power generation costs then comparable to parabolic troughs.
Solar towers have good longer-term prospects for high conversion efficiencies. Projects are under implementation in Spain and under preparation in South Africa. In future, central receiver plant projects will benefit from similar cost reductions to those expected from parabolic trough plants. The anticipated evolution of total electricity costs is that they will drop to 7 € cents/kWh in medium term and to 5 € cents/kWh in long term.



Parabolic dish systems are comparatively small units which use a dish-shaped reflector to concentrate sunlight, with superheated fluid being used to generate power in a small engine at the focal point of the reflector. Sometimes, instead of fluid, electricity is directly generated using Sterling Engine.

Solar to electric efficiencies can go up to 30%. Their potential lies primarily in decentralised power supply and remote, stand-alone power systems. The range of power generation is from 5 kW to 25 kW per dish. For larger capacity plants, a number of dishes are used. Projects are currently planned in the United States, Australia and Europe. In terms of electricity costs, an attainable near-term goal is a figure of less than 15-20 € cents/kWh, depending on the solar resource.



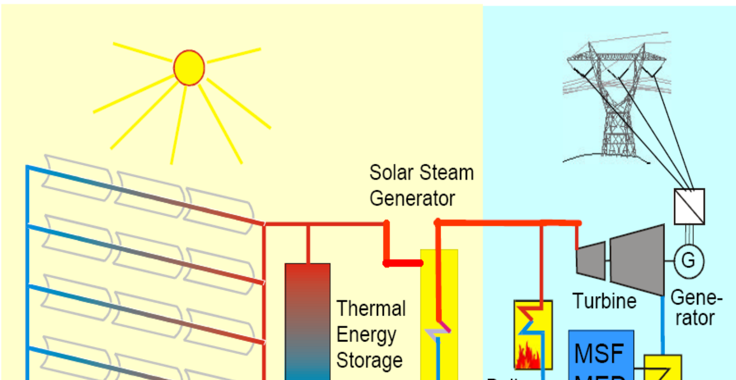
Compact Linear Fresnel Reflector (CLFR) solar thermal power consists of multiple solar collector lines which feed saturated steam to thermal storage and then to turbine block.

CLFR solar power plants use a simple Rankine cycle system for power generation from the steam collected by the solar field. Pipes in the absorber carry water which boils and can reach over 545 degrees F (285^{o}C) at about 70 times atmospheric pressure. This high pressure steam drives a steam turbine generator, then is recondensed to water and used over and over. This power system is common to conventional types of power plants; what is different is that sunlight, not burning fuel or splitting atoms, produces the heat to boil the water. This operating point provides cost savings and efficiencies in the solar collectors and thermal energy storage systems.

Benefits of Solar Thermal Power

Solar thermal electricity offers a number of advantages when considered as part of a country or region's energy generation options mix. Solar energy is the world's most abundant sustainable resource. It represents an even larger resource because of the favourable geography of many of the world's developing countries. Solar thermal, based on a hot fluid, can integrate well with conventional thermodynamic cycles and power generation equipment, as well as with advanced, emerging technology. It offers despatchable power when integrated with thermal storage, and thus good load matching between solar insolation (exposure to sunlight) and the strong growth (in many countries) in electrical demand during summer.

The collector technology itself is constructed of predominantly conventional materials—glass, steel, and concrete, and no fundamental scientific breakthroughs are required for the cost to continue to drop. There is also the advantage that at a time when deep cuts to greenhouse gas emissions



are being called for, solar thermal can be installed in large capacities, yet constructed of modular, repeated, well-known components. Depending on solar radiation levels, the cost of electricity for a one-off plant is presently around 16 to 20 cents per kilowatt-hour (c/kWh), which might be acceptable for some small applications (kilowatts or a few megawatts), but difficult to justify for larger multi-MW installations.

A major benefit of solar thermal power is that it has little adverse environmental impact, with none of the polluting emissions or safety concerns associated with conventional generation technologies. There is hardly any pollution in the form of exhaust fumes or noise during operation. Decommissioning a system is not problematic. Each m^2 of reflector surface in a solar field is enough to avoid the annual production of 150-250 kg of CO_2. Solar thermal power can therefore make a substantial contribution towards international commitments to reduce the steady increase in the level of greenhouse gases and their contribution to climate change.

Moreover, the cost of collecting solar thermal energy equivalent to one barrel of oil is about US$50 right now (already less than the current world price of oil) and is likely to come down to around US$20 in future. US venture capitalist, Vinod Khosla says that CSP is competitive now [with ‘clean coal’] and poised for explosive growth (Solar Power Conference, 2006).

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: 11 MWe, with another 10 MW currently under construction.)	Stand-alone, small off-grid 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	• 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	• Good mid-term prospects for high conversion efficiencies, operating temperature potential beyond 1,000°C (565°C proven at 10 MW scale) • Storage at high temperatures • Hybrid operation possible	• 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	• Reliability needs to be improved • Projected cost goals of mass production still need to be achieved.

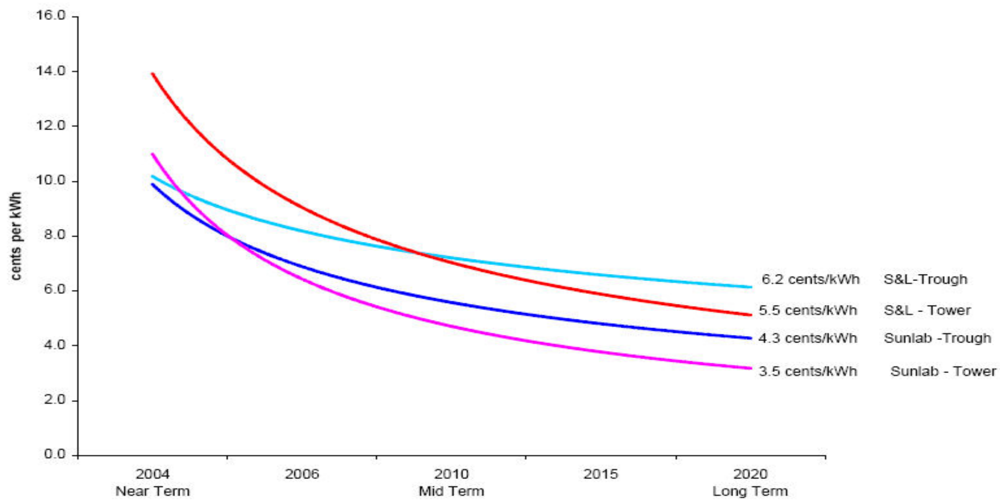
Cost and Efficiencies

Dr David Mills (who pioneered the CSP plant at the Liddell power plant in New South Wales using CLFR technology) recently projected that construction cost of solar-thermal plants shall reduce from US$3,000/kW of capacity to US$1,500/kW over the next "several" years. The New York Times last year quoted GE Energy executives estimating coal plant construction between US$2,000 and US$3,000/kW.

Ausra, a leading company in CSP, says it can generate electricity for 10 c/kWh (close to the current cost using natural gas), and it expects the price to drop even further.

The existing plants prove that concentrated solar power is commercially feasible, but costs must decrease. Electricity from solar thermal plants currently costs between US$0.13/kWh and US$0.17/kWh, depending on the location of the plant and the amount of sunshine it receives. Conventional power plants generate electricity for between US$0.05 and US$0.15/kWh (excluding any carbon taxes or cap and trade related costs) but in most places it's below US$0.10 (wind power generally costs around US$0.08/kWh).
Another estimate from Sandia labs showed solar thermal costs (for solar towers) could fall to around 4 c/kWh by 2030. Graph below indicates mid-term & long-term projections of levelized cost of electricity generation through CSP (through and tower) and Seargent & Lundy and Sunlab technologies.

Figure ES-1 — Levelized Energy Cost Summary



The efficiency of the CSP plant depends on the Solar to Electricity generation. The average level of solar insolation is 1kW/m2; the amount of solar energy available on the Earth's surface. This can be concentrated several thousand times using CSP systems. The efficiency with which this radiation can be transformed into thermal energy is dependent upon a combination of optical efficiency and heat conversion efficiency. The optical efficiency of the system is defined by accuracy of the reflective shape of the solar collectors. Heat conversion efficiency is defined by the physical characteristics of the solar receiver to convert solar radiation to thermal energy.

Optical efficiencies of up to 98% have been achieved along with heat conversion efficiencies of between 70 and 95%. In CSP systems that produce electricity, the concentrated heat is used to produce steam, either directly or indirectly, which is then used to produce electricity. The efficiency of this system, solar to electric, is dependant upon the combination of radiation to thermal efficiency and of the steam cycle efficiency. Experimental installations have shown peak efficiencies of up to 29% for parabolic dish systems. This efficiency is dependent upon which system is used, with the most mature technology, the parabolic trough system being the least efficient.

Today's parabolic trough developers state that their new collectors are 20% more efficient than those of the most recent Solar Electric Generating Station (SEGS).

Moreover, various new concepts have been developed from the basis of the parabolic trough technology. Some options are as follows:

- ***Integrated Solar Combined Cycle Systems*** would integrate a parabolic trough (or a solar tower) with a gas turbine combined-cycle plant, the solar heat supplementing the waste heat from a gas turbine to augment power generation in the steam Rankine bottoming cycle. This would reduce costs mainly by increasing the solar to electricity efficiency.
- ***Direct solar steam***, where steam is generated at high pressure and temperature directly in the parabolic troughs (or Fresnel reflectors). This would reduce costs by eliminating the need for costly mineral oil and heat exchangers and reduce efficiency losses. This option might, however, make storage more complex.

- ***Linear Fresnel reflectors*** would approximate parabolic shape with fragmented mirrors. This could drastically reduce capital costs in view of a low cost structure, a low cost fixed receiver which is composed of mild steel pipe, and exceptionally low reflector costs.
- ***Molten salts use in trough field,*** an option under investigation by the Italian ENEA (2003) would allow raising temperature and efficiency, thus reducing costs. The challenge seems to protect molten salts from freezing in the solar field during cold nights.

While there remains a large potential for cost reductions from research and development on all elements of this technology, from global concepts to almost all elements, this potential could only be reached if there is an active marketplace for these technologies and entrepreneurs capable of integrating lessons from experience as well as concepts and materials from laboratories.
An active market place could also presumably reduce costs by mass production, economies of scale, increasing the hours of operation, reduction in O&M costs, reduction of risk premium and risk mitigation costs as the market develops, experience of suppliers of parts and assemblers. In-depth studies suggest that full competitiveness could be reached for trough technology after the installation of 5,000 MW of capacity.

Expansion of CSP technologies will be limited, however, by the availability of the resource. They seem to require a minimum of yearly direct insolation of about 2,000 kWh/m^2, but insolation of 2,500 kWh/m^2 is more likely to favour competitiveness – though costs will also depend on land costs (SEGS plants expand on about 2 ha per MWe), local construction and operating costs, and other local factors.

Partial list of Solar Thermal Power Plants/Projects

Based on above technologies, a number of Solar Power Plants have been set-up. The following are the major plants which are in operation or under construction/ announced:

Operational

- Solar Energy Generating Systems, USA Mojave desert California, total of 354 MW, parabolic trough design
- Nevada Solar One, USA Nevada, 64 MW, parabolic trough design
- Liddell Power Station, Australia, 95 MW heat, 35 MW electrical equivalent as steam input for conventional power station, Fresnel reflector design
- PS10 solar power tower, Spain Seville, 11 MW, power tower design

Under construction

- Andasol 1 solar power station, Spain, 50 MW with heat storage, parabolic trough design
- Andasol 2 solar power station, Spain, 50 MW with heat storage, parabolic trough design
- La Risca 1 solar power station, Spain, 50 MW , parabolic trough design
- PS20 solar power tower, Spain Seville, 20 MW, power tower design
- Beni Mathar Plant, Morocco, 20 MW for hybrid plant, technology unknown
- Solar Tres Power Tower, Spain, 17 MW with heat storage, power tower design

Announced

- Ivanpah Solar, USA California, 500 MW + 400 MW optional extension, power tower design
- Mojave Solar Park, USA California, 553 MW, parabolic trough design
- Pisgah, USA California near Pisgah north of I-40, 500 MW, dish design
- Unnamed, USA Florida, 300 MW, Fresnel reflector design
- Imperial Valley, USA California, 300 MW, dish design
- Solana solar power plant, USA Arizona southwest of Phoenix, 280 MW, parabolic trough design
- Beacon Solar Energy Project, USA California, 250 MW, parabolic trough design
- Negev Desert, Israel, 250 MW, design will be known after tender
- Carrizo Solar Farm, USA California near San Luis Obispo, 177 MW, Fresnel reflector design
- Upington, South Africa, 100 MW, power tower design
- Shams, Abu Dhabi Madinat Zayad, 100 MW, parabolic through design

Solar Thermal Power Generation in India

India is a sunny country with a total solar energy potential of 20MW every square km. In the Thar Desert of Rajasthan, this could go up to 37.5 MW/km^2 as seen from the under noted 'back of the envelope' calculation:

The solar intensity is 6kwh/m^2/day or 250w/m^2. Considering the cheapest and most inefficient method of linear fresnel lens having efficiency of 15%, the power produced would be 37.5w/m^2, i.e. around 1GW/25 km^2. ...and Thar Desert area is 2.28 lakh km^2 (0.23 million km^2) and is capable of producing 9000 GW of power!! As per XI plan, the electricity demand by 2011-12 is only 160 GW!!!

World Bank along with GEF and KfW sponsored a 35 MW solar thermal power plant at Mathania, Rajasthan, but very little progress has been made during the last 10 years.

Ministry on New & Renewable Energy (MNRE) has been supporting Research, Design and Development activities in New and Renewable Energy including solar energy in the country.

In a bid to develop solar power potential in the country, MNRE has so far installed 33 grid-interactive solar photovoltaic power plants with financial support from the centre. The aggregate capacity of these plants is 2.12 MW, which is expected to generate about 2.55 million units of electricity annually.

MNRE's future plans

During the XI Plan, MNRE has proposed a subsidy element of Rs. 200 crore for development of 50 MW grid-interactive solar power.

Incentives available

MNRE provides incentives to academic, research institutions and industries, including private institutions engaged in the research in solar energy. They are eligible to receive grant for undertaking R&D activities. In addition, for private industries, expenditure on R&D is eligible for deduction from profits under Income Tax Act.

Also, under grid-interactive solar power generation, private companies are eligible for production based incentive for power fed to the grid from **MW capacity solar power plants set up on own land**. Proposals from project developers with a maximum aggregate capacity of 5 MW, either through a single project or multiple projects of a **minimum capacity of 1 MW** each, are being considered under the programme.

For projects approved and commissioned by 31.12.2009, MNRE will provide generation based incentive up to Rs. 10 per kWh for solar thermal power after taking into account the tariff provided by the SERC or the utility.

Taking a cue from the above MNRE scheme, Rajasthan on 2.4.2008 declared preferential tariff of Rs. 13.78/kWh, West Bengal Rs. 11/kWh and Punjab Rs. 7.00/kWh. Other states are also in the process of announcing their Renewable Purchase Obligation and preferential solar feed-in tariffs.

On 30th June 2008, Prime Minister formally launched India's National Action Plan on Climate Change (NAPCC). NAPCC focuses on national energies through Eight National Missions. One of the Mission is on Solar Energy. The action plan envisages 1000 MW power generation through the solar mode by the end of 12th Plan (2017). NAPCC also envisages that 5% of the energy requirements of the country should be from renewable sources.

Considering the northward rise of crude oil prices and growing concerns about the impacts of climate change, there is a definitive bright future for solar thermal power.