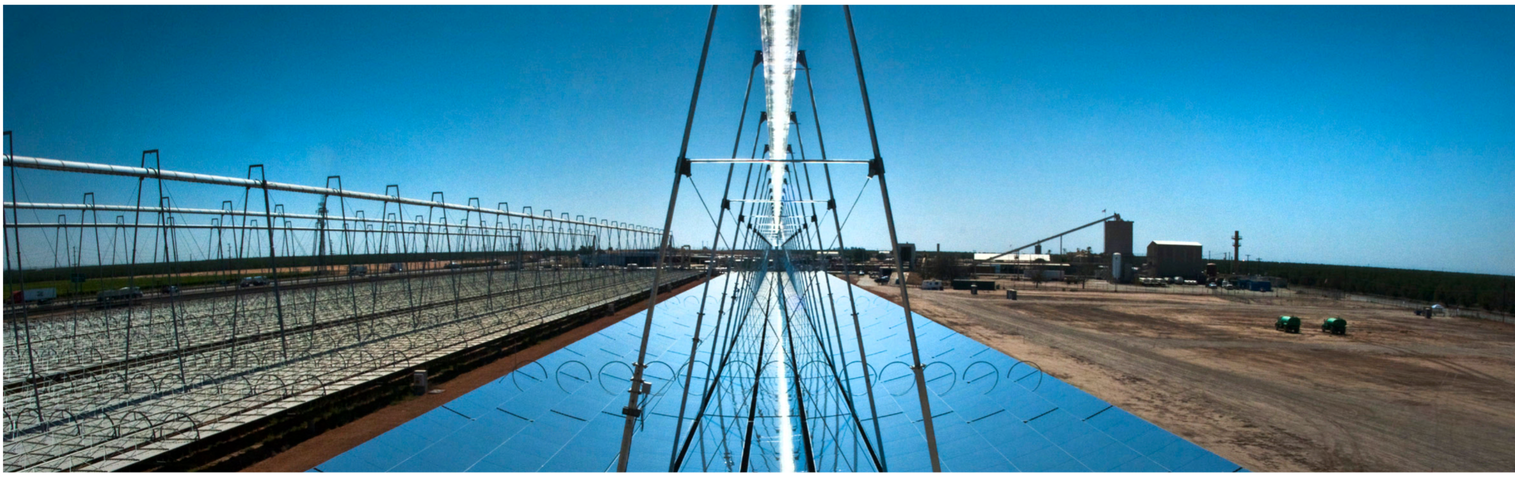
Australian Government
Department of Climate Change and Energy Efficiency

Concentrating Solar Power in India

Report commissioned by the Australian Government and prepared by IT Power

Concentrating Solar Power in India



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Prepared by the IT Power Group, a specialist engineering consultancy focusing on renewable energy, energy efficiency and climate change. IT Power has offices in Australia, China, Fiji, India, Kenya, Mongolia, Morocco, Portugal, UK and USA.

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Executive Summary

This report is an outcome of the AusAID Public Sector Linkages Program (PSLP) project, '*Concentrating Solar Power in India*'. The report was commissioned by the Australian Government Department of Climate Change and Energy Efficiency (DCCEE) with the cooperation of the Government of India Ministry for New and Renewable Energy (MNRE).

The aim of this report is to analyse the context, barriers and policy options for the growth of the Concentrating Solar Power (CSP) industry in India, for use by government policy and program implementation staff in both countries. It may also be of interest to others such as CSP developers and investors.

Global status of CSP

CSP technologies use systems of mirrored concentrators to focus direct beam solar radiation to receivers that convert the energy to high temperature for power generation. There are four main configurations that are commercially available - Parabolic Trough, Linear Fresnel, Paraboloidal Dish and Central Receiver. Typically, this heat is transformed to mechanical energy through a steam turbine and then into electricity. CSP has advantages compared to photovoltaics as it can readily incorporate thermal energy storage and/or fossil fuel boosting to provide dispatchable power. The use of relatively 'low tech' manufacturing methods for solar collector fields, together with the use of steam turbine technologies adapted from the existing thermal power generation industry, makes the prospect of continued, rapid scale-up of CSP capacity very feasible.

Key features and status of the four main CSP technologies are summarised below.

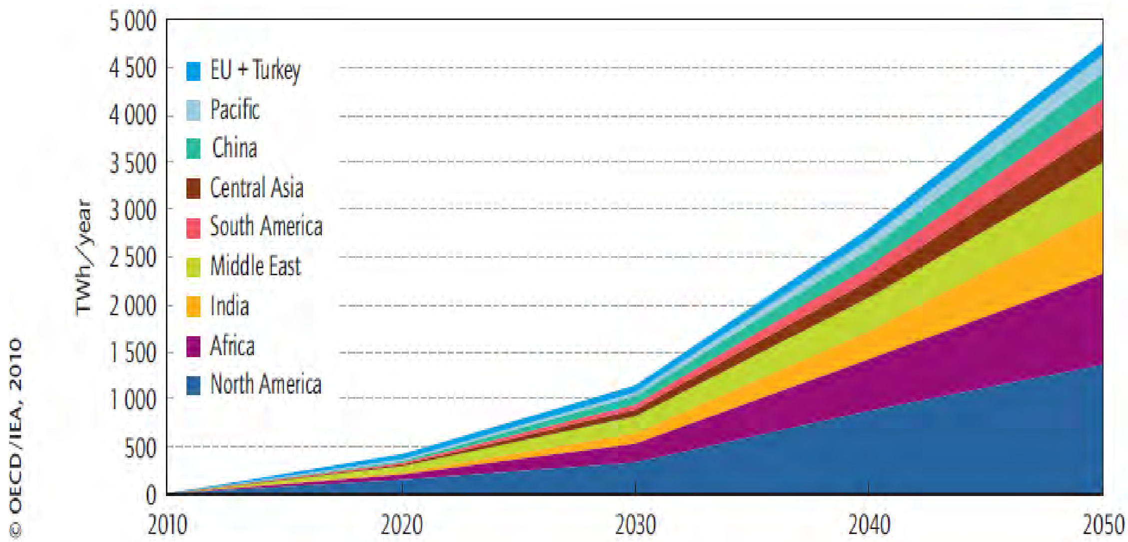
Technology	Annual solar to electricity efficiency	Focus type	Practical operating temperature	Power cycles considered	Commercial maturity	Installed generating capacity mid 2010
Linear Fresnel	8 - 10%	Linear	150 to 400°C	Steam Rankine Organic Rankine	Medium	8 MW_e
Parabolic troughs	12 - 15%	Linear	150 to 400°C	Steam Rankine Organic Rankine	High	943 MW_e
Central receiver tower	20 - 30% (concepts)	Point	300 to 1200°C	Steam Rankine Brayton (gas turbine)	Medium	38 MW_e
Parabolic dishes	20 - 30%	Point	300 to 1500°C	Stirling Engine Steam Rankine Brayton (gas turbine)	Low	1.5 MW_e

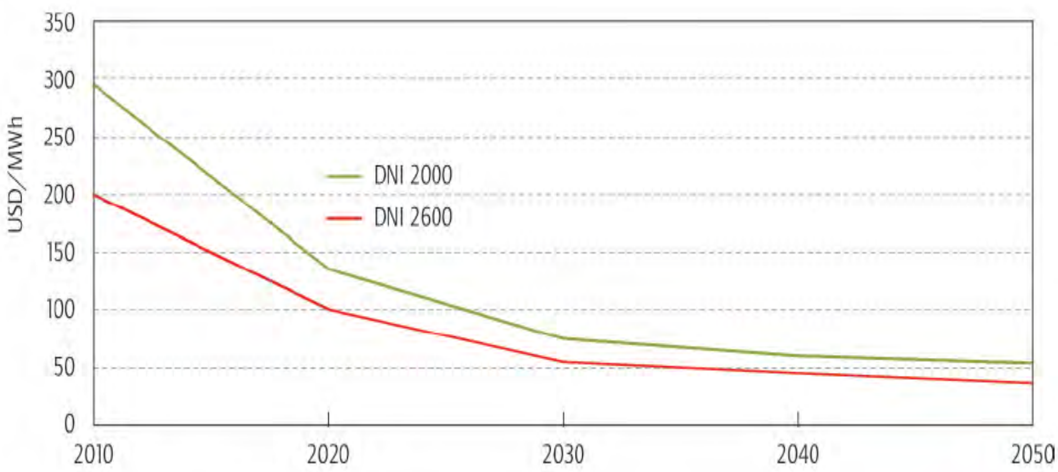
Concentrating solar thermal power project developments were limited for a long period following an initial period of growth in the 1980's. Since 2005, CSP project activities have recommenced and gained considerable momentum. The CSP sector is widely forecast to continue to grow at very high rates. This growth has been mainly in Spain and now increasingly in south-western USA and is linked to Feed-in Tariffs and Renewable Portfolio Obligations in those jurisdictions.

The International Energy Agency's Solar Power and Chemical Energy Systems (SolarPACES) program is the umbrella under which the CSP community has worked together and shared information for many years, (see http://solarpaces.org/). This website has good overview information and a link to a project listing hosted by the National Renewable Energy Laboratory at: www.nrel.gov/csp/solarpaces/

The nine Solar Energy Generating Systems (SEGS) plants in Southern California were built by the Luz company beginning in 1984 and ending in 1990. These gas-boosted CSP plants have a total capacity of 354 MW_e and have been generating effectively for over 20 years with their O&M costs declining and annual output increasing over time. This track record establishes the trough technology approach as truly proven and this is the reason that most of the new, large projects are also variations on the SEGS technology approach.

The International Energy Agency (IEA) published a CSP Technology Roadmap in 2010 and it presents a high credibility summary of the global situation and way forward. The following two figures are from this Roadmap and show that global CSP electricity generation is projected to grow to 4,700 TWh per year by 2050, with Levelised Energy costs dropping from US $200 / MWh to $40 / MWh over that period, with half of the cost reduction achieved over the next 10 years.

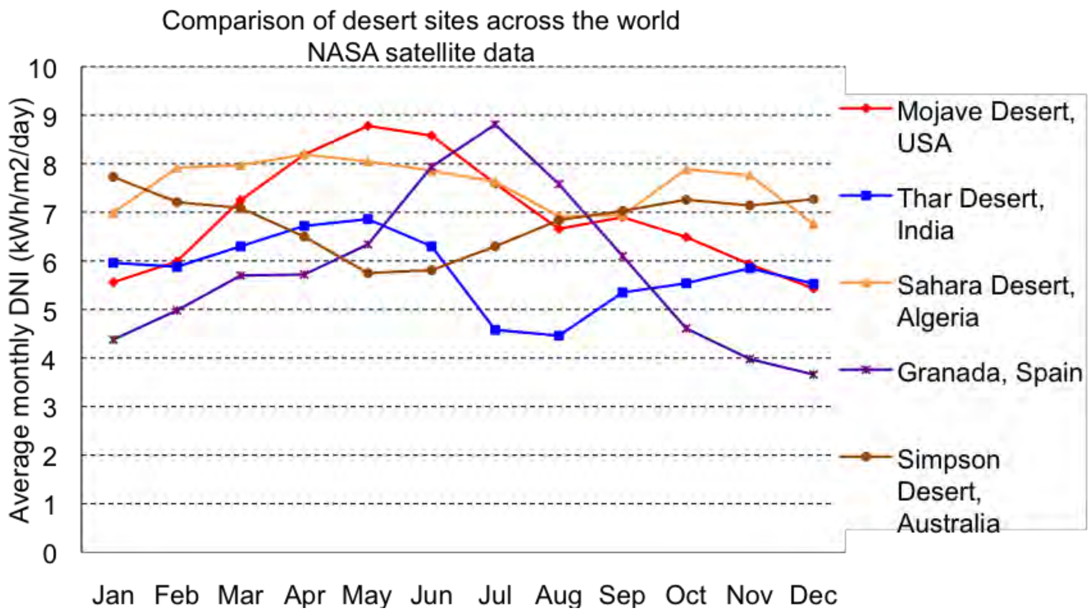




Note DNI is Direct Normal Irradiance, in units $kWh/m^2/yr$

Indian Solar Resource

Direct Normal Irradiation (DNI - the portion of solar radiation that CSP plants utilise) data for India is available from calculations based on satellite measurements from several sources including NASA. Ground based measurement data is limited, although a government tender for 51 monitoring stations was advertised in November, (C-WET, 2010). The best sites in India are in the north west of the country. The graph below compares Jodhpur, on the edge of the Thar Desert in Rajasthan with other desert locations around the world.



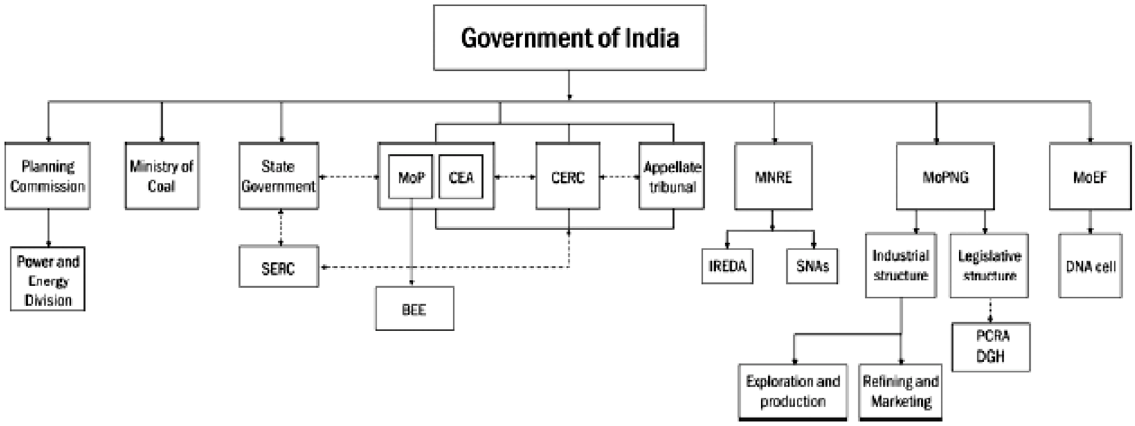
The Jodhpur curve shows a dip in the middle of the year coincident with the monsoon. The North African deserts have the best possible DNI resource on the planet, both on an annual average and minimum variability basis. The comparison shows that the Sahara desert offers a solar resource that is both more consistent through the year and about 25% higher on average than Jodhpur, which is almost exactly comparable on an annual average basis to Granada, one of the best Spanish sites. The Mojave desert, essentially the best possible USA site, is better than Jodhpur and Granada but not quite as good as North Africa.

Indian Energy Market and enabling policy

The Indian economy is growing rapidly and providing the electricity generation capacity to support this is a key challenge. Installed capacity is predicted to grow from 167 GW in 2010 to 300 GW by 2017. There is an extensive transmission network but it is widely acknowledged as requiring major strengthening. Whilst the network coverage is extensive, it is not universal, with the order of 100,000 villages and more than 400 million people not connected.

There are several agencies responsible for components of the Indian energy sector. The Planning Commission provides the national oversight with regulatory power residing with the Central Electricity Regulating Commission (CERC) and the State Electricity Regulating Commissions (SERCs). In addition, there is the Federal Ministry of Coal, Ministry of Power (which includes the Central Electricity Authority and the Bureau of Energy Efficiency), Ministry of New and Renewable Energy, Ministry of Petroleum and Natural Gas and the Ministry of Environment and Forests (which includes the Designated National Authority that approves Clean Development Mechanism projects).

The following figure (USAid, 2007) gives an indication of the organisational structure.



Jawaharlal Nehru National Solar Mission

The main enabler for photovoltaic and CSP projects is the Jawaharlal Nehru National Solar Mission, (JNNSM). The Solar Mission was launched by the Prime Minister, Manmohan Singh in January 2010. It focuses on a target of 20 GW of solar capacity by 2022. In the first phase, 1 GW of grid-connected solar is targeted for 2013 with an approximate 50:50 split between CSP and photovoltaic (PV) technologies expected. The trading arm of the National Thermal Power Corporation, the NTPC Vidyut Vyapur Nigam Ltd (NVVN) has been given the responsibility for implementing phase 1. NVVN will offer a 25 year Power Purchase Agreement (PPA) for successful Solar Mission projects at a preferential tariff.

The Solar Mission is generating interest from all the major international CSP players. This comes at the same time as an upsurge of interest in Australia sparked by the $1.5 billion in funding on offer from the Solar Flagships program that is aiming for 1 GW of solar by 2015.

The guidelines for phase 1 of Solar Mission include a 30% local content requirement and the need for the technology to have been demonstrated in operation at a scale of at least 1 MW_e for at least 12 months, plus a range of financial criteria for the developers. A tariff cap of Rs. 15.3 / kWh (approximately AU $0.34 / kWh) is on offer, with a reverse auction system required if proposals with more than the capacity target are offered. The Request for Selection closed on 24 September 2010.

On 18 October 2010, the Hindu Business Line website reported that 77 CSP proposals totalling 1,815 MW were received. On 22 November 2010, The Indian-Commodity website reported that seven CSP proposals had been selected totalling 470 MW with significant tariff discounts of up to Rs 4.82, (more than 30%).

On 13 December 2010, the NVVN website was updated and indicated that the successful CSP proposals for phase 1 of Solar Mission were as follows:

Bidder Name	Bidder's City	Project Type	Capacity (MW)	Location	State
Lanco Infratech Limited	Hyderabad	thermal	100	Jaisalmer, Nachna, Chinnu	Rajasthan
KVK Energy Ventures Private Limited	Hyderabad	thermal	100	Jaisalmer, Nachana-1, Chinnu	Rajasthan
Megha Engineering and Infrastructures Ltd	Hyderabad	thermal	50	Anantapur, Pamidi, Virannapalle	Andhra Pradesh
Rajasthan Sun Technique Energy Private Limited	Navi Mumbai	thermal	100	Bikaner, Kolayat, Ladkan	Rajasthan
Aurum Renewable Energy Private Limited	Mumbai	thermal	20	Jamnagar, Dwarka, Mojap	Gujarat
Godawari Power and Ispat Limited	Raipur	thermal	50	Jaisalmer, Jaisalmer, Parewar	Rajasthan
Corporate Ispat Alloys Limited	Mumbai	thermal	50	Jaisalmer, Pokhran, Nokh	Rajasthan

In addition to the Solar Mission, there are also Renewable Purchase Obligations, State based initiatives and tariffs that may benefit CSP projects.

Barriers

Barriers can be classified in numerous ways. For the purposes of this report, the following classifications have been chosen for barriers to CSP deployment both globally and specifically in India or Australia.

Cost

A major barrier for CSP is it current high cost of electricity produced, particularly where the external costs of fossil fuel combustion are not reflected in electricity pricing. The high proportion of up front capital investment needed for CSP projects magnifies the barrier.

Financing

This is a significant barrier. To achieve financial closure, the revenue equation must provide investors with an acceptable return and allow for debt and interest to be paid back. Financiers have indicated that they are unfamiliar with CSP technologies and that the Power Purchase Agreement on offer is not bankable.

Government policy

At the most basic level, policy is needed to allow CSP systems to earn revenue for electricity production that is sufficient to allow financial closure to be achieved on reasonable projects. Other Government policy settings are also very important, such as industry development policies, intellectual property law, general law and order plus country stability.

Approvals and land

Without suitable sites and approvals, no project can proceed. There is great scope for facilitation and streamlining.

Grid and services connection

Large-scale CSP plants need a grid connection. Gas, water, sewerage, roads, must also be considered to varying degrees and according to the technology solution being used. Long term water security is a key concern with climate change and competing needs.

Technology shortcomings

The ideal CSP technology would be one with high performance, low capital investment cost, high reliability and minimal O&M costs. Technology shortcomings for any given technology / technology proponent include those inherent to the technology and those that emerge with the specific project.

Solar data

Reliable long term DNI data collected at high frequency is needed to predict system output accurately, mainly as an input to investment decisions. Very few areas of the sunbelt regions of the planet have adequate data.

Manufacturing scale-up

For CSP to achieve significant penetration in a given market, millions of square meters of solar concentrator systems of various types along with all the supporting plant/ infrastructure will need to be manufactured. Facilities and the skilled human resources to do this are needed.

Matching business cultures

CSP, like other renewable energy technologies, is rapidly becoming a global industry, the issue of doing business in a (business) culture other than the place of origin will be encountered by all major players.

Each of these potential barriers has been analysed via review of previous publications and input from relevant stakeholders. In almost every area, India is taking steps to address the barriers that are heading in the right direction and indeed serve as a global example. There is always more that can be done and the conclusions and recommendations below flow from this analysis.

Capability building

If India is to achieve its ambitious goals in CSP, then considerable effort is needed in skills and capability building. A particularly effective model that could be investigated for facilitation is encouraging Indian commercial organisations to take equity positions in overseas CSP companies. Personnel exchanges can also play a useful role in building capability and overcoming barriers. It is noted that there are a range of bilateral schemes involving India and other countries including Australia (e.g. the Australia-India Strategic Research Fund). Most of these target the research sector and much could be gained by broadening the eligibility to allow commercial organisations and their staff to benefit from similar activities.

In an exchange or secondment, the needs of the three key stakeholders need to be met:

- the people being seconded;
- the parent institution; and
- the host institution.

A model is needed such that all three see a direct and appropriate benefit to the process and the overall results advances the needs of the industry and the country. There are risks with simplistically conceived funding of secondment / collaboration between countries. These arise in particular where the institutions on either side are struggling to attract the funding they need to advance their core goals. In such an environment an apparently well meaning funding of collaboration can see institutions being driven to marriages of convenience to seek funding.

Pilot plants

For a country embarking on growing its involvement with CSP, a first successful pilot plant of some kind can have an enormous educational and consciousness raising benefit. CSP has been discussed in India for many years but there has been no significant pilot plant constructed. When this CSP in India study was first proposed, the Solar Mission had not been announced and there were few CSP proposals being investigated. Previously considerable effort was invested in the proposed first plant at Mathania, with some Global Environment Fund support. However, this project did not attract sufficient support and never eventuated. The Solar Energy Centre in Gurgaon, (about 25km southwest of New Delhi) had a 50 kW_e trough demonstration plant that was decommissioned after a short period of operation. There are successful Scheffler dish, large-scale solar cooking systems and various dish prototyping efforts around the country.

Currently, the major developments include Acme making progress in constructing a first tower based system using ESolar technology, in Bikaner Rajasthan. MNRE's Solar Energy Centre (SEC) in Gurgaon is building a 1 MW_e solar thermal power plant involving two technologies - parabolic trough and Linear Fresnel Reflector. The project is lead by the Indian Institute of Technology (IIT) Bombay, and the troughs are to be provided by Abengoa. SunBorne Energy is also embarking on a research / pilot system at the Solar Energy Centre. IIT is establishing a campus in Jodhpur Rajasthan, with a large area earmarked for a R&D CSP test centre. In addition, some of the projects to emerge under phase 1 of the Solar Mission are expected to be constructed over the next two years.

However, there is scope for further work on the pilot plant concept. Pilot systems can offer:

- Demonstration of the viability of newly developed, Indian technology and overseas technology.
- Opportunities for established overseas technology providers to test the business environment in India.
- Opportunities for Indian technology licensees to demonstrate technical capability.
- Opportunities for established technology companies to trial alternative component suppliers and designs.
- Training and R&D facilities for researchers engineers and technicians.

Suggested criteria for a good pilot location include:

a) Good solar resource to maximise potential operating hours.

b) Easy access from an airport to maximise demonstration value to visitors.

c) Access to neighbouring fabrication / construction / maintenance capability.

d) Reasonable accommodation options for visiting personnel.

e) Generation of sufficient revenue from operation to cover O&M costs over several years of continuous operation.

f) Approvals process to be as simple as possible.

A concept of creating one or more 'Demonstration Solar Parks' to facilitate commercially driven pilot plants in the 1 to 5 MW_e size range is recommended. Internationally, the Plataforma Solar de Almeria (PSA) facility in Spain (shown in the Figure below) has many lessons to offer. Noting, however, that it has a much greater R&D focus than the demonstration Solar Park concept. It is globally the largest existing solar thermal test facility. The more than 100 hectare site is utilised for testing and optimisation of a variety of high-temperature solar technologies. It was established through a Spanish-German collaboration and also closely collaborates with several large companies.

Conclusions and Recommendations

India has sufficient land area with high resource (DNI) for CSP to make a major contribution to its energy mix, along with the will to make this happen. As with many countries, including Australia, the available data on solar resource is not ideal in quantity or quality. Any move to improve on this will assist the industry as a whole, as the lack of data is an impediment to securing finance cost-effectively. However, it is not likely to be a key determining factor for the future of CSP in India compared to policy settings and other issues.

The Solar Mission is a visionary and inspiring policy measure that has the potential to be a leading example for the world. Features like the eligibility requirement that CSP technology must have been demonstrated for at least 12 months at a scale of 1 MW_e or above are very sensible and should be maintained. No doubt many lessons will be learned as the phase 1 process unfolds and the financially and technical feasibility of projects is tested.

The reverse auction approach to tariff determination carries considerable risk of allocations being made to 'adventurous' bidders who may ultimately be unable to deliver, although the built in system of increased bid bonds for higher discounts seeks to discourage this.

Choosing mechanisms for determining the income stream that CSP project developers could benefit from is probably the hardest aspect of government policy setting. The Solar Mission model of setting a maximum tariff and inviting a reverse auction by bidders, appears to have several advantages. However, focusing on lowest bidders carries significant risks as it may discount the importance of technical and business capability in assessments. Many qualified observers have suggested that the timelines for financing, construction and commissioning demanded under phase 1 will be extremely challenging to meet.

The Solar Mission rules plus those of other state based measures are potentially missing some key opportunities. Energy storage, whilst not precluded, is not suitably encouraged with the flat tariffs on offer. Some incentive via a time-of-generation linked tariff would be more likely to produce the best technical solutions. Current rules preclude hybridisation with biomass or fossil plants and this appears less than optimal given the potential synergies that exist. The opportunity to provide solarised or solar enhanced fossil or biomass hybrids is one which could improve peak supply and dispatchability, key requirements for an improved Indian power network.

With all these issues the main point is to make careful adjustments in light of experience. The lessons of the US experience with the SEGS plants and the Luz company should be kept in mind. A sudden, and somewhat unpredictable, policy reversal led to the failure of the most successful company the previous policy had created and lead to a 20 year global CSP hiatus.

India, being a federation of states, has many aspects relevant to renewable energy that are shared responsibilities of federal and state levels of government. This adds to the potential for complexity and confusion, particularly for a new industry that is growing and throwing up issues not previously experienced. Progress is clearly being made, but a lot of issues remain. A promising way of cutting through this is the establishment of Solar Parks in high DNI areas. Rajasthan has well advanced plans in this regard and Gujarat is also pursuing this concept. Large areas of land that have all the necessary approval processes for a CSP development, plus the necessary grid and water supply issues addressed have the potential to reduce project timelines.

The Solar Park concept could also be applied to advantage in a manner tailored for small-scale demonstrations. Specifically those needed to meet the 'at least 1 MW_e for at least 12 months' requirement for the Solar Mission. Small-scale, demonstration oriented Solar Parks could be similar in nature to the large Solar Parks, but should be sited next to cities with major infrastructure and air access (whilst still having as high a DNI resource as possible). Such parks should specifically limit system size to say 5 MW_e as a maximum. To support these earlier stage activities a preferential tariff for small systems could be utilised. To be effective this tariff would need to be significantly higher than the main Solar Mission CSP tariff.

There are many aspects of the Indian business culture and society in general that are very different to the countries that are the current dominant CSP players. India's strong track record of technical success in every new field that it has seriously engaged in, from wind turbines to car manufacturing, makes it clear that a major player position in CSP is feasible. To accelerate the necessary technology transfer process, policy measures that facilitate Indian equity investment in existing CSP companies around the world, together with carefully designed schemes for overseas secondments and training, are recommended.

The specific recommendations from this study are:

1. Modify State based and Solar Mission tariffs to recognise time-of-generation benefits and incentivise energy storage.

2. Modify State based and Solar Mission guidelines to allow CSP tariffs to be earned proportionate to solar contribution as part of a solar-hybrid system.

3. When the current phase 1 process is complete, review Solar Mission timelines for financing, construction and commissioning based on experience.

4. Continue and expand facilitated Solar Parks for large-scale CSP projects.

5. Establish one or more 'Demonstration Solar Parks' for small-scale, commercial demonstration systems and support these with a higher tariff.

6. Establish further projects to improve on DNI data availability, by both adding ground based data gathering and also to reverse analyse, correlate and re-calibrate all existing forms of historical data. Make all such data freely available and easily accessible.

7. Investigate facilitation measures (e.g. tax incentives, soft loans or revolving equity fund) aimed at assisting Indian companies to make equity investments in CSP companies around the world.

8. Establish and / or review targeted schemes for CSP related industrial, research and policy secondments / traineeships / fellowships around the world.

9. Maintain or even strengthen the guideline of 'at least 1 MW_e demonstrated for at least 12 months' for future phases of the Solar Mission.

10. Implement a loan guarantee program for worthwhile CSP projects, similar to that in the US.

11. Avoid any sudden changes of policy settings that cause companies nurtured under the previous policy framework to fail.

12. Investigate options to provide investment incentives for expanding network infrastructure in high DNI regions.

13. Provide more resources to MNRE to facilitate improved information flows for industry and other stakeholders, e.g. upgrade and redesign the website and include factsheet summaries, case studies and updates on key activities.

1 Introduction

This report is an outcome of the AusAID Public Sector Linkages Program (PSLP) project, '*Concentrating Solar Power in India*'. It was commissioned by the Australian Government Department of Climate Change and Energy Efficiency (DCCEE)[1] with the cooperation of the Government of India Ministry for New and Renewable Energy (MNRE).

The aim of this report is to analyse the context, barriers and policy options for the growth of the CSP industry in India. In the time that has elapsed since the project was proposed, the Government of India has announced its Jawaharlal Nehru National Solar Mission (JNNSM). This visionary policy has significantly addressed many of the barriers for CSP in India. Consequently the report's focus has evolved to examine how the JNNSM has altered the investment landscape, options to enhance its potential for long-term success and potential complimentary measures. Many of the observations are applicable to Australia, where the Solar Flagships program aims to develop local capacity by supporting the initial capital costs of two large-scale CSP projects.

The report aims to provide analysis for government policy and program implementation staff in both countries. It may also be of interest to others such as CSP developers and their investors from both India, Australia and elsewhere.

CSP is a proven technology approach and involves concentrating energy from the sun's rays to heat a receiver to high temperatures. Typically, this heat is transformed to mechanical energy through a steam turbine and then into electrical energy. In areas of high direct normal solar irradiance, CSP has advantages compared to photovoltaics as it can readily incorporate thermal storage and/or fossil fuel boosting to provide dispatchable power. It can also be used for producing fuels and direct high-grade heat for industrial processes. The use of relatively 'low tech' manufacturing methods for solar fields together with the use of steam turbine power generation adapted from the existing thermal power generation industry makes the prospects of continued rapid scale-up of CSP capacity very feasible.

Over the last three decades the world wind industry has grown at an average rate of approximately 20% per year to reach a total installed capacity of 194 GW in December 2010. It has exceeded 1.5% of total world electricity generation (AWEA 2008) and wind capacity is now being installed at a faster annual rate than nuclear. Over a shorter period, the solar photovoltaics industry has grown with comparable or higher rates of growth but from a lower base and now has a worldwide installed capacity of about 22 GW. Concentrating solar thermal power technology developments were stagnant for a long period following an initial period of growth in the 1980's. Since 2005, CSP developments have recommenced and gained considerable momentum. The CSP industry is widely forecast to continue to grow at very high rates. This growth has been mainly in Spain and now increasingly in south-western USA and is linked to Feed-in Tariffs and Renewable Portfolio Obligations in those jurisdictions.

[1] At the time the project began, the relevant section of DCCEE was part of the Department of the Environment, Water, Heritage and the Arts (DEWHA).

CSP has potential for significant growth in the coming decades in locations with plenty of sunshine and clear skies. The International Energy Agency's CSP Technology Roadmap (IEA, 2010) includes scenarios where the global installed capacity of CSP is between 630 GW and 1,500 GW by 2050.

India has the potential to become a major global force in the CSP industry due to the forecast growth in its power generation sector and the effective government support of which the Solar Mission is a key component. India has developed a globally competitive automotive industry and the rapid development of its wind industry is an indicator of the future potential for this growing market.

This report reviews the global status of CSP technology, examines the solar resources and data availability in India, and provides an overview of the electricity market and policy environment in India. It then examines barriers to CSP and the enablers and additional ideas that will help overcome them, both globally and specific to India. Capability building and possible approaches to pilot plant construction are also explored.

2 Global CSP Overview

2.1 CSP Technologies

CSP technologies use systems of mirrored concentrators to focus direct beam solar radiation to receivers that convert the energy to high temperatures for power generation.

There are four main configurations that are commercially available:

- Linear Fresnel,
- Parabolic Trough,
- Central Receiver Tower, and
- Dish.

The Fresnel and Trough technologies reflect the solar radiation to a linear focus and continuously move the mirrors in one axis to keep the sun focussed on the receiver. The Central Receiver Tower and Dish technologies reflect the solar radiation to a point focus and require movement of the mirrors in two axes to maintain focus. The point focus systems concentrate the sun to a higher degree than the linear focus options, as a result, the hot receiver is smaller and so heat loses are less for any given operating temperature. Consequently the Tower and Dish options are usually operated at higher temperatures which allows for higher efficiencies in power generation. This performance advantage is offset by the more complex geometry and hence higher specific costs of manufacture per unit area of reflector. There is no consensus on which approach inherently produces power at the lowest cost. Commercial proponents are actively pursuing all four technologies.

Concentrating systems use the direct beam component of solar radiation. Unlike flat plate photovoltaics (PV), they are not able to utilise radiation that has been diffused by clouds or dust or other factors. This makes them suited to areas with a high percentage of clear sky days.

Most commercial CSP systems use steam turbine based power generation. At an early stage of commercial development, Stirling engines are also offered. Direct heating of gas turbine cycles is being investigated, as well as utilising high efficiency PV cells with a cooling system at the focus for direct conversion of solar energy to electricity. Direct driving of thermo-chemical processes has also attracted attention, but is yet to be carried out commercially.

The '*Australian High Temperature Solar Thermal Technology Roadmap'* (Wyld Group, 2008), gives a detailed overview of the various CSP technologies and trends. The International Energy Agency's '*Technology Roadmap Concentrating Solar Power'*, (IEA, 2010) is also a key reference that provides a good overview of the status of CSP today and its potential for future deployment. The report *Solar Thermal Electricity 2025*, (AT Kearney, 2010) provides an excellent overview of the opportunities for improving the economics of various CSP technologies.

In addition, there are many worthwhile CSP websites published by developers and interest groups. One of the most definitive and technically reliable is that maintained by the IEA's SolarPACES (Power and Chemical Energy Systems) program (www.solarpaces.org).

Key features and status of the main four CSP technologies are summarised below.

Technology	Annual solar to electricity efficiency	Focus type	Practical Operating temperature	Power cycles considered	Commercial maturity	Installed Generating Capacity Mid 2010
Linear Fresnel	8 - 10%	Linear	150 to 400°C	Steam Rankine Organic Rankine	Medium	8.4 MW_e
Parabolic Trough	12-15%	Linear	150 to 400°C	Steam Rankine Organic Rankine	High	943 MW_e
Central Receiver Tower	20 - 30% (concepts)	Point	300 to 1200°C	Steam Rankine Brayton (gas turbine)	Medium	38 MW_e
Parabolic Dish	20-30%	Point	300 to 1500°C	Stirling Engine Steam Rankine Brayton (gas turbine)	Low	1.5 MW_e

Table 2.1: Summary of CSP technologies

Linear Fresnel Reflector (LFR)

LFR systems produce a linear focus on a downward facing fixed receiver mounted on a series of small towers. Long rows of flat or slightly curved mirrors move independently on one axis to reflect the sun's rays onto the stationary receiver.

Figure 2.1: Ausra's Kimberlina Linear Fresnel Reflector power plant located near Bakersfield, California, (Ausra)

The fixed receiver, as well as avoiding the need for rotary joints for the heat transfer fluid, works to minimise convection losses with a permanently down facing cavity. The systems built to date have featured receivers of parallel tubes, non-evacuated and sometimes with a plain glass cover. The fixed, down-facing receiver helps to facilitate the use of direct steam generation because in a two-phase boiling region, the liquid remains in contact with the side of the tube that is receiving the radiation.

The proponents of the LFR approach argue that a simple design with near flat mirrors and less structure closer to the ground, outweighs a lower optical and thermal efficiency overall. To increase optical efficiency and packing density, a configuration termed Compact Linear Fresnel Reflectors (CLFRs), alternates the direction of mirrors between parallel receivers according to sun position to minimise land use.

Parabolic Trough

Parabolic trough-shaped mirrors produce a linear focus on the receiver tube along the parabola's focal line. The complete assembly of mirrors plus receiver is mounted on a frame that tracks the daily movement of the sun in one axis, (East to West). Relative seasonal movements of the sun in the other axis result in lateral movements of the focus line which remains on the receiver but can have some spill at the row ends.

Figure 2.2: Parabolic Trough Collector (Nevada Solar 1 system).

A heat transfer fluid is pumped through the receiver tubes and back to a central plant where it is circulated through heat exchangers to produce steam in a boiler. Most existing plants use a thermal oil as the heat transfer fluid, however the use of molten salt or direct steam generation has been demonstrated. The receiver tubes in most of the plants are complex. They incorporate a glass tube with an evacuated space between am inner metal pipe that has a selective surface coating, with high absorbtivity in solar wavelengths and low emissivity for infrared wavelengths. Small trough systems for process heat applications can use simpler, non-evacuated receivers.

Trough systems are the most commercially mature CSP technology.

Central Receiver Tower

A central receiver tower system involves an array of heliostats (large mirrors with two axis tracking) that concentrate the sunlight on to a fixed receiver mounted at the top of a tower. A heat-transfer fluid passing through the receiver absorbs the highly concentrated radiation and typically transfers it to ground level for steam based power generation. Systems have been operated with water/steam, molten salts and air based receivers. Pressurized air receivers at temperatures of 1,000°C or more, have been demonstrated to directly operate gas turbine cycles. Ultimately, combined cycle operation where the exhaust heat from a high temperature gas turbine is used to produce steam for a steam turbine cycle, offers the possibility of 50% or more cycle efficiency.

Figure 2.3: PS10 Central Receiver system, Spain.

The potential for sophisticated high efficiency energy conversion at a single large receiver point is the advantage of the power tower approach. The down side however is that the optical efficiency is not as high as a dish, as a result of the reduction in projected area of heliostats at low reflection angles.

Parabolic Dish

Dish systems, like troughs, exploit the geometric properties of a parabola, but as a three dimensional paraboloid. The reflected direct beam radiation is concentrated to a point focus receiver and heats this to operating temperatures typically between 500 and 1000°C or more - the same temperature capabilities as tower systems.

Much of the R&D and commercial activity with dishes is associated with focus mounted Stirling engine generators that produce electricity directly in size ranges typically from 3 kW_e to 25 kW_e.

Figure 2.4: The Australian National University's 500m^2 SG4 dish concentrator.

However, dishes can also be used with heat transfer fluids or direct steam generation, with fields of dishes providing heat energy to a central plant. As an alternative to the Stirling engine, small Brayton cycle gas turbines are also being investigated. High efficiency PV receivers with cooling have also been utilised in dish systems.

Dish systems offer the highest conversion efficiencies of all the CSP technologies. They are however the least commercially mature. Dishes up to 24m diameter have been demonstrated.

2.2 Existing Power Plants

Deployment of CSP technologies had been negligible for a long period following an initial period of growth in the 1980s that was stimulated by tax incentives. Since 2005, developments have recommenced and gained considerable momentum with continued expansion expected. This growth has predominantly been in Spain and now increasingly in the south-western states of the US. The post-2005 growth has been supported by Feed-in Tariffs and Renewable Portfolio Obligations in those jurisdictions.

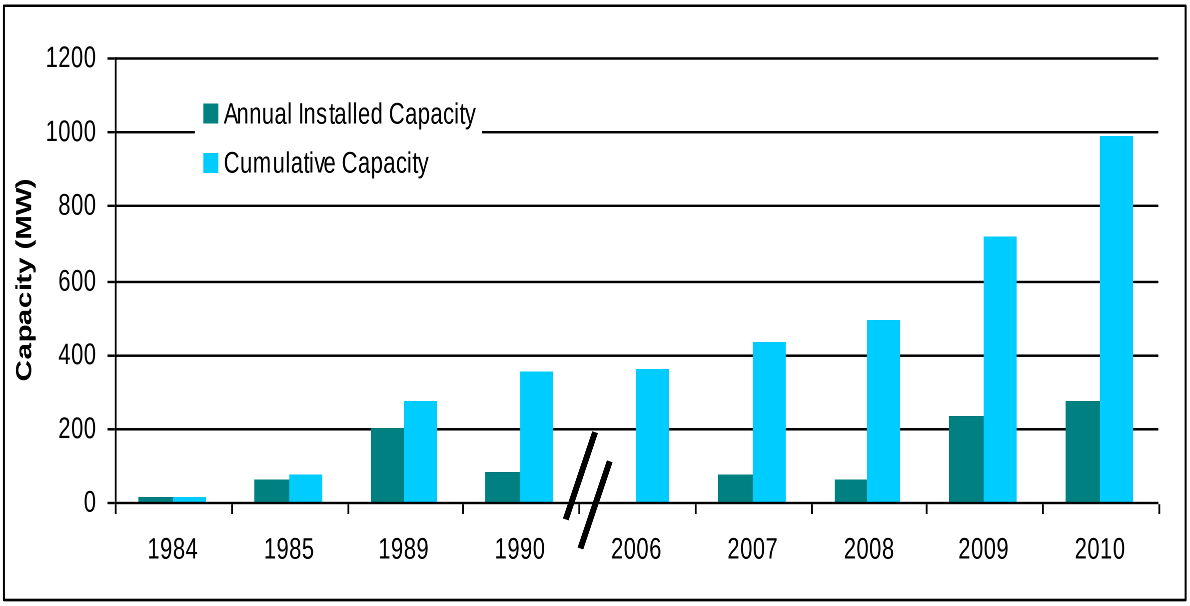


Figure 2.5: Global installed capacity of concentrating solar thermal power plants.

With the industry evolving so fast, listing projects proposed or under development is likely to be out-of-date before a report is published. Also the number of proposals has reached a point that such a listing would be cumbersomely large. There are many sources of information that can be monitored to track progress. It should be noted in reading listings of announced projects that, historically, only about a third of those announced have actually achieved financial closure and been constructed.

The IEA Solar Power and Chemical Energy Systems (SolarPACES) program is the umbrella under which the CSP community has worked together and shared information for many years. Its website at http://solarpaces.org/ has good overview information and a link to a project listing hosted by NREL at http://www.nrel.gov/csp/solarpaces/. This is a reliable source for projects, however the status of the projects discussed is sometimes several months behind, so that a project noted as under construction could actually have commenced generation.

Wikipedia also has comprehensive listing, however given the open source nature of the site, data must be treated with some caution. It would appear that some projects listed as under construction are really only announced, although some listed as announced may have started construction, see: http://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations

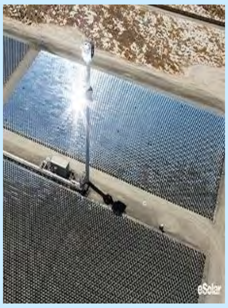
The Spanish Solar Thermal industry association website also publishes a list of projects and their status in Spain. As with other sites, care needs to be taken in interpreting the relevant date of the information, see: http://www.protermosolar.com/boletines/29/mapa.html

For the USA, the Solar Energy Industries Association website has a similar listing at: http://www.seia.org/galleries/pdf/Major%20Solar%20Projects.pdf

Table 2.2, lists working CSP power plants over 1 MW_e in capacity, as at November 2010 (largely based on the NREL listing). The list may not be comprehensive as there may be some commercial demonstration systems that have been commissioned without extensive publicity.

Company	Capacity (MW)	Location	Technology	Technology Provider	Remarks	Picture
Solar Energy Generating Systems	354	Mojave Desert California, USA	Parabolic trough	Luz	Collection of 9 units ranging from 20 to 80MW and operating since the 1980s	
Solnova	150 (3x50)	Seville, Spain	Parabolic trough	Abengoa	Solnova 1 (May 2010) Solnova 3 (May 2010) Solnova 4 (August 2010)	
Andasol solar power station	150 (3x50)	Granada, Spain	Parabolic trough	Solar Millennium AG	Andasol 1 (2008) Andasol 2 (2009) Andasol 3 (2010)	

Nevada Solar One	64	Boulder City, Nevada, USA	Parabolic trough	Acciona Solar Power	Completed June 2007	
Ibersol Ciudad Real	50	Puertollan, Ciudad Real, Spain	Parabolic trough	Iberdrola/ Schott	Completed May 2009	
Alvarado I	50	Badajoz, Spain	Parabolic trough	Acciona Solar Power	Completed July 2009	
Extresol 1	50	Torre de Miguel Sesmero (Badajoz), Spain	Parabolic trough	Sener Group/ Schott	Completed February 2010	
La Florida	50	Alvarado (Badajoz), Spain	Parabolic trough	SAMCA/ Schott	Completed July 2010	
Yazd integrated solar combined cycle power station	17	Yazd, Iran	Parabolic trough	NA	World's first solar combined cycle power plant	
Archimede solar power plant	5	Near Siracusa, Sicily, Italy	Parabolic trough	ENEA	ISCC with heat storage Completed July 2010	
Saguaro Solar Power Station	1	Red Rock Arizona, USA	Parabolic trough	Starnet	2006	

Keahole Solar Power	2	Hawaii, USA	Parabolic trough	Sopogy	-	
PS10 Solar Power Tower	11	Seville, Spain	Power tower	Abengoa	World's first commercial solar tower	
Shiraz solar power plant	0.25	Shiraz, Iran	Parabolic trough	NA	Iran's first solar power plant	
PS20 Solar Power Tower	20	Seville, Spain	Power tower	Abengoa	Completed April 2009	
Jülich Solar Tower	1.5	Jülich, Germany	Power tower	DLR/Jülich Solar Institute (SIJ)	Completed December 2008	
Sierra SunTower	5	Lancaster, California, USA	Power tower	e-Solar	eSolar commercial power plant, North America's only operating solar tower, completed August 2009	
Maricopa Solar	1.5	Peoria, Arizona, USA	Dish/ Engine	Stirling Energy Systems, Tessera Solar	Stirling Energy Systems / Tessera Solar's first commercial-scale Dish Stirling power plant. Completed January 2010	

Liddell Power Station Solar Steam Generator	2	New South Wales, Australia	Linear Fresnel Reflector	Ausra	Electrical equivalent steam boost for coal station	
Puerto Errado 1	1.4	Murcia, Spain	Linear Fresnel Reflector	Novatec Solar España S.L.	Completed April 2009	
Kimberlina Solar Thermal Energy Plant	5	Bakersfield, California, USA	Linear Fresnel Reflector	Ausra	Ausra demonstration plant (2008)	
Solar Energy Development Centre	2?	Har Hotzvim Technology Park, Jerusalem, Israel.	Tower	Brightsource	Commenced June 2008	

Table 2.2: Operational Solar Thermal Power Plants at end 2010
(images from respective project websites).

The first entry in Table 2.2 refers to the Solar Energy Generating Systems (SEGS) plants in Southern California. There are nine plants in total built by the Luz company of Israel beginning in 1984 and ending in 1990. The first two plants were 15 MW_e each, SEGS 3-6 were 30 MW_e each and the final 3 plants were 80 MW_e each. These plants have now continued to generate effectively for over 20 years and operation and maintenance (O&M) costs have declined and annual output increased over that time. This track record establishes the trough technology approach as truly proven. It means that new trough projects are able to attract debt financing in preference to the other technologies and consequently is the reason that most of the new projects are also variations on the SEGS technology approach.

The case study of the Californian SEGS plants (Lotker, 1991), notes that the total of 354 MW_e of installed capacity required US $1.2 billion to construct and incorporates more than two million square metres of glass mirror. Between their completion and 2009, they were responsible for more than half of the solar electricity ever generated and more importantly, they continue to operate with over 99% availability and have shown reductions in O&M costs over their operating life, (Richter et al, 2009).

2.2.1 Technology providers

Listing commercial technology providers is also a challenging task, as the industry is developing quickly and new entrants, mergers and acquisitions are frequent. The following is offered as an indicative list of companies that have been directly linked to working CSP power stations. There are many more commercial players who are new entrants, technology developers or previously involved with prototype systems. In addition, there are many more commercial participants who are component suppliers or active in parts of the value chain.

Fresnel	Trough	Tower	Dish
MAN Ferrostaal / Solar Power Group, Germany	Sener, Spain	Abengoa, Spain	Stirling Energy Systems, USA
Novatec Biosol, Germany now Transfield, Australia	Solar Millennium, Germany	KAM, Germany	Infinia, USA
Ausra, California now Areva, France	Abengoa, Spain	Sener, Spain	Solar Systems, now owned by Silex, Australia
	ACS-Cobra, Spain	Bechtel, USA	Sclaich Bergman und partner, Germany
	Acciona, Spain	Brightsource, USA	
	Solel, Israel now Siemens, Germany	SolarReserve, USA	
	Skyfuel, USA	ESolar, USA	

Table 2.3: Commercial technology providers

2.2.2 Typical power station characteristics

The experience with completed commercial power stations allows some indicative observations on issues such as water, land, construction time and personnel requirements to be made.

Water use

Water is required for CSP plants for:

- condenser cooling,
- make-up for steam/condensate cycle,
- collector cleaning, and
- other general purposes including, fire fighting, staff use and general services.

Water requirements for trough and Fresnel plants are estimated to be approximately 3 kilolitres / MWh, while higher conversion efficiency tower plants are estimated to use less at about 2 kilolitres / MWh, (IEA, 2010). It is feasible to utilise dry-cooling to reduce water consumption in arid regions however note that this would result in an estimated decrease in electricity production from a trough plant by around 7% and increase the cost of the electricity by about of 10%.

By way of example, a feasibility study for a 15 MW_e trough plant in Rajasthan (DLR & Evonic, 2009), estimates the requirements for demineralised (DM) water for the steam cycle and for cooling water (CW) for the wet cooling towers as follows:

> 'DM water consumption: 10,000 m3/a
> (5% cycle make up with 2,288 equivalent full load hour / year operation for 90 t/h main steam flow)
> CW water consumption: 183,000 m3/a
> (2% CW make up for 4,000 m3/h CW flow considering COC = 4 and operating for 2,288 equivalent full load hour / year)'

Table 2.4 indicates water use with wet and dry cooling for conventional steam, combined-cycle, gas turbine, and parabolic trough solar power plants. The water use for conventional plants is based on a California Energy Commission report. The water use for the parabolic trough plants is based on data from the SEGS plants operating in the Mojave Desert.

Plant Type	Steam Condensing	Auxiliary Cooling and Other Load	Total
Stand-alone steam plant	2725(1)	114(2)	2839
Simple-cycle gas turbine	0	568(3)	568
Combined-cycle plant (2/3 CT + 1/3 steam)	908 (1/3 x 720)	416 (2/3 x 150 + 1/3 x 30)	1325
Combined-cycle plant with dry cooling	0	416	416
Stand-alone steam plant with dry cooling	0	114	114
Parabolic Trough with wet cooling	3483(4)	303(5)	3785
Parabolic Trough with dry cooling	0	303	303

(1) evaporation + blowdown = 12 gpm / MW (45lpm/MW)

(2) estimated at ~5% of evaporation + blowdown

(3) mid-range of 75-200 gal / MWh f(284 -757 l/MWh) for turbine cooling, emissions control and hotel load.

(4) based on historical data from SEGS (higher than conventional because of lower net steam cycle efficiency of SEGS, in part due to HTF pumping and night time parasitics.

(5) Includes make-up water requirements for steam cycle (60 gal / MWh = 227l / MWh) and solar field mirror wash (20 gal / MWh = 227l / MWh) data from KJCOC.

Table 2.4: Water Requirements for Power Generation (reproduced from NREL (2010B) with original figures converted to litres per MWh of Plant Output)

Thermal storage

One of the identified key competitive advantages of CSP, is the ability to build in thermal storage for dispatchable operation. Large amounts of high temperature thermal energy can be stored in straightforward and cost effective ways compared to the complex and costly options that must be considered for large-scale storage of electricity from other renewables, such as PV and wind. Configurations can be optimised for peaking, shoulder or base-load power generation via the relative sizing of thermal store and power block.

As the percentage of solar capacity in a grid rises, some level of short-term storage makes management of grid operations less onerous. Even if no specific investment in storage is made, the thermal inertia of CSP systems provide some smoothing of power outputs. For example, for the proposed Anta 15 MW_e system (DLR & Evonic 2009), the 400°C heat tansfer fluid in 1,000m of piping contains enough stored heat to run the system at maximum output for around three minutes.

The technology for thermal storage that is most advanced commercially is two tank molten salt. The first commercial power plant to implement this approach is the 50 MW_e Andasol-1 trough system in Spain. It commenced operation at the end of 2008 and has enough storage (1,010 MWh_{th}) to run for 7.5 hours at full capacity or longer at part load. It achieves this using two tanks of molten Nitrate salt[2]. The 28,500 tonnes of salt always remains molten and cycles between a 'cold' tank at 292°C and a hot tank at 386°C.

Land area

The amount of land required for trough systems without storage has been reported as 2 ha / MW and for Fresnel systems with no storage at 4 ha / MW, (Australian Cleantech, 2010).

Care needs to be taken when interpreting data on areas as some reports refer to collector area rather than land area. The German Aerospace Centre has reported that a 30% land use factor for existing trough plants is typical, (DLR, 2005) as the spacing of rows needs to ensure that shading is minimised. For example, the Solnova 50 MW_e plant consists of 300,000m^2 of collector spread over 120 hectares, (2.4 ha / MW). Similarly, the Alvarado 1 plant, near Badajoz in the Extremadura region of Spain, has a capacity of 50 MW_e and uses parabolic trough technology, with over 184,000 mirrors on a 130 hectare site (2.6 ha / MW)

Incorporating storage requires an increase in the size of the collector field and some land for the storage components. For example, the 50 MW_e Andasol plants with 7.5 hours of storage have a gross electricity output of around 180 GWh per year and a collector surface area of over 510,000m^2 spread over 200 hectares, (4 ha / MW). These plants operate at a higher capacity factor than those without storage and highlight the requirement to take care when comparing plants on a 'per MW' basis.

Brightsource's proposed Ivanpah solar tower project will consist of 3 towers with heliostat fields for a total of 392 MW_e on 1,457 hectares, (3.7 ha / MW).

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[2] The salt composition is 60% $NaNO_3$ + 40% KNO_3

Staffing levels

A wide range of forecasts exist for staffing levels for CSP plants.

Brightsource's proposed Ivanpah 392 MW_e solar tower project is forecast to create around 1,000 jobs at peak of construction and have 86 ongoing operations and maintenance jobs (0.2 ongoing jobs / MW).

AT Kearney (2010) suggests that a 100 MW_e plant would require between 40 and 45 full time equivalent employees for operation and maintenance.

The Anta feasibility study forecasts the operations and maintenance team needed for the 15 MW_e trough project will be 21 staff to operate and maintain the 147,150m^2 collector field and 19 staff to operate and maintain the power block on a 2 shift operation, (DLR / Evonik, 2009). This is 2.6 ongoing jobs / MW which, compared to the previous examples, illustrates the benefits of economies of scale.

Construction time

Typical construction times from ground breaking to end of commissioning for large commercial plants are of the order of 18 months. In addition to this, proponents need to factor in the time required to reach financial closure which can be very long.

Figure 2.5 gives an indicative timetable of 39 months for the for the Anta 15 MW_e trough plant:

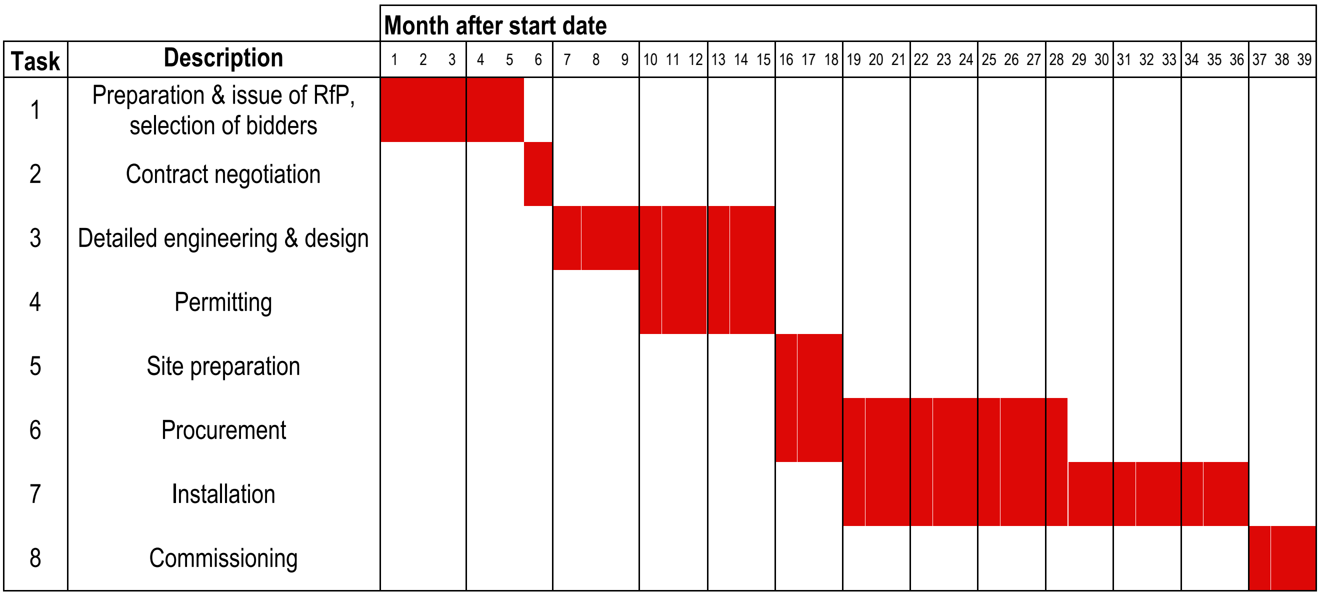


Figure 2.5: Indicative timeline for trough plant in Rajasthan, (DLR & Evonik, 2009).

2.3 Costs and forecasts

Key metrics in considering the economic performance of any energy technology are the Levelised Cost of Electricity (LCOE) generated and the Internal Rate of Return (IRR) for investors. This is forecast from estimated capital costs plus ongoing cost of inputs (O&M, fuels, debt servicing and other variable inputs). As the capital cost is amortised over a system's lifetime, choosing an appropriate discount rate is another key consideration.

For CSP, the initial capital cost dominates the forecast. Consequently the installed cost per MW is another commonly discussed parameter. However, care needs to be taken in making comparisons as it is actually the installed cost per MW divided by the capacity factor that influences the viability of a proposal. Most CSP plant now incorporate some amount of energy storage. Storage is usually used to run a smaller generator for a longer time with the same amount of collected energy. In this case, installed cost per MW will be higher but the annual capacity factor will also be higher.

It is misleading to translate costs between projects in different countries and years simplistically based on exchange rates. Whilst the cost of many input commodities may be global and can be converted in this way, the cost of manufacturing, particularly labour, and other inputs are country specific. The best approach for an indicative conversion would be to compare the relative costs of a technology produced at scale in two countries and that has similar inputs and manufacturing intensity to CSP systems. Going beyond this, it should be noted that while in Spain and the USA the CSP industry is reasonably established and starting to progress down a cost curve, the first major projects in a country which is new to the technology, such as India or Australia, will incur extra costs as the capability and supporting manufacturing infrastructure is established for the first time. Identifying appropriate escalation rates to allow past project costs to be compared to the present is also difficult. Consequently, in the discussion that follows, costs are left in the currency and year value they were initially reported in. Appendix A contains some recent exchange rate data and indicates its variability[3].

CSP is considered to be an essentially proven technology that is at an early stage of its cost reduction curve. A period of exponential growth in installed capacity together with an exponential decay in cost of energy produced is confidently predicted by the industry.

[3] To allow indicative comparisons to be made, the following represent the approximate averages from the last half of 2010:

US $1 = Rs. 45 US $1 = AU $1 US $1 = EU 0.75 EU 1 = AU $1.4 AU $1 = Rs. 43

English language Indian documents frequently use pre-fixes from the Indian numbering system for financial quantities: Lakh = 100,000 and Crore (CR) = 10,000,000.

The '*Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts*' study, (Sargent & Lundy, 2003) analysed the cost reduction potential for Tower and trough systems utilising a bottom-up process. Their projected cost reduction forecasts for Tower systems are shown below in the Figure 2.6.

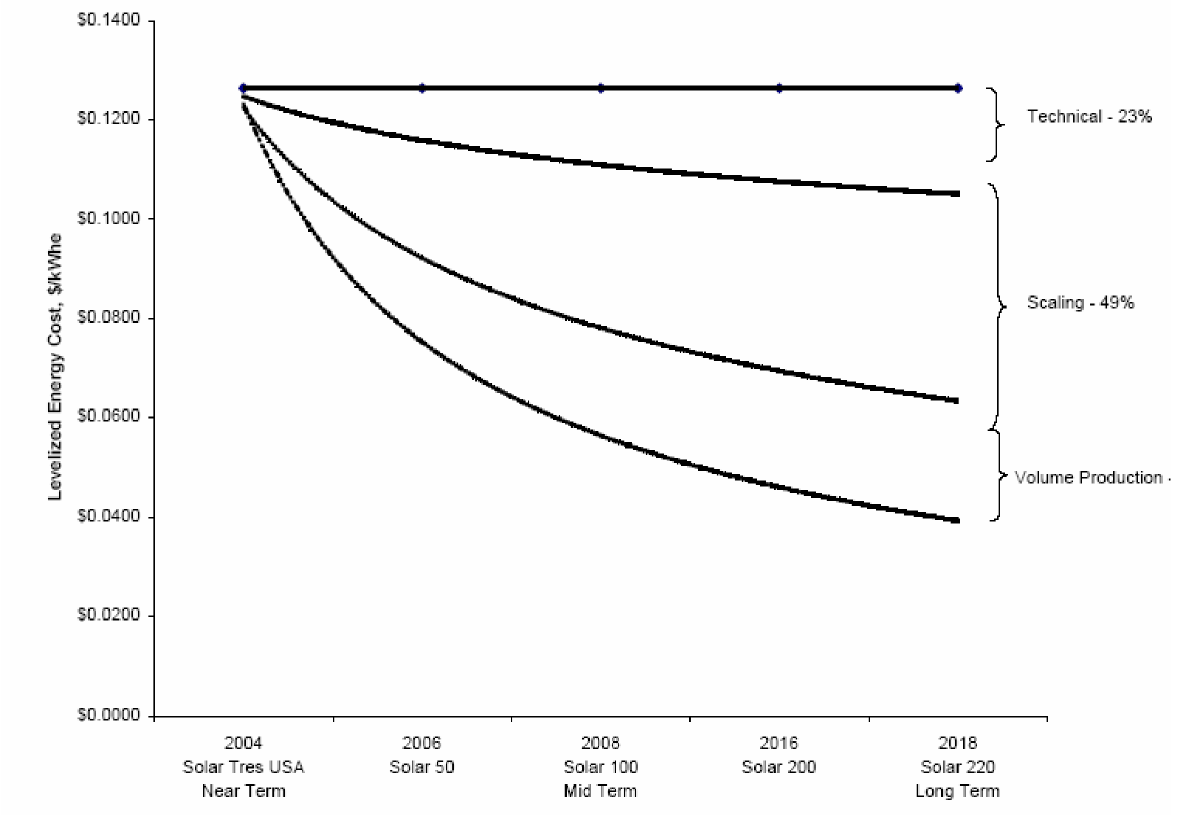


Figure 2.6: Levelised Cost of Electricity forecasts, (Sargent & Lundy, 2003).

The trend to a learning curve of cost reduction as installed capacity increases, is logically linked to:

- technical improvements as lessons are learned from installed plants and parallel R&D efforts identify performance improvements,
- scaling to larger installed plant size, that allows for more efficient and more cost effective large turbines and other components to be used, and
- volume production that allows fixed costs of investments in production efficiency to be spread over larger production runs.

A major study (DLR, 2005) of the potential for CSP in the countries surrounding the Mediterranean concluded that CSP could grow to provide over 50% of the electricity generation in those countries. In doing so, employment in the sector could grow to close to two million persons while the cost of generation was forecast to decrease to around EU 0.05 / kWh by 2030.

The '*European Concentrated Solar Thermal Roadmap*' (Pitz-Paal et al, 2004), establishes recommended priorities for R&D efforts that remain valid today. It reports previous cost reduction studies and also predicts a growth in installed capacity to 40 GW by 2025, with a reduction in the LCOE to EU 0.05 / kWh. This reduction is predicted from a claimed base of between EU 0.15 and 0.20 / kWh in 2004. This compares favourably with the Spanish feed-in tariff of EU 0.21 / kWh introduced at that time. The European roadmap indicates that, based on the information available at the time, there was no clear indicator of a cost winner among the CSP technology options. This is still the case today.

The '*CSP Global Outlook*' study produced jointly by GreenPeace, SolarPaces and Estela, (Richter et al, 2009), indicates that with appropriate efforts,

> 'concentrated solar power could meet up to 7% of the world's power needs by 2030 and fully one quarter by 2050'.

This report claims that the costs for CSP electricity are falling and are US $0.15 / kWh at good US sites. It also indicated that 80% of the lifetime costs are in construction and initial debt, with ongoing O&M accounting for the remaining 20%. They estimate that new parabolic troughs using current technology with proven enhancements can produce electrical power today for about US $0.12 / kWh in solar-only operation mode under the conditions in south-western USA. In Spain, it is reported that the cost currently ranges from approximately EU 0.15 / kWh (US $0.19) at high solar sites to approximately EU 0.23 / kWh (US $0.29) at less favourable sites. These costs were forecast to reduce to between EU 0.10 to 0.14 / kWh (US $0.15 to $0.20) by 2020.

Three future scenarios are analysed by Richter et al (2009):

- a reference scenario based on 2007 IEA World Energy outlook assuming only measures in place at that time,
- a moderate scenario that assumes all proposed policy measures and targets around the world are implemented and met, and
- an advanced scenario that represents a best case CSP vision, that could be achieved if optimal policies were adopted around the globe.

The results predicted for global installed capacity till 2050 and the shares predicted for India China and the 'OECD Pacific category are given in Table 2.5.

Forecast cumulative installed capacity (MW_e)				
Scenario	**2015**	**2020**	**2030**	**2050**
Reference	4,065	7,271	12,765	18,018
Moderate	24,468	68,584	231,332	830,707
Advanced	29,419	84,336	342,301	1,524,172

Forecast cumulative installed capacity in 2020 in key regions (MW_e)				
Scenario	**Global**	**India**	**China**	**OECD Pacific (incl Australia)**
Reference	7,271	30	30	475
Moderate	68,584	2,760	8,334	2,848
Advanced	84,336	3,179	8,650	9,000

Table 2.5: Forecast CSP installed capacities (Data from Richter et al, 2009).

Australia is considered to be the major part of an 'OECD Pacific' category. In the regional breakdown of these figures, the predictions for India under the advanced scenario, are less in 2020 than the Solar Mission target. Indeed both China and OECD Pacific are predicted to outperform India under the advanced scenario. Given that the report pre-dates the Solar Mission announcement, it illustrates the sensitivity of outcomes to government policy settings. It also illustrates that the "advanced" scenario, is probably not the most extreme optimistic projection that could be contemplated.

Regarding cost learning curves, the authors note that:

> 'The general conclusion from industrial learning curve theory is that costs decrease by some 20% each time the number of units produced doubles. A 20% decline is equivalent to a progress ratio of 0.80.'

Further:

> 'The changes in electricity prices for the industry so far in its first development phase is equivalent to a progress ratio of about 0.90.'

Their predictions of investment cost reduction over time are shown in Table 2.6.

Scenario	**Reference**		**Moderate**		**Advanced**	
Year	**Progress ratio**	**Investment cost**	**Progress ratio**	**Investment cost**	**Progress ratio**	**Investment cost**
	(%)	**(Euro/kW)**	**(%)**	**(Euro/kW)**	**(%)**	**(Euro/kW)**
2005	0.90	4,000	0.90	4,000	0.90	4,000
2010	0.90	3,800	0.90	3,800	0.90	3,800
2015	0.90	3,400	0.92	3,230	0.86	3,060
2020	0.94	3,000	0.96	2,850	0.89	2,700
2030	0.96	2,800	0.98	2,660	0.91	2,520
2040	0.96	2,600	0.98	2,470	0.91	2,340
2050	0.08	2,400	1.00	2,280	0.93	2.160

Table 2.6: Forecast capital cost reduction over time for CSP systems (Richter et al, 2009).

The predicted investment costs combined with annual installed capacity projections predict expenditure could rise to EU 175,000 billion per year under the advanced scenario in 2050.

The US Electric Power Research Institute has a reputation for very conservative assumptions in costing of renewable energy systems. They estimate (EPRI, 2009), an installed cost for a 150 MW trough plant without energy storage in 2008 as US $4,851 / kW and link this to a LCOE of $290 / MWh. If six hours storage is included, the installed cost is $6,300 / kW but the higher resulting capacity factor means a lower estimated LCOE of $225 / MWh. Other LCOEs quoted for comparison include, super-critical coal $66 / MWh, wind $99 / MWh and PV $456 / MWh. Whilst EPRI is often criticised for its conservatism, their report has a very useful discussion of risk related issues.

A recent roadmap published by the IEA for CSP technology presents a highly credible summary of the global situation and way forward, (IEA 2010). The roadmap notes a view that PV costs are now lower than CSP. The benefits of thermal energy storage, potential for easy hybridistaion with existing fossil fuelled technologies and in the longer term, solar fuels production, are discussed in detail. Regarding growth projections, the IEA roadmap chooses to suggest a likely path that lies between the moderate and advanced scenarios from the Richter et al (2009) outlook as shown in Figure 2.9.

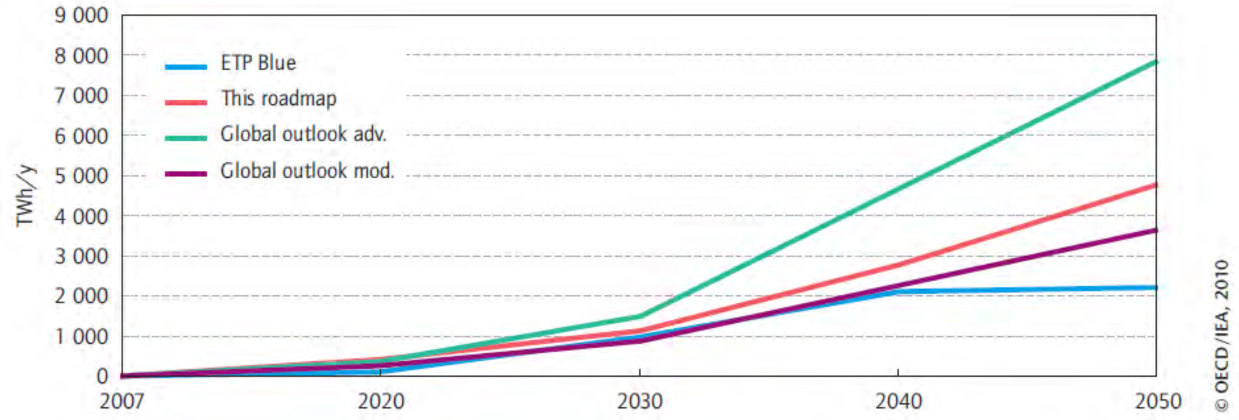


Figure 2.9: CSP generation growth projections from a range of scenario's from the CSP Roadmap (IEA, 2010).

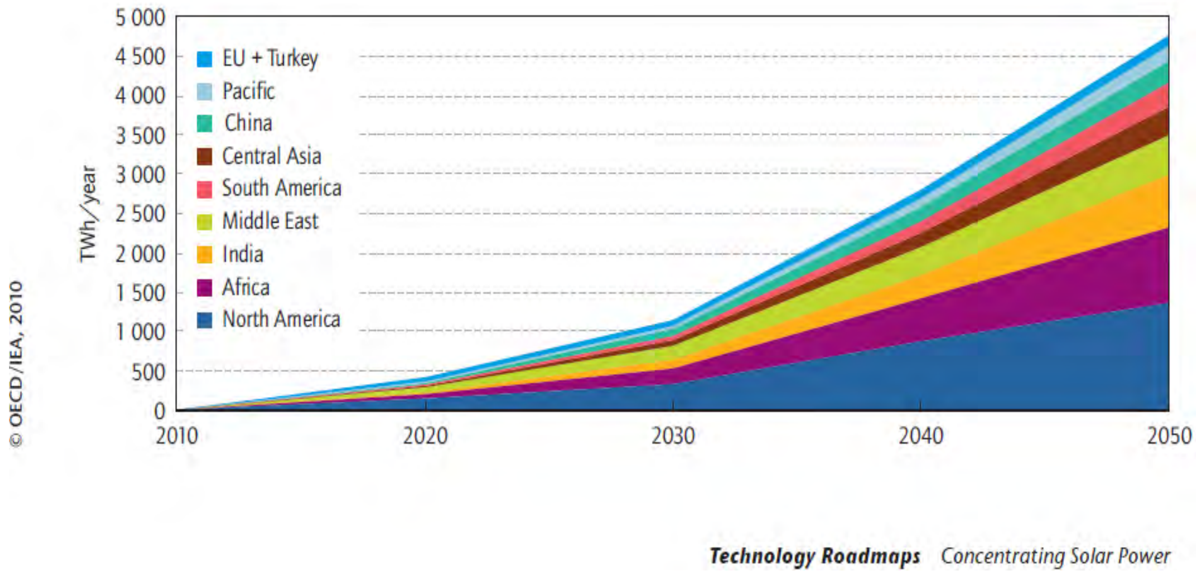
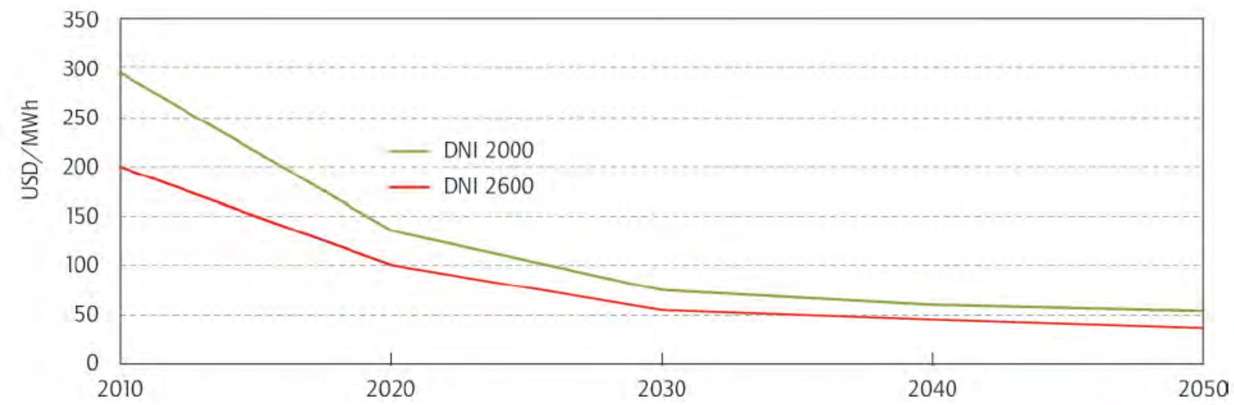


Figure 2.10: Predicted regional shares of CSP generation from the CSP Roadmap (IEA, 2010).

Figure 2.10 provides predicted shares of the generation by country / region. India is projected to have the third largest share of production through the later stages of this growth phase. Interestingly, Australia is not assessed separately.

According to the Roadmap, current (2010) investment costs for trough plants are between US $4,200 / kW (no storage / good solar resource) to US $8,400 / kW (high storage / moderate solar). LCOE is suggested to be US $200 / MWh to US $295 / MWh for large trough plants, based on a 30 year life and 10% discount rate. These LCOE estimates are very similar to those of EPRI.

The Roadmap's predicted LCOE cost reduction over time is shown in Figure 2.11 for high and low average solar radiation scenarios. Whilst analysts universally predict such asymptotic decay in costs to some ultimate level, it should be emphasised that predictions of the final level are highly dependent on a range of very uncertain assumptions. Despite this, the consensus is that in the long term, CSP should be competitive with alternative large-scale clean energy options.



Note DNI is Direct Normal Irradiance, in units kWh /m^2 / yr

Figure 2.11: Levelised Cost of Electricity forecasts, from the CSP Roadmap (IEA, 2010).

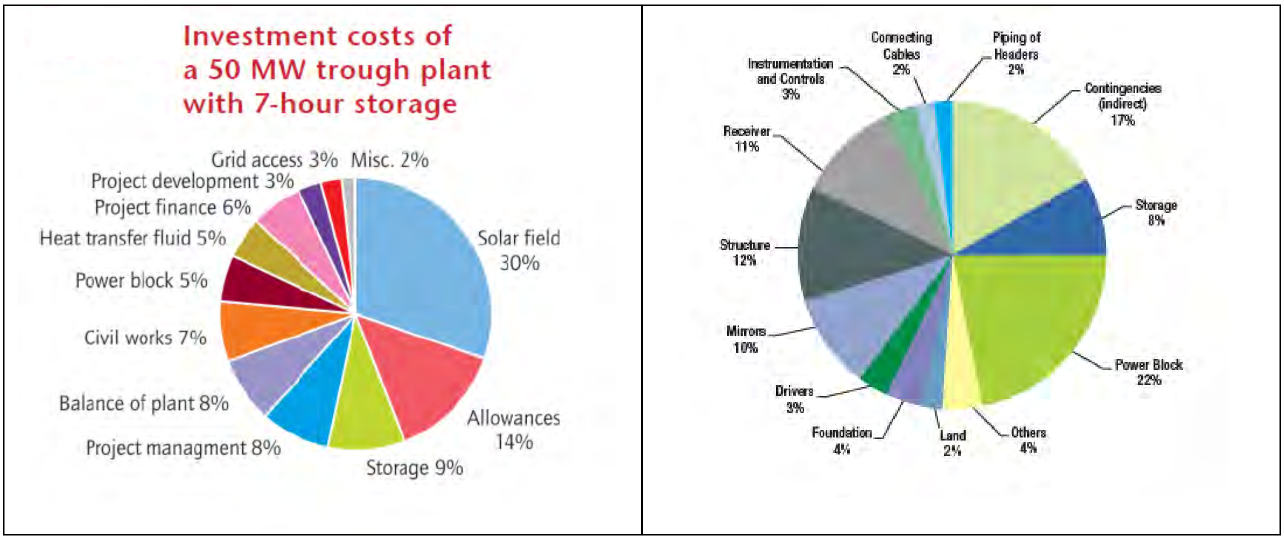


Figure 2.12: Capital cost breakdown for CSP plants - on the left (IEA, 2010) and on the right (Australian Cleantech, 2010).

Figure 2.12 gives two versions of the indicative proportional capital cost breakdown by component for CSP plants. The IEA Roadmap version has the solar field as a single element, although the heat transfer fluid is separate, whereas the one from Australian Cleantech identifies mirrors, structure and receivers, foundations plus drivers separately. If costs are split between a solar collector field and a power block with financing and contingency components allocated proportionately, the picture is that a bit over half the project cost is attributed to the solar aspects. A similar pie chart in Kistner and Price (1999) is consistent with this interpretation. Precise cost breakdowns are technology and project specific.

In Australia, the context and priorities for CSP have been examined with a 2008 High Temperature Solar Thermal (HTST) Roadmap commissioned on behalf of the Council of Australian Governments, (Wyld Group, 2008). Key conclusions were that HTST represented a major opportunity in Australia, with an ultimate potential for grid-connected systems of the order of 20,000 MW_e. It was noted that the federal government's Renewable Energy Target that was expanded at that time to 20% by 2020, would not assist CSP to come down the cost curve, because it would largely be met by mature technologies, particularly wind. It was also identified that a carbon price would need to reach AU $50 / tonne to make a major contribution.

The HTST Roadmap includes a thorough survey of international commercial activities at the time and it is illuminating to read that in light of actual developments in 2010. Many of the planned and announced activities and plants have taken different directions. However, the industry has expanded even more successfully than was predicted at that time. Regarding costs, the HTST Roadmap incorporated its own analysis by McLennan Magasanik Associates and noted the results were in line with a previous Connell Wagner report for NSW conditions. The Roadmap indicated that a LCOE in the range of AU $170 to $210 / MWh was feasible with reductions to $120 to $150 / MWh possible based on installed costs of AU $3,000 / kW.

The potential for CSP in India has previously been examined by; Beerbaum & Weinrabe (2000), Brar, Sanke & Tuli (2008) and Purohit and Purohit (2010) among others. Overall a shared conclusion is that there is great potential and more than enough suitable land with sufficient solar resources levels to allow CSP to make a very major contribution to the national energy supply.

The question of how the varying assessments of cost internationally would translate to India received much attention in the lead up to the announcement of the Solar Mission phase 1 guidelines and the determination of the tariff cap. The Capital Cost norm released by the Indian Central Electricity Regulatory Commission (CERC, 2010), discusses all the issues contributing to CSP capital costs in detail and refers to overseas experience in trying to deduce a reference value for India. The starting point was a proposal that a figure of Rs. 14.2 Cr / MW quoted as equivalent to US $3.1m / MW be used. Submissions from SunBorne Energy, Abengoa, Acme, NTPC (2009) and others were considered as well as further analysis carried out by the Commission.

Table 2.13 contains a summary of these submissions, values in Indian Rs. Cr / MW

Item description	SunBorne	Acme	NTPC	Acira			
				Domestic	Tight pricing	Right pricing	Imported
Solar Field Cost	10.92	8.39	16.00	9.91	11.66	12.89	13.41
Mirrors / Frames / HTF/ Receivers /BOS of solar field	6.82	7.98		8.06	9.59	10.65	11.11
Solar Field Construction / EPC	4.10	0.40		1.85	2.08	2.24	2.30
Power Block	4.48	5.63	5.44	4.25	4.25	4.25	4.25
STG / Mech. Equip / Elect. Equip.	2.90	3.50	3.86				
Construction for Power Block	1.58	2.12	1.58				
Preliminary / Pre-Op Expense	0.25	0.96	1.01	1.34	1.49	1.60	1.65
Contingency	0.58	0.28	1.80				
IDC	1.01	0.71	0.78				
TOTAL Project Cost	**17.24**	**15.97**	**25.03**	**15.50**	**17.40**	**18.74**	**19.31**

Table 2.13: Suggested capital cost breakdowns from submissions as reproduced in CERC (2010). Note values in Rs. Crore / MW (Cr = 10,000,000).

Ultimately the Commission's assessment following its own analysis process, was expressed as a published 'capital cost norm' as shown in Table 2.14.

Item description	Capital Cost Norm for Solar Thermal (Rs Cr/MW)
Direct Cost	13.48
Solar Block	12.90
Power Block	
Land	0.18
General Civil and Structural works	0.40
Indirect Cost	1.82
Preliminary & pre-operative expenses	
Contingency	
IDC	
TOTAL CAPITAL COST	**15.30**

Table 2.14: Capital Cost norm from the
Indian Central Electricity Regulating Commission, (CERC, 2010).

2.4 Summary

The CSP industry has recommenced growth since 2005, with its credibility based on 20 years of successful operation of large-scale trough plants. Trough plants continue to be the dominant technology, but other approaches are offered with a view to achieving lower LCOE. There is no widely accepted view of which CSP technology will produce the lowest LCOE in the future.

There are wide ranges in the current understood installed cost of CSP systems globally. Real costs will be technology and project specific. Translating these costs to a new country like India or Australia introduces even further uncertainty. Published cost estimates for India vary by a factor of nearly 80% from lowest to highest. It is clear though, that as the industry expands both locally and globally, this uncertainty will reduce and installed costs should fall quite rapidly. India's relatively lower labour costs and higher fossil fuel costs will contribute to the benefit of CSP projects.

3 Indian Electricity Market

3.1 Load growth

The Indian economy is growing rapidly and providing the electricity generation capacity to support this is a key challenge. Historic growth of India's electricity generation is shown in Figure 3.1.

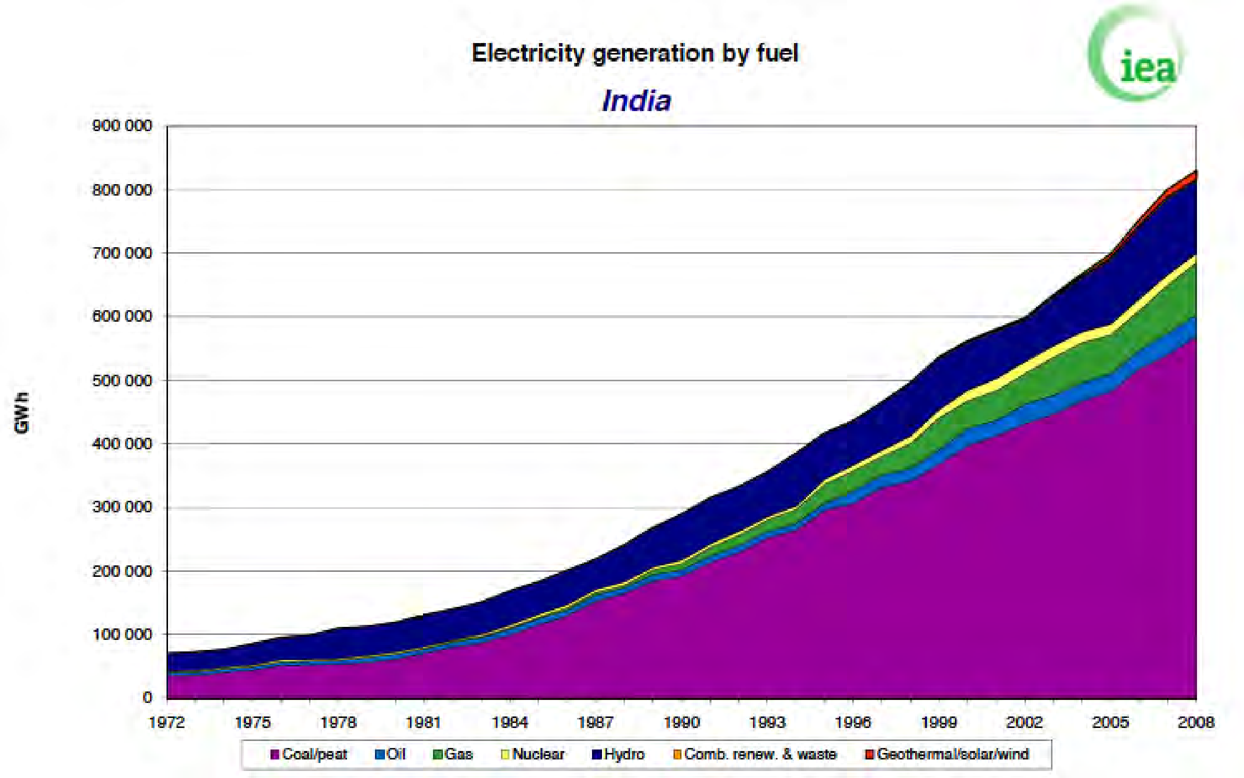


Figure 3.1: Annual electricity generation
(http://www.iea.org/stats/pdf_graphs/INELEC.pdf , accessed October 2010)

The strong growth in demand for electricity is expected to continue and is due to many factors including:

- overall economic and population growth,
- strong growth in the energy-intensive manufacturing sector,
- rising consumption in households,
- the provision of electricity to those currently without access, and
- provision of electricity for unfulfilled demand.

Figure 3.2 shows the corresponding growth and composition of primary energy sources. It can be seen that biomass use, for cooking and heat, has traditionally been a large fraction of primary energy, but is essentially static in absolute terms and so is becoming a decreasing fraction of the total. Coal now dominates, with a large fraction being imported. Oil consumption, largely for the transport sector, is growing at a commensurate rate and the country is heading towards relying on imports for 90% of its oil. Natural gas consumption is also growing, it is understood that domestic sources are constrained and imports now account for approximately 25% of consumption. With such high growth overall, it is understandable that energy security is a major policy driver and hence one of the benefits of growing domestic renewable energy generation.

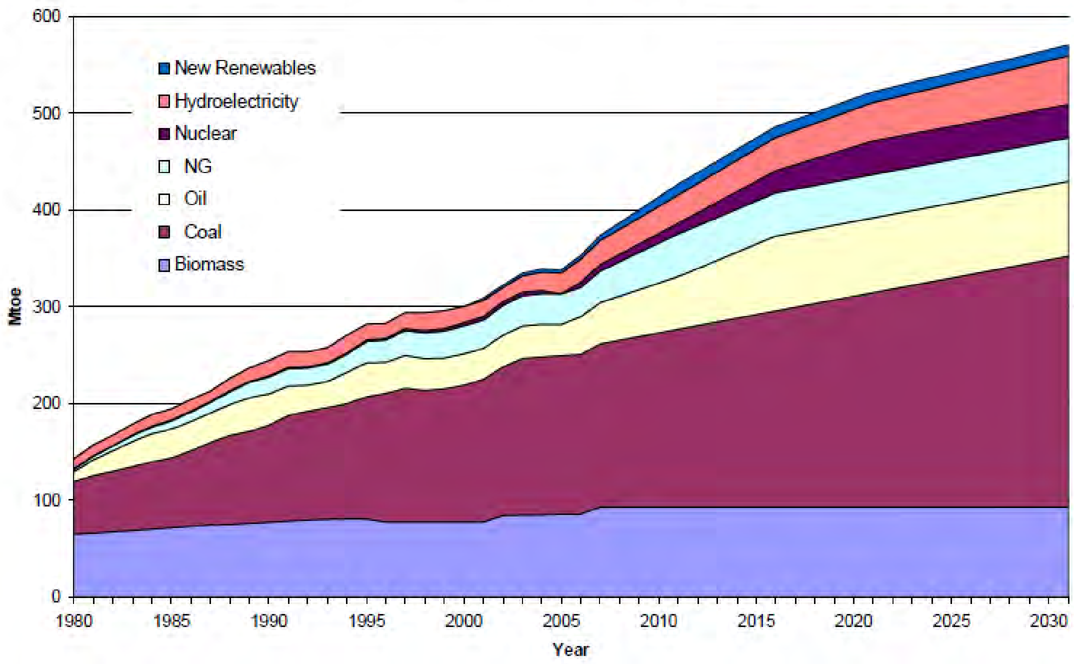


Figure 3.2: Indian primary energy supply growth and composition, note 1 Mtoe = 11.6 TWh, (USAID, 2007)

As of the end of October 2010, the Ministry of Power's Central Electricity Authority website reported that India's generation capacity was more than 167 GW, (CEA, 2010). Electricity consumption is officially predicted to grow at 8% per year (Baker & Mackenzie, 2008).

The various government initiatives including the Solar Mission, should see an increase in the amount of renewable energy generation, however the bulk of the growth is still expected from coal-fired generation.

A USAid country report for India, (USAid, 2007) stated:

> 'to scale-up production and transportation of coal, further explore and develop offshore oil and gas, add some 60,000 MW of new, cleaner power generation, and rehabilitate the power delivery network is estimated to require around US $600 billion over the next twenty-five years'.

The Central Electricity Authority reported for 2009-10 that the demand for electricity exceeded supply by 10% and the peak deficit was more than 15 GW. The scale of the challenge facing the Indian electricity sector can be seen from the forecast requirement to double current installed capacity to over 300 GW by 2017.

3.2 Electricity Regulation

India has three main levels of government:

- Federal Government (referred to as Central or Union),
- State Governments, and
- Local Governments
  (referred to as Municipal corporations, Municipalities or Panchayats).

Federal and State levels have legislatures based on two houses of parliament. Law making is a shared responsibility between Federal and State, with designated spheres of responsibility.

The Indian electricity sector is primarily governed by the Federal Electricity Act 2003, (the Act). The Act reformed the previous vertical integration of the electricity sector. It also opened the electricity sector to competition making it easier to connect distributed generation and enabled access to grid infrastructure to allow generators to sell directly to customers rather than through the State Electricity Boards. The Act aims to facilitate private investment in electricity infrastructure through providing a consistent legal framework across the country.

The Act specifies the role of the Central Electricity Regulation Commission (CERC) and the corresponding State Electricity Regulation Commissions (SERCs). In addition, the Act also supports renewable generation by allowing for preferential tariffs and Renewable Purchase Obligations (RPO) for the state utilities. CERC is responsible for formulating tariff orders and guidelines for renewable generation. These guidelines are utilised by the SERCs to formulate tariffs for renewable generation projects.

Table 3.1 summarises the various policies and Acts that impact on the electricity sector.

Year	Title	Main Thrust
2006	Rural Electrification Policy	Establishes a national goal for universal access, assigns responsibilities for implementation, and creates new financing arrangements
2006	National Urban Transport Policy	Encourages integrated land use and transportation planning in cities
2006	National Tariff Policy	Provides guidance on establishing power purchase tariffs by State Electricity Regulatory Commissions
2005	National Electricity Policy	Provides guidelines for accelerated development of the power sector
2003	Electricity Act	Legislates a comprehensive reform and liberalization process for the power sector
2001	Energy Conservation Act	Provides the legal frame work and institutional arrangements for embarking on a national energy efficiency drive
2001	Accelerated Power Development and Reforms Program	Establishes intervention strategies for distribution reforms in the power sector

Table 3.1: Summary of Indian central government policies impacting the electricity sector, (USAid, 2007).

The Electricity Act 2003 opens the market for continuous electricity trading. The market is moving in this direction, but at present most activity is in the form of long term Power Purchase Agreements (PPAs). Some network congestion at times is acknowledged.

The reforms to the power market provide opportunities for private sector investments. Investors will ensure minimal risk in achieving their required rates of return before considering any contribution to the costs of future power infrastructure.

Figure 3.3 gives an indication of the range of agencies involved with the Indian energy sector. The Planning Commission provides the national oversight with regulatory power residing with the CERC and the SERCs. In addition, there is the Federal Ministry of Coal, Ministry of Power (which includes the Central Electricity Authority and the Bureau of Energy Efficiency), Ministry of New and Renewable Energy, Ministry of Petroleum and Natural Gas and the Ministry of Environment and Forests (which includes the Designated National Authority that approves CDM projects).

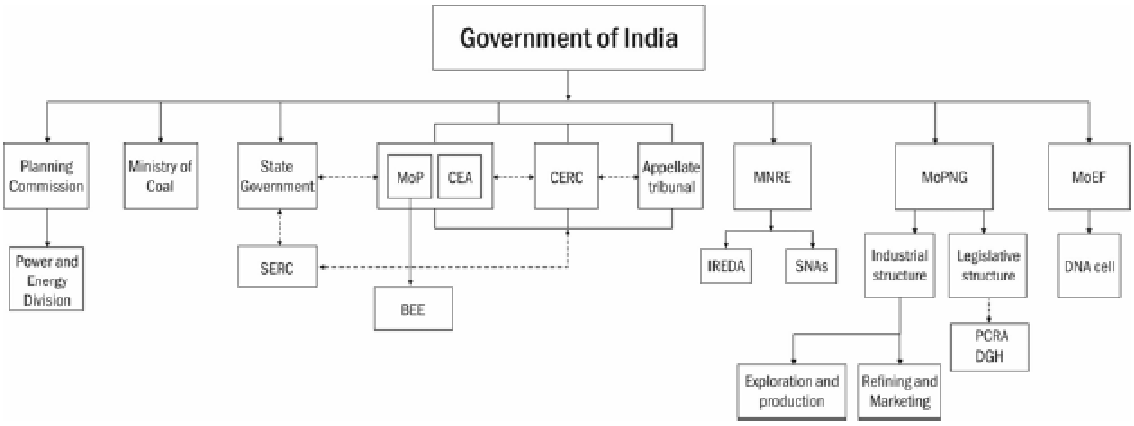


Figure 3.3: Key Government Energy Agencies in the Indian energy sector (USAid, 2007).

Renewable energy specifically is administered at the federal level by the Ministry for New and Renewable Energy (MNRE). There are also corresponding state nodal agencies, for example the Rajasthan Renewable Energy Corporation (RREC). MNRE facilitates research, design, development, manufacture and deployment of new and renewable energy systems. It also administers the Indian Renewable Energy Development Agency (IREDA) which is a public limited government company established to:

- operate a revolving fund for development and deployment of new and renewable sources of energy,
- provide financial support to specific projects and programs for generating energy through new and renewable sources or conserving energy through energy efficiency,
- provide assistance in upgrading technologies for new and renewable energy, and
- develop new criteria, systems and concepts for financing projects based on new and renewable sources of energy and energy efficiency.

MNRE is also responsible for the policy oversight of the Solar Mission. It also administers the Solar Energy Centre and the Centre for Wind Energy Technology (CWET 2010).

A listing of the various State Electricity Regulatory Commissions' websites is provided in Table 3.2.

STATE	ELECTRICTY COMMISION WEBSITE
Andhra Pradesh	www.ercap.org
Maharashtra	www.mercindia.org.in
Tamil Nadu	www.tnerc.tn.nic.in
Rajasthan	www.rerc.gov.in
Kerala	www.erckerala.org
West Bengal	www.wberc.net
Karnataka	www.kerc.org
Gujarat	www.gercin.org
Haryana	www.herc.nic.in
Orissa	www.orierc.org
Himachal Pradesh	www.hperc.org.in
Uttar Pradesh	www.uperc.org
Madhya Pradesh	www.mperc.org
Punjab	www.pserc.nic.in
Bihar	www.berc.co.in
Assam	www.aerc.nic.in
Uttaranchal	www.uerc.org
Delhi	www.dercind.org
Jharkhand	www.jserc.org

Table 3.2: Websites for Indian State Electricity Regulatory Commissions, (Baker & Mackenzie, 2008).

3.3 Generation mix

The mix of generation technology types within the total 167 GW_e of installed capacity is shown in Figure 3.4.

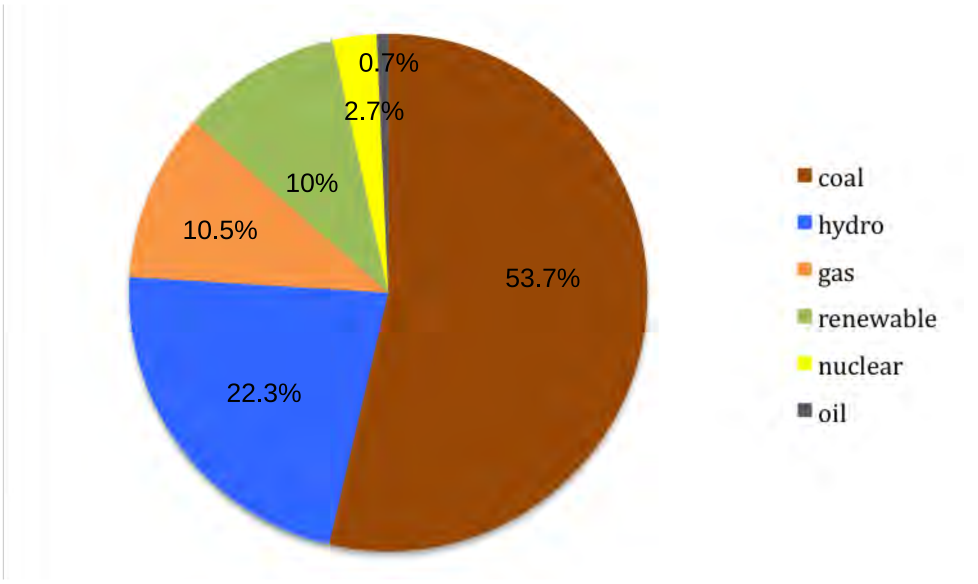


Figure 3.4: Energy Source Shares of Total Power Generation Capacity (data from Baker & Mackenzie, 2008).

These generating assets are held 34% by central government agencies, 52% by state agencies and 14% by private investors. Within generating types, the ownership of coal, natural gas and large hydro assets largely follows this breakdown. Nuclear generators are owned exclusively by the central government. New renewable assets on the other hand are 79% privately owned, with the balance held by state agencies, (Baker & Mackenzie, 2008).

Coal dominates the power sector, however there is diversification to natural gas. New coal plants going forward are likely to use super-critical technologies for the highest possible efficiencies and reduced emissions. Options such as ultra super-critical plants and integrated gasification, combined cycle plants are being considered for the future. The possibility of retiring some of the older, thermal plants below 100 MW_e has been canvassed. The private sector is playing an increasing role in big power projects.

3.4 Transmission and Distribution

Figure 3.5 gives an overview of the transmission system. More detailed and recent regional maps are provided at Appendix B.

High Voltage transmission is a mixture of 400kV, 132kV and 33kV, substations drop this to 11kV for the distribution system. Transformers drop the 11kV to 440/220V for users. High Voltage transmission covers the country reasonably well, however the 11kV distribution systems are limited. A substation is expensive and needs a load of several tens of MW_e to justify installation. There are a significant amount of people in intermediate areas where the load is not sufficient to justify a substation and around 50% of rural households do not have access to electricity supplies. In these areas without grid-connection, diesel-fired generation is common. There is a well-developed level of small entrepreneurial activity in this market and local mini-grids are common. A solar mini-grid can be economical given the high generation costs from small diesel generation systems. While diesel generation is a minor part of the national mix, it is also widely used as back-up generation due to poor reliability of supply from the grid.

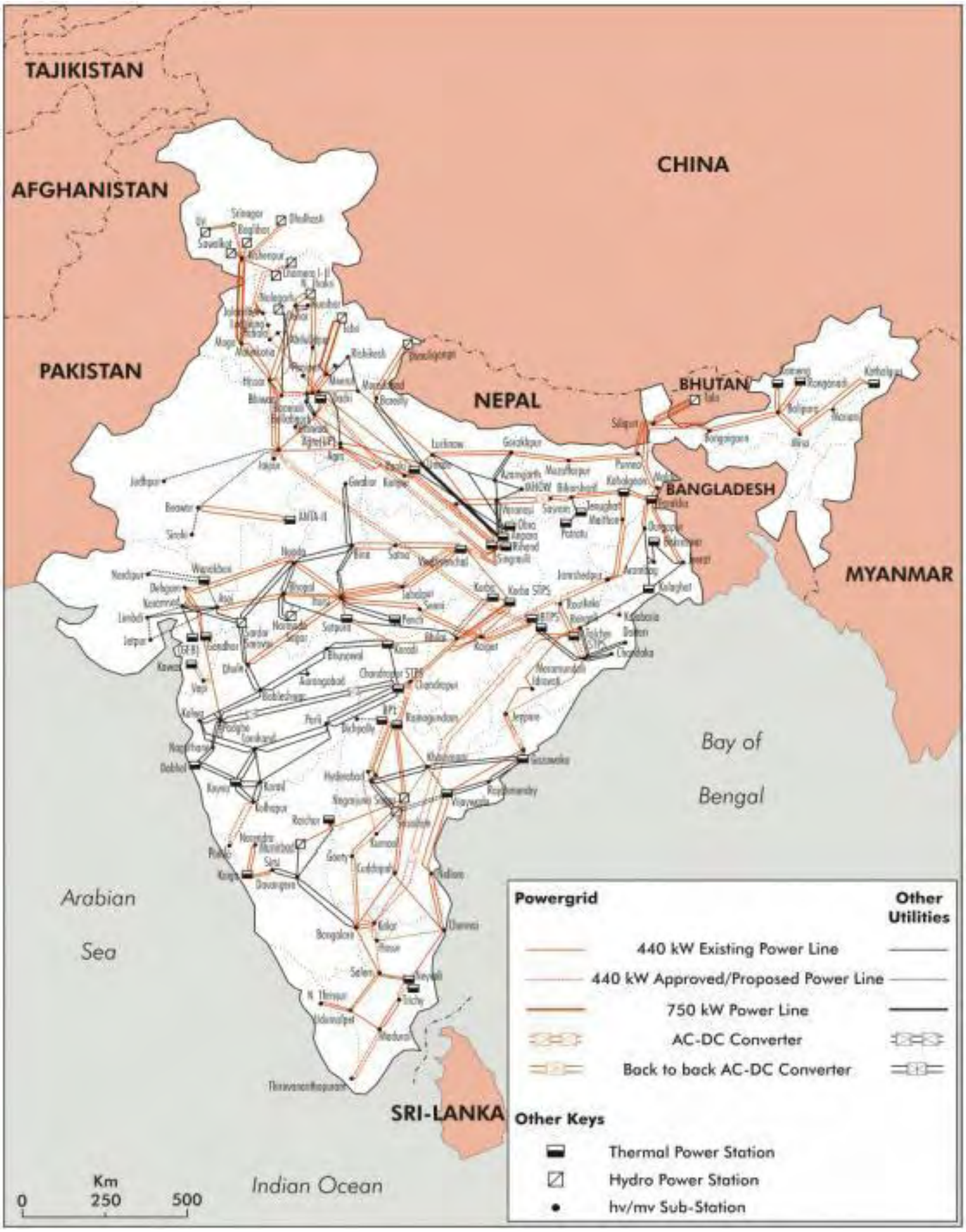


Figure 3.5: Indian electricity transmission system, (IEA, 2002).

Currently transmission is shared between Central and State agencies. Distribution activities have some private sector involvement. Historically, India's grid system has grown up around separate regional efforts. Separate states were connected to one of Northern, Eastern, Western, Southern and North-Eastern regional grids. In 2006, all except the Southern grid, were integrated and operate synchronously (Purohit & Purohit, 2010). Moves towards a national grid system are coordinated by the Central Transmission Utility (trading as Power Grid Corporation).

According to many sources, transmission and distribution losses are over 30%, with a large proportion of this being due to theft and unmetered use, for example Baker & Mackenzie, (2008) estimate 33% while Aroro et al, (2010) estimate 40% of power generated is lost.

3.5 Approvals

An indicative listing of the various approval processes that would be needed for construction of a CSP system have been listed by DLR & Evonic, 2009. This list is reproduced in Table 3.3

Statutory Permits and Clearances (To be obtained prior to construction)		
	Description	**Authority**
1	Pollution clearance (Water and Air)	MoEF & State Pollution Control Board,
2	Environmental and Forest clearance	State Government Ministry of Environment & Forest (MoEF), GOI
Non - Statutory Permits and Clearances (To be obtained prior to construction)		
1	Clearance from Archaeological department	Government of India
2	Real Estate Rights & right to access and use of site including right of way for all corridors to the Facility.	State Government / Concerned Agency
3	Consent of relevant Panchayat the development of Project site and township site	Directorate of Town Planning of State Government
4	Import licenses and formalities	Controller of Import Authorities
5	Tariff Approval	State Electricity Regulatory Commission

Table 3.3: Approval processes for construction of a CSP system in India, (reproduced from DLR & Evonic, 2009).

3.6 Issues

In summary it is apparent that consideration of CSP technologies in India, must be considered in the context of a power sector that is experiencing rapid growth and has many identified weaknesses. A team from NREL, REN21, GTZ and IRADe, have produced an '*Indian Renewable Energy Status Report*', (Arora et al, 2010) as a background report for the Delhi International Renewable Energy Congress (DIREC) held in October 2010. A quote from this report is pertinent to the challenges facing the Indian power sector:

> 'The single biggest institutional need in the Indian energy sector is to improve management of the power sector, especially governance of distribution entities. Nearly 40 percent of energy supplied into state transmission systems is lost, not billed, incorrectly billed, or the payment not collected. This is extremely poor by any standards, and puts the Indian power sector well below others in the region in terms of technical, financial or commercial performance. Since the State Regulatory Commissions (SRC), empowered by the Electricity Act of 2003, has been recently set up, it may benefit from capacity building and political and budgetary support. The agenda of loss-making state-owned enterprises, poor commercial performance, misplaced subsidies, and tariff distortions is daunting indeed. Moreover, there are other mandates related to undertaking renewable energy development, EE improvement, formulation and implementation of regulations on service quality and service obligations, and outreach efforts designed to enhance public participation and break the deadlock around tariff increases versus quality of supply improvements. Given these major challenge, enhanced governance is the key institutional need in the power sector'.

4 India's Solar Resources

4.1 Introduction

CSP technologies rely on Direct Beam radiation for operation. That is radiation direct from the sun that has not been diffused or deflected by clouds or other atmospheric factors and so can be focussed by the mirrors. Ideally the data needed to assess potential sites is short interval, Direct Normal[4] Irradiation (DNI) measurements collected over several years. In India as in Australia, there is much less data available than would ideally be desired.

Time series data rather than annual averages are important because the output of a CSP plant is not simply a linear function of the radiation it receives. This is particularly the case for the thermal conversion processes that dominate in CSP systems. Issues include:

- In designing a CSP plant, knowledge of the seasonal variation in DNI resource is needed to make an optimal economic assessment of the degree to which the solar field is oversized relative to the power block in the high season and undersized in the low season.
- Power blocks have an efficiency that decreases with part load (due to reduced solar input) and a threshold load under which they cannot operate. Thus to predict the power block's total daily output, knowledge of the time dependence of input heat transfer fluid energy flow is required.
- The thermal receivers in collector fields take many minutes to reach operating temperature from cold, hence to accurately predict their output, data at time resolutions of one minute or less is required to predict performance in situations of intermittent cloud.

In general, DNI data can be obtained in one of three ways:

- Measurements using a tracking pyroheliometer or other instrument at frequent intervals over many years are the ideal data source for a particular site, as long as the instrument has been maintained in good calibration. Depending on dust and pollution, the accuracy of data can deteriorate by up to 1% per day if the pyroheliometer is not kept clean.
- Measurements of Global Horizontal radiation from a non-tracking instrument provide indirect information. There are established methods for deducing DNI from Global Horizontal mathematically. However, the calculation is dependent on assumptions for a range of parameters, which introduce considerable inaccuracies.
- Measurements of reflected radiation taken with geostationary satellites allow the Global Horizontal radiation to be deduced using knowledge of the local reflectivity (albedo) of the earth's surface. DNI can in turn be derived from this using the mathematical methods mentioned above. The satellite approach is the least accurate and currently only available at low frequency. It has the advantage of the widest geographic coverage and is now available across the globe. Satellites can also have the advantage of providing long term data sets from archives kept over the life of the satellite, which can be used to complement ground-based data taken over short timeframes.

[4] The significance of 'normal' is that DNI data is expressed as the energy flux that would be intercepted by a plane surface that moves continuously such that the solar radiation always falls at an angle of 90° to the surface.

4.2 Available data for India

Several sources of data for India are available, based predominantly on satellite measurements.

NASA http://eosweb.larc.nasa.gov/sse/

The US National Aeronautics and Space Administration based satellite measurements (NASA, 2010 A) produce the general assessment of global DNI shown in Figure 4.2. The NASA website service allows DNI data to be downloaded for any grid reference across the globe. The data is in the form of monthly averages and is derived from 22 years of satellite data with an effective 30km grid. Hourly data is derived using a calculation procedure based on an average day for each month. The methodology is described in detail at the website, (NASA, 2010 B).

Solemi www.solemi.de

Solemi is a service run by the DLR (Deutsches Zentrum für Luft- und Raumfahrt), Germany's aerospace research centre. Solemi provides solar radiation data from the Metosat-5 and Meteosat-7 satellites with a nominal spatial resolution of 2.5 km and half-hourly temporal resolution. Solar radiation maps and hourly time series are available for approximately half the earth's surface including India. Approximately 10 years of data collected from the satellites is available. DNI data is derived from satellite data using a method of comparing a reference image (ground only) with the visual spectrum data collected by the satellite.

Meteonorm www.meteonorm.com

Meteonorm is a weather data and modelling tool that provides approximately 20 years of data for global solar radiation and other climate data including temperature, humidity and wind speed. The data is collected from ground based weather stations and supplemented with satellite data where there is a low density of weather stations. Hourly values are available but are calculated from collected data using a stochastic model. In India, ground based weather station data is available for Jodhpur (Rajasthan), Ahmedabad and Bhavragar (Gujarat), Delhi, Nagpur, Pune and Mumbai (Maharastra), Goa, Chennai (Tamil Nadu) and Thiruvananthapuram Trivandrum (Kerala). Figure 4.3 shows the Meteonorm world DNI map.

NREL www.nrel.gov/rredc/

The US National Renewable Energy Laboratory (NREL) produces solar resource maps based on satellite data with DNI derived from a set of algorithms. NREL has produced DNI maps for regions of India as part of projects in 2008 and 2009. In 2010, NREL released 10km resolution DNI resource maps for India based on the SUNY satellite to irradiance model. This model uses hourly data from January 2002 to December 2008 collected from the Meteosat-5 and Meteosat-7 satellites and has been previously validated against ground-based data for other locations (NREL, 2009). The model has been updated to better reflect the effects of dust and anthropogenic pollution which change rapidly in India.

Handbook of Solar Radiation Data for India

A widely used source of information on the Indian solar resource is provided in the Handbook of Solar Radiation Data published in 1981. The handbook includes tables of global, diffuse, and direct solar radiation and related climate parameters for 18 stations in India. These tables present hourly values of measured global and diffuse radiation data. The direct solar radiation is calculated from the global and diffuse radiation data. In addition, there are mean values of direct solar radiation observed with angstrom pyroheliometers at 13 stations, four times a day. The data sets are based on careful measurements made over long periods of up to 21 years by stations in the country operated and maintained by the India Meteorological Department (IMD).

Solar Radiation Hand Book (2008) www.indiaenvironmentportal.org.in/files/srd-sec.pdf

The Solar Radiation Hand Book (SEC et al 2008), was a joint project of the MNRE, the Solar Energy Centre and the IMD. It summarises 1986 to 2000 data collected at 23 sites in India. It contains mean monthly global and diffuse solar radiant exposure plus mean hourly air temperature for 23 sites. It also lists the mean sunshine hours for 17 sites.

Figure 4.1 shows the location and type of solar radiation monitoring systems operated by the Indian Department of Meteorology. There are 25 sites in total collecting some form of radiation data. Of these sites, there are two sites in north-west India collecting direct radiation data, in Jodhpur and Ahmedabad.

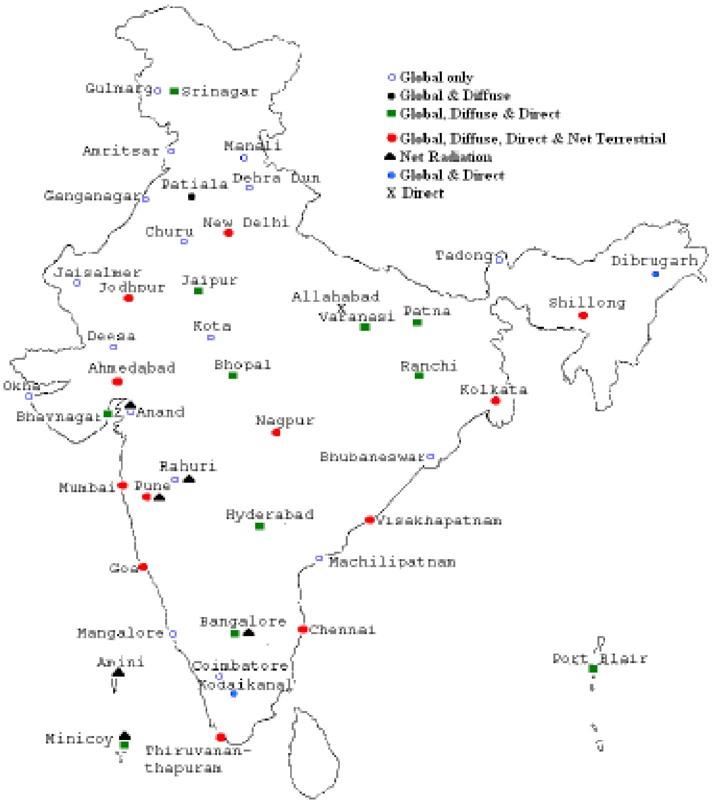


Figure 4.1: Solar Radiation Handbook monitoring stations
(SEC et al, 2008)

3Tier www.3tier.com/en/products/solar/

The company 3Tier also have a modelled solar dataset for India that includes wind and temperature data. The Indian dataset is based on half-hourly imagery from the Meteosat satellites in the period 1999 to 2009. 3Tier have modeled hourly values of Global Horizontal Irradiance, Direct Normal Irradiance and Diffuse Horizontal Irradiance at a horizontal resolution of 2 arc-minutes, (approximately 3 kilometers). There is a fee charged to access the detailed data, however, some overview aspects of the data for India are available from the website.

ISHRAE www.ishrae.in

The Indian Society of Heating Refrigeration and Air Conditioning Engineers (ISHRAE) has synthesized and compiled hourly average Direct Normal Irradiance data for 58 Indian cities including Jaisalmer using IMD data. These data sets are also available from the US Department of Energy's website, (US DoE, 2010). These data sets were developed to use with building energy performance simulation programs and are available in TMY format[5].

Other Data Sources

There will be other solar data sources that are not included in this listing. For example, several companies are likely to have previously carried out analysis or have monitoring underway. These studies may be considered commercial-in-confidence and the details may not be published.

Raw data sets from the IMD monitoring stations are clearly in existence, however it is not clear to what extent these data sets are made publicly available. Publishing these datasets on a website would provide equitable access to all interested parties.

4.3 India's solar resource in a global context

The following maps show world annual average DNI from two of the available data sources, NASA and Meteonorm.

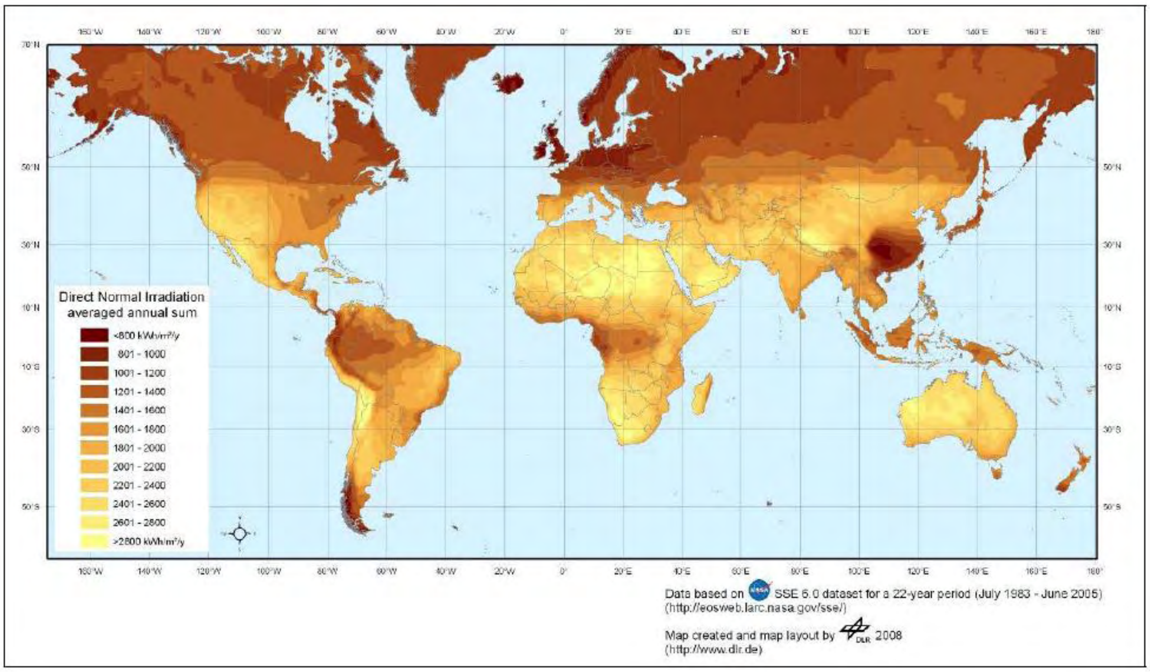


Figure 4.2: Annual Direct Normal Irradiation in kWh/m^2/year
from NASA (Yellow is highest)

[5] In TMY format the meteorological measurements are made at hourly intervals over a number of years to build up a picture of the local climate. As a simple average of the yearly data underestimates the amount of variability, the month that is most representative of the location is selected.

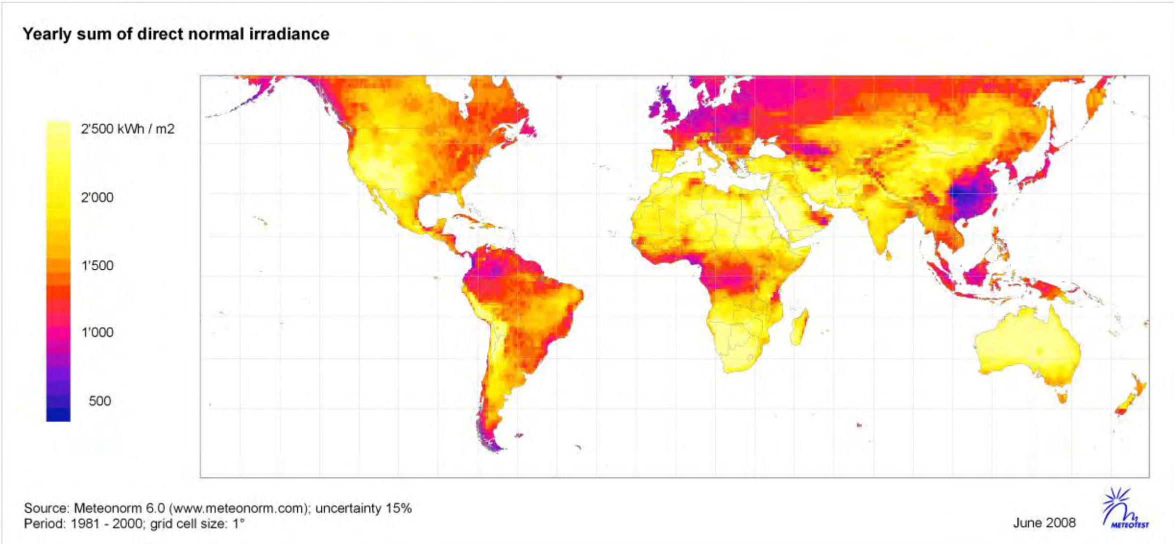


Figure 4.3: Annual Direct Normal Irradiation in kWh/m^2/year produced by Meteonorm (yellow is highest)

Table 4.1 compares the best desert sites across the world in terms of annual average DNI.

Country	Location	Latitude	Longitude	Annual Average DNI kWh/m^2/ day	Annual Average DNI kWh/m^2/ year
Saudi Arabia	Rabul Khali (Arabian desert)	20° N	50° E	7.61	2,778
Nigeria	Algadez (Sahara desert)	17° N	8° E	7.57	2,763
USA	Mojave desert (location of SEGs powerplants)	35° N	115° W	6.95	2,537
Australia	Oodnadatta, South Australia (Simpson Desert)	28° S	135° E	6.83	2,493
Spain	Granada (location of Andasol power plants)	37° N	3° W	5.82	2,124
India	Jodhpur, Rajasthan (Thar desert)	26° N	72° E	5.77	2,106

Table 4.1: Comparison of desert sites across the world using NASA data.

Both the NASA and Meteonorm maps show a range of approximately 1,800 to 2,200 kWh/m^2/year for DNI across India. It is apparent from this and from Table 4.1 that India has an annual DNI resource that is comparable to the best European sites such as Spain, though lower than the best sites in the USA and Australia. Abengoa Solar considers sites with an annual average DNI larger than 1,900 kWh/m^2/year as potential sites for CSP plants (DLR & Evonic, 2009).

The Middle Eastern and North African deserts represent the best DNI resources on the planet, both on an annual average and minimum variability basis, but there are not yet any CSP power plants operating in these deserts. The Mojave Desert in the US is home to the SEGS power plants and has slightly more than 20% higher resources than Jodhpur and Granada.

Figure 4.4 compares desert sites across the world in terms of monthly DNI averages.

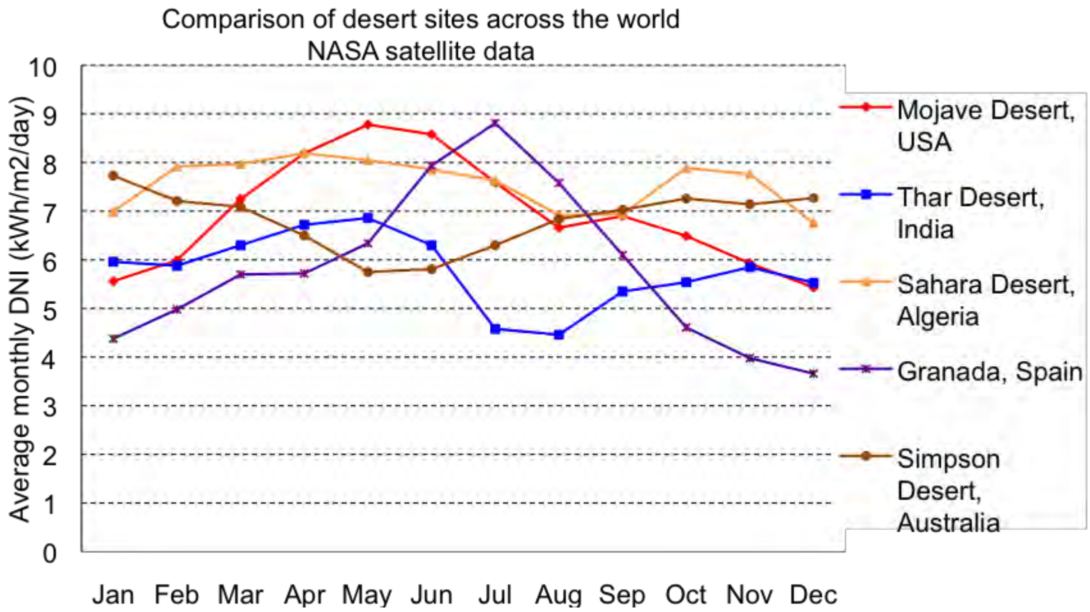


Figure 4.4: Comparison of DNI on a monthly basis for desert sites across the world

It can be seen from Figure 4.4 that Jodhpur, on the edge of the Thar desert in India, is almost exactly comparable on an annual average basis to Granada, one of the best Spanish sites at which the Andasol power plants are located. Based on the NASA data, Jodhpur has slightly less seasonal variability than Granada, which is preferable from a commercial perspective for a CSP power plant. However, the impact of the annual monsoon season is noticeable with July to September being the months of lowest DNI. This shows that in terms of solar resources, India has sites comparable with Spanish sites where commercial CSP plants are already in operation. Although the profile of the solar resource is somewhat different, the performance of sites in Spain provides some guidance as to the expected performance of sites in India.

4.4 Comparison of sites across India

Detailed maps of the Indian solar resource are available from several sources including NREL, Meteonorm, Solemi and the Solar Radiation Hand Book (SEC et al, 2008). The National Renewable Energy Laboratory (NREL), Golden Colorado, USA has prepared a DNI map of India with a 10km resolution and this is provided as Figure 4.5.

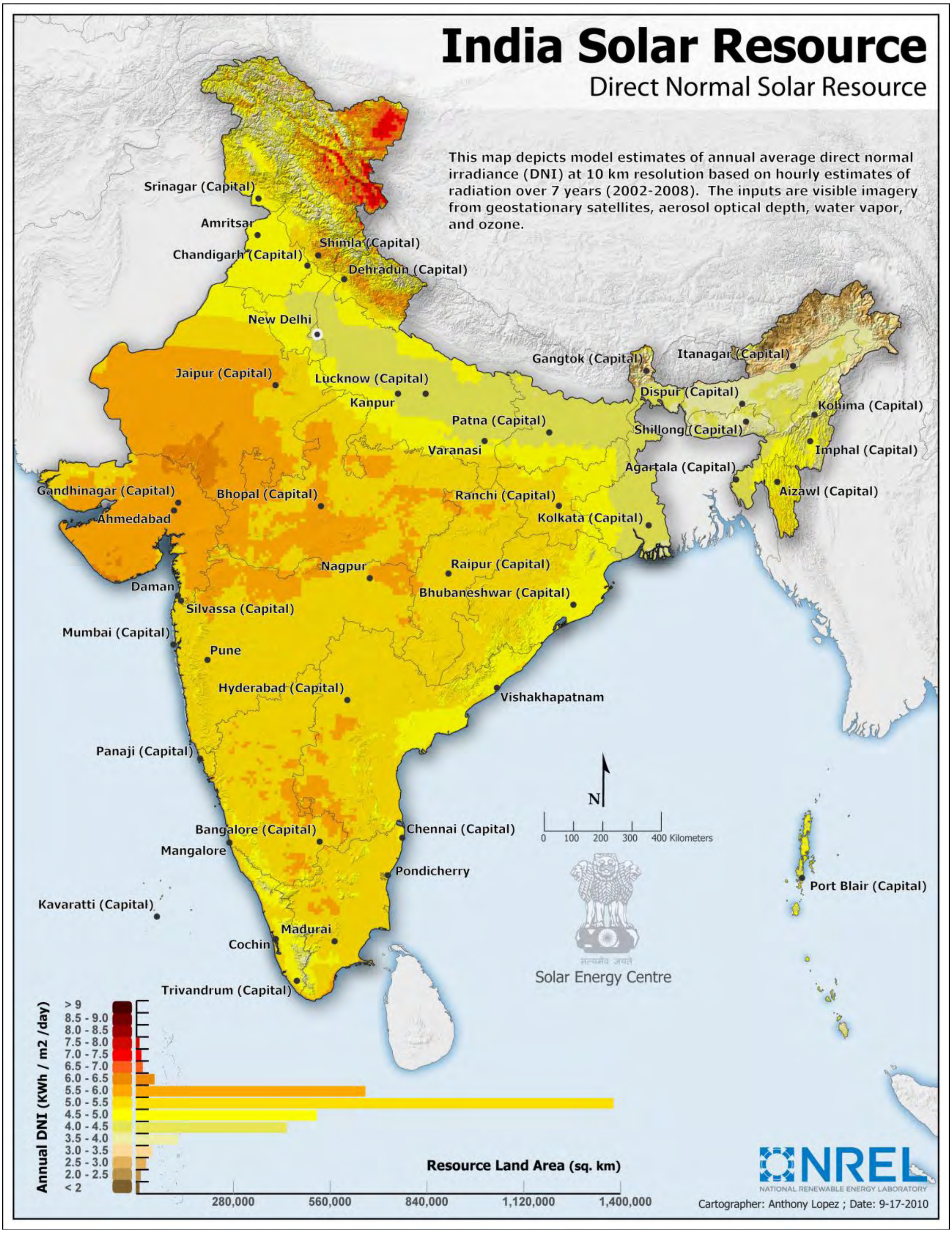


Figure 4.5: NREL 10km resolution DNI map of India (2010)

It is apparent from Figure 4.5 that north-west India (Rajasthan and Gujarat in particular) offers the best average DNI resource in the country. The extreme north (Jammu and Kashmir) also has a region with even better resources that is worth investigating, however, this region is expected to have limited grid-connectivity and suitable flat sites for CSP plants due to the mountainous terrain.

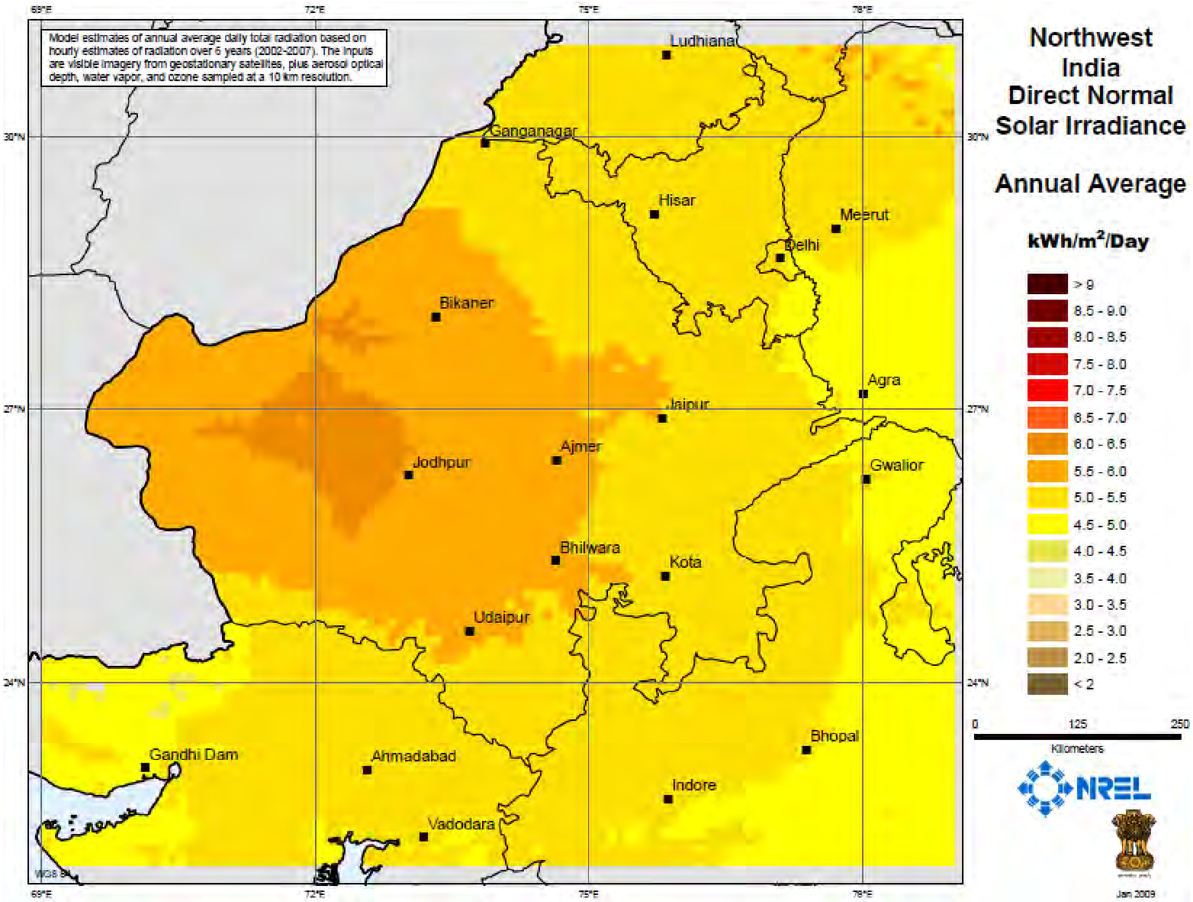


Figure 4.6: DNI map of north-west India, (NREL, 2009)

MNRE's Solar Energy Centre in Delhi provides data for solar resources (SEC, 2010), which were produced as part of an NREL project on north-west India, (MNRE, 2010D). Figure 4.6 shows the annual average DNI map for the north-west of India. It indicates that within Rajasthan, the Thar desert region, with Jodhpur at its border, has the highest DNI availability. Note that the newer NREL map of India (Figure 4.5) shows higher resources for Gujarat making it equal with most of Rajasthan. Both maps are produced from satellite data so there is approximately 15% uncertainty in the figures shown. There are limited ground based monitoring systems in this region to validate the satellite data.

The '*Techno-economic evaluation of concentrating solar power generation in India*' study, (Purohit & Purohit, 2010) used data from the '*Handbook of Solar Radiation Data for India*', (Mani, 1981) to examine the potential economics of CSP plants at a range of locations in India. Table 4.2 is reproduced from their study. For comparison, DNI corresponds to the final column designated at direct solar radiation for two-axis tracking. This table correlates with the maps and confirms Rajasthan sites such as Bikaner and Jaisalmer, as among the best available.

Location	State	Latitude (°N)	Longitude (°E)	Altitude (m)	Direct beam irradiation - One Axis tracking (kWh/m²/yr)	Direct beam irradiation - Two axis tracking (kWh/m²/yr)
Jaisalmer	Rajasthan	26.9	70.92	231	2543	2650
Bikaner	Rajasthan	28	73.3	224	2332	2426
Barmer	Rajasthan	25.75	71.38	194	2241	2326
Kota	Rajasthan	25.18	75.5	257	2023	2098
Jodhpur	Rajasthan	26.3	73.02	224	2020	2093
Jobner	Rajasthan	27	75.08	427	1945	2010
Udaipur	Rajasthan	24.58	73.7	582	1929	1997
Leh	Jammu & Kashmir	34.15	77.57	3514	1902	1984
Jaipur	Rajasthan	26.82	75.8	390	1846	1909
Gwalior	Madhya Pradesh	26.23	78.25	207	1802	1862
Rajkot	Gujarat	22.3	70.78	138	1770	1824
Bhopal	Madhya Pradesh	23.27	77.42	503	1762	1822
Ahmadabad	Gujarat	23.07	72.63	55	1756	1816
Bhuj	Gujarat	23.25	69.67	80	1730	1787
Okha	Gujarat	22.48	69.12	7	1710	1760
Hissar	Haryana	29.17	75.77	221	1705	1757
Bhavnagar	Gujarat	21.75	72.18	5	1689	1747
Indore	Madhya Pradesh	22.72	75.8	567	1677	1732
Baroda	Gujarat	22.3	73.25	34	1676	1730
Jamnagar	Gujarat	22.47	70	21	1675	1727
Agra	Uttar Pradesh	27.17	78.08	169	1670	1720
Lucknow	Uttar Pradesh	26.75	80.88	128	1638	1689
Bhubneshwar	Orissa	20.25	85.87	26	1607	1652
Nagpur	Maharashtra	21.15	79.12	311	1601	1651
Mumbai	Maharashtra	19.12	72.85	14	1597	1641
Bellary	Karnataka	15.15	76.85	449	1555	1591
Jabalpur	Rajasthan	23.15	79.97	411	1531	1576
Kolhapur	Maharashtra	16.7	74.23	570	1528	1564
Surat	Gujarat	21.2	72.87	11	1517	1562
Pune	Maharashtra	18.53	73.85	563	1521	1561
Amritsar	Punjab	31.63	74.87	234	1474	1522
New Delhi	Delhi	28.58	77.2	216	1477	1521
Vishakapatnam	Andhra Pradesh	17.72	83.23	3	1483	1520
Hyderabad	Andhra Pradesh	17.45	78.47	545	1478	1514
Jammu	Jammu & Kashmir	32.67	74.83	367	1457	1509
Saharanpur	Uttar Pradesh	29.97	77.55	275	1450	1494
Cuttack	Orissa	20.48	85.87	24	1440	1480
Kanyakumari	Tamil Nadu	8.08	77.5	37	1444	1466
Raipur	Chhattisgarh	21.27	81.6	289	1400	1441
Patna	Bihar	25.5	85.25	52	1396	1437
Dehradun	Uttarakhand	30.32	78.03	683	1359	1400
Coimbatore	Tamil Nadu	11	77	431	1365	1387
Chandigarh	Chandigarh	30.73	76.88	347	1337	1376
Pantnagar	Uttarakhand	29	79.5	244	1318	1357
Chennai	Tamil Nadu	13	80.18	16	1326	1347
Imphal	Manipur	24.77	93.9	781	1307	1345
Nellore	Andhra Pradesh	14.45	79.98	20	1234	1254
Kodaikanal	Tamil Nadu	10.23	77.47	2345	1217	1240
Calcutta	West Bengal	22.65	88.45	6	1151	1179
Dibrugarh	Assam	27.48	95.02	111	836	858

Table 4.2: Direct Solar Radiation at a range of locations.
Data taken from Purohit & Purohit, (2010), sorted from highest to lowest direct beam radiation level.

4.5 Comparison of measured data with satellite data

Figure 4.7 shows the annual variation in DNI for Jodhpur using data from NASA, NREL monthly maps and the derived and measured values from Mani.

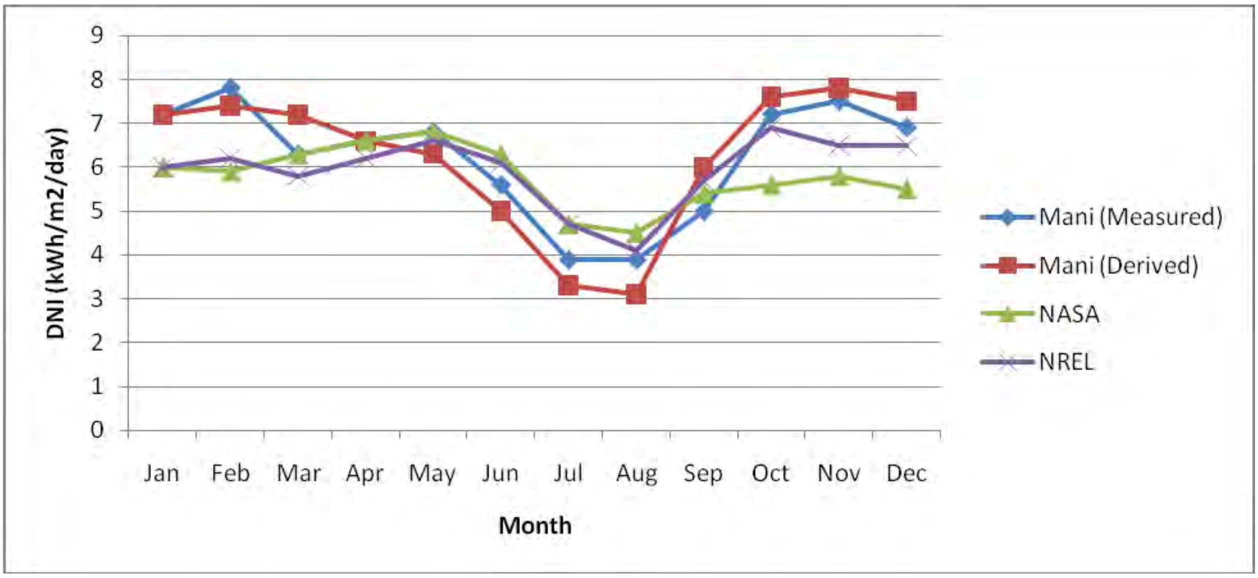


Figure 4.7: Comparison of measured and derived data for Jodhpur, Rajasthan based on measured and derived data from Mani (1981), NASA and NREL satellite data

Notes for Figure 4.7:

1. NREL data is taken from monthly maps as no raw data was available.
2. The time periods over which measurements were taken vary between data sources.
3. Mani's measured data is a 22 year average to 1981.
4. NASA data is a 22 year average to 2005.
5. NREL data is a 6 year average based on hourly data for the years 2002 to 2007.

Annual averages for NASA data, derived and measured data from Mani, and derived data from NREL are compared in Table 4.3.

Data – source	Annual average kWh/m^2/day
NASA data	5.77
Derived data – hand book of solar radiation	6.2
Measured data – hand book of solar radiation	6.2
NREL map (2009)	6

Table 4.3: Comparison of annual average DNI for Jodhpur from various data sources

The comparison shows that

- All the data sources show the same pattern of weather variations, however there is significant month to month variation between them.
- There is major dip in the direct solar radiation coinciding with the monsoon's arrival in June to October. The dip is mainly due to the presence of cloud in the atmosphere.

- The measured and derived data from the Mani's '*Handbook of Solar Radiation Data*' agree with each other within 10% on a month-by-month basis and within 1% on an annual average basis.
- The NASA data and the Mani Handbook data have larger variations between them. The Handbook data shows more radiation available during the November to February period and less during the monsoon seasons compared with the NASA data. This may reflect that the intensity of the monsoon can vary from year to year.
- The annual averages from NASA and NREL satellite data are less than those from Mani. This may indicate the diversity over the different time periods that data was collected, or may be an indication that the satellite derived data is underestimating the true resource.

Other analyses have been done for sites in Rajasthan including DLR & Evonik (2009) which analyses the potential for a CSP power plant in Eastern Rajasthan. Figure 4.8 compares various data sources across the year for Anta.

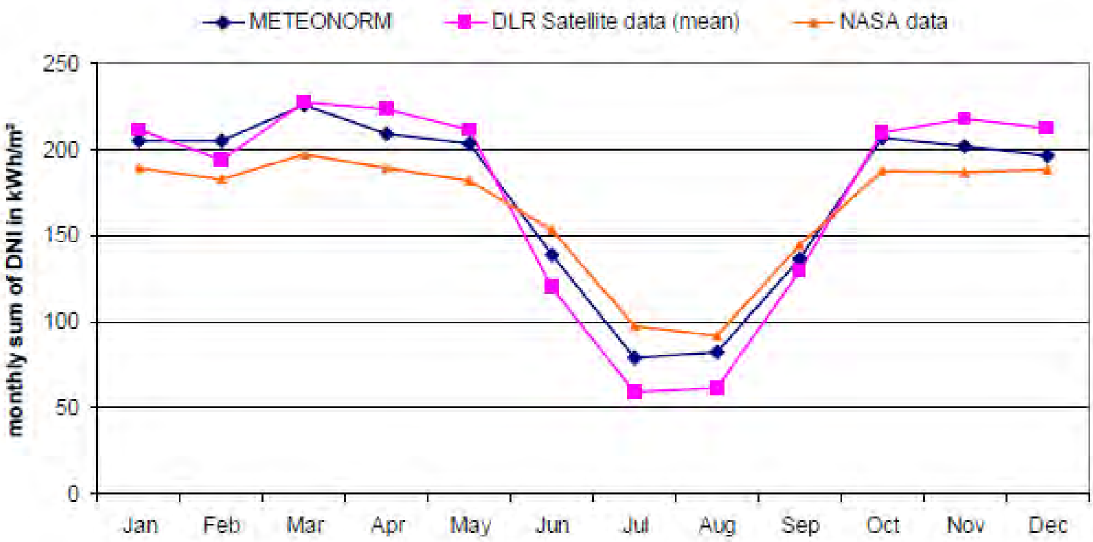


Figure 4.8: Monthly DNI for Anta site, (DLR & Evonik, 2009)

Year to year variability

Figure 4.9 gives the year to year variability based on SOLEMI data and would be a good indication of the typical year to year variability at other sites in Rajasthan.

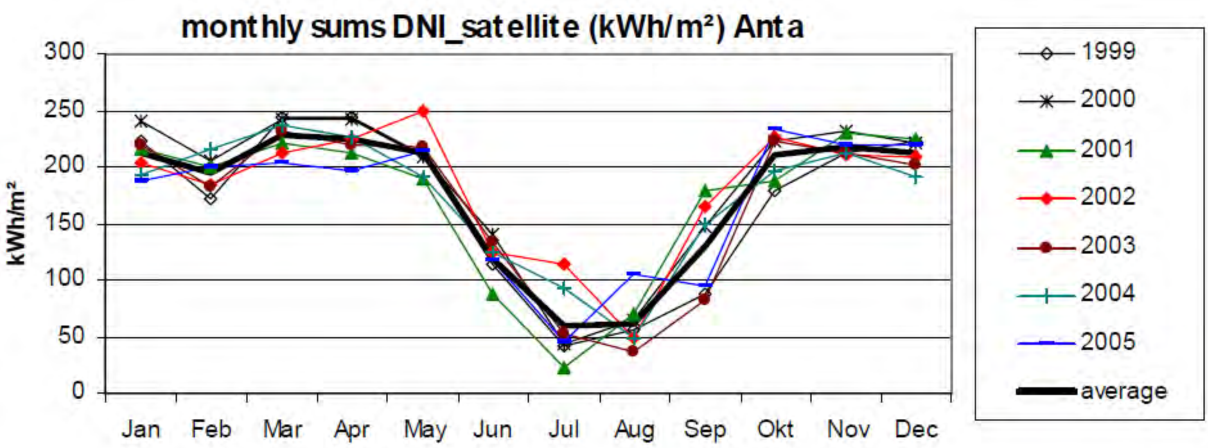


Figure 4.9: Monthly DNI for Anta by year (DLR & Evonik, 2009).

The Anta study also attempted to indentify useful Indian Meteorology Bureau solar data. Jaipur data was obtained from IMB Pune.

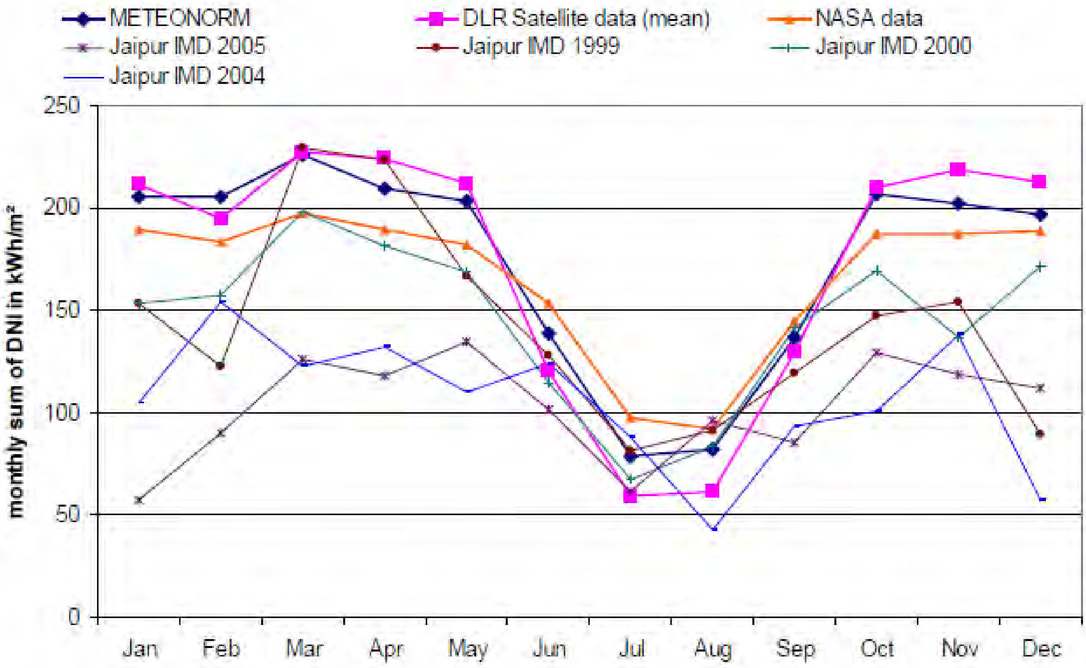


Figure 4.10: Monthly sum of DNI for Anta from Jaipur IMD dataset compared to METEONORM, DLT satellite and NASA data, (DLR & Evonik, 2009).

All the IMB years compared above are lower that the NASA or DLR predictions. The IMB data for Jaipur does have hourly values. The Anta study concluded the IMB data set was of limited use for a feasibility study as it was missing associated ambient temperature and humidity data. The study reproduced graphs from IMB data of hourly average and peak DNI values for various years. The peak values are informative as the outer envelope is indicative of the behaviour or the solar resource across a perfect clear day.

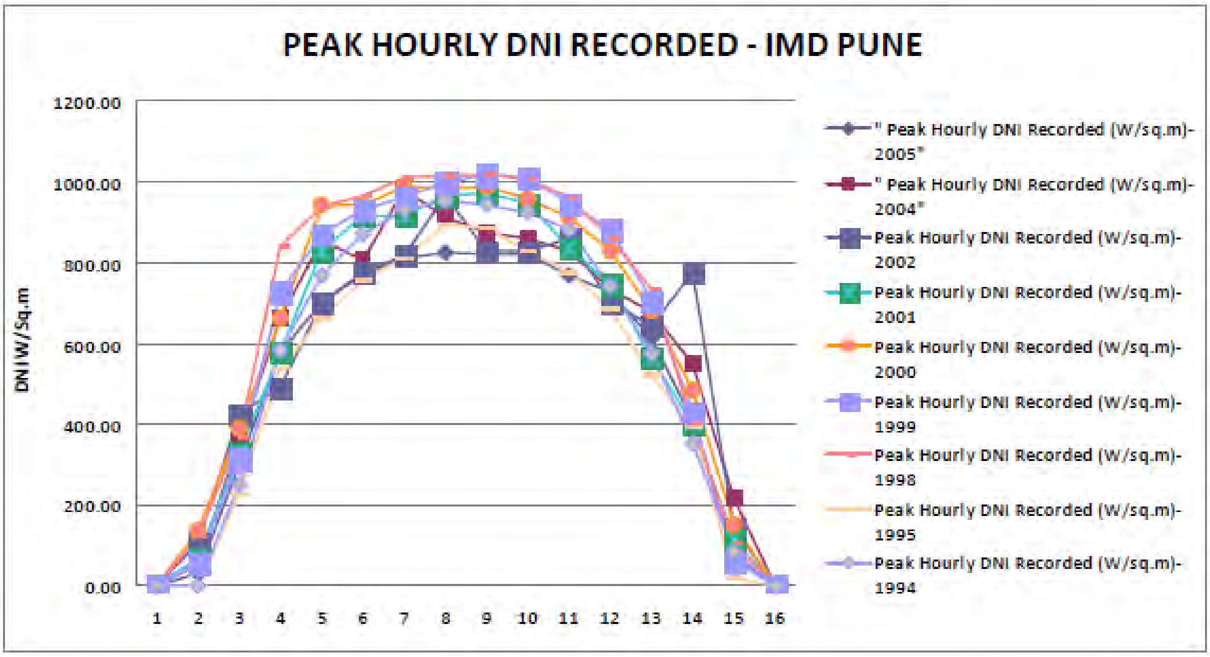


Figure 4.11: Peak hourly DNI data for Jaipur, from the IMD Pune office (DLR & Evonik, 2009).

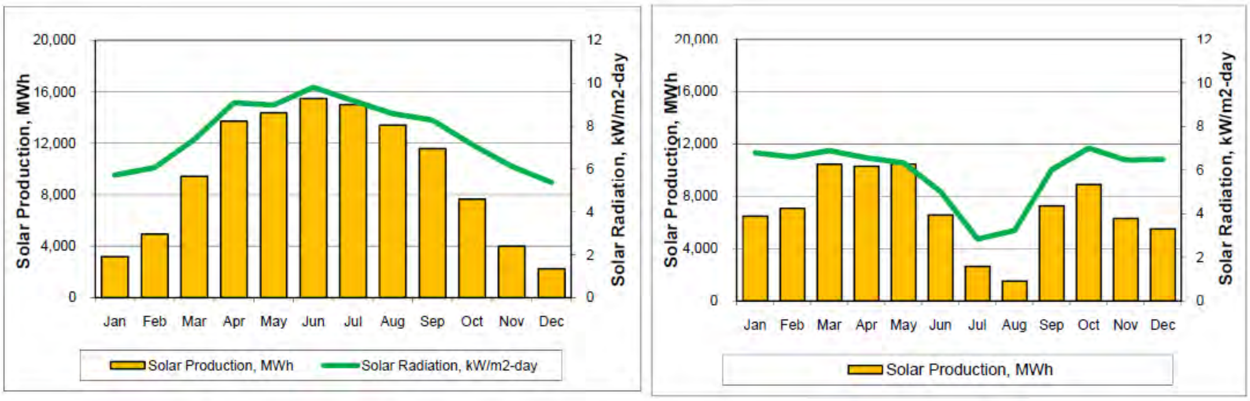
4.6 Effect on CSP system performance

A rough, rule-of-thumb would assume that the annual output of a CSP plant is proportional to the average DNI of the site. In reality, it is more complex as noted in the introduction. In addition to the instantaneous DNI level, wind speed, humidity and ambient temperature effect the level of thermal loss from receivers. They also effect the effectiveness of condenser cooling to a significant extent. On balance, a low ambient temperature will improve system performance because the lower condenser temperatures (for a steam system) that result, improve turbine efficiencies by more than the smaller penalty in increased receiver thermal losses caused by an increased temperature differential.

Another key factor is the sun angle. A dish system has the advantage that it always presents its full aperture to the sun. DNI is the true input to a dish system. For the linear concentrators, the sun will not be perfectly normal to the axis of the receiver and this will reduce the amount of energy actually intercepted by the mirrors. The effect will be least in mid-year for India when the sun passes higher in the sky and also be minimised the closer to the equator a system is. The effect can be seen in Table 4.2 where the two-axis tracking direct radiation is always higher than the single-axis tracking, but the Southern Indian locations have the least variation. A tower plus heliostat system is even more complex, and the effect depends on the heliostat field design.

To predict actual output a full system model is needed. The SAM model that has been provided in the public domain by NREL (2010) is widely recognised baseline model. Detailed knowledge of the technologies to be used is required to use such a forecasting model accurately.

By way of example, a presentation to a CERC public hearing (SunBorne Energy, 2010), included some indicative performance comparisons between Daggett and Indian sites as shown in Figures 4.12 and 4.13. Without reference to the detailed assumptions, it is difficult to analyse the performance forecasts. However, it can be seen that the predicted solar production is far from proportional to the solar radiation levels and that the output for a given radiation level at the US site is not the same as predicted for the Indian sites.



Daggett, CA

Jodhpur, RJ

Figure 4.12: Comparison of solar radiation and forecast output of solar thermal trough plants, (SunBorne, 2010)

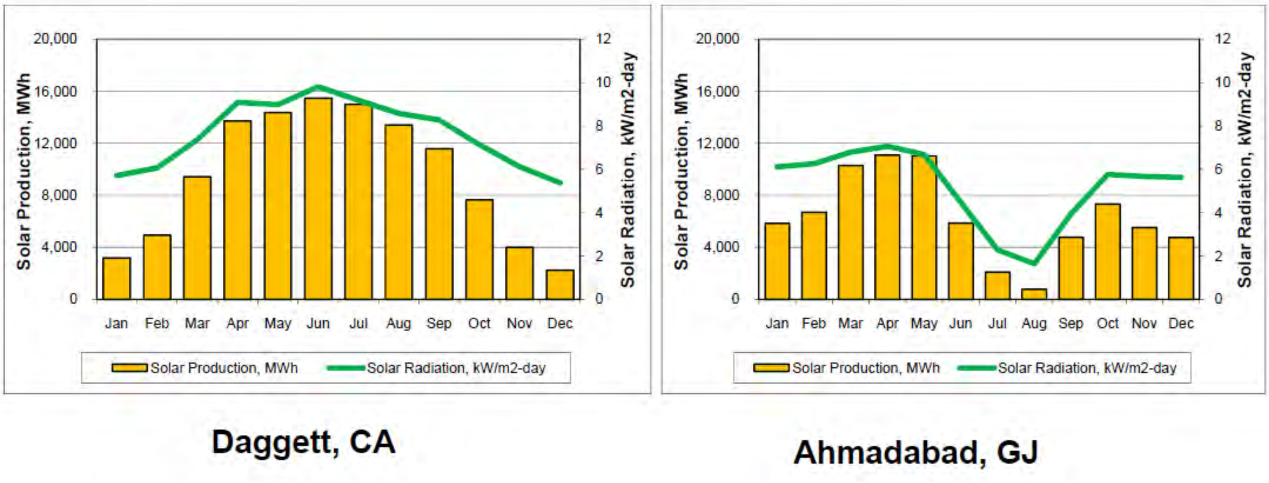


Figure 4.13: Comparison of solar radiation and forecast output of solar thermal trough plants, (SunBorne, 2010)

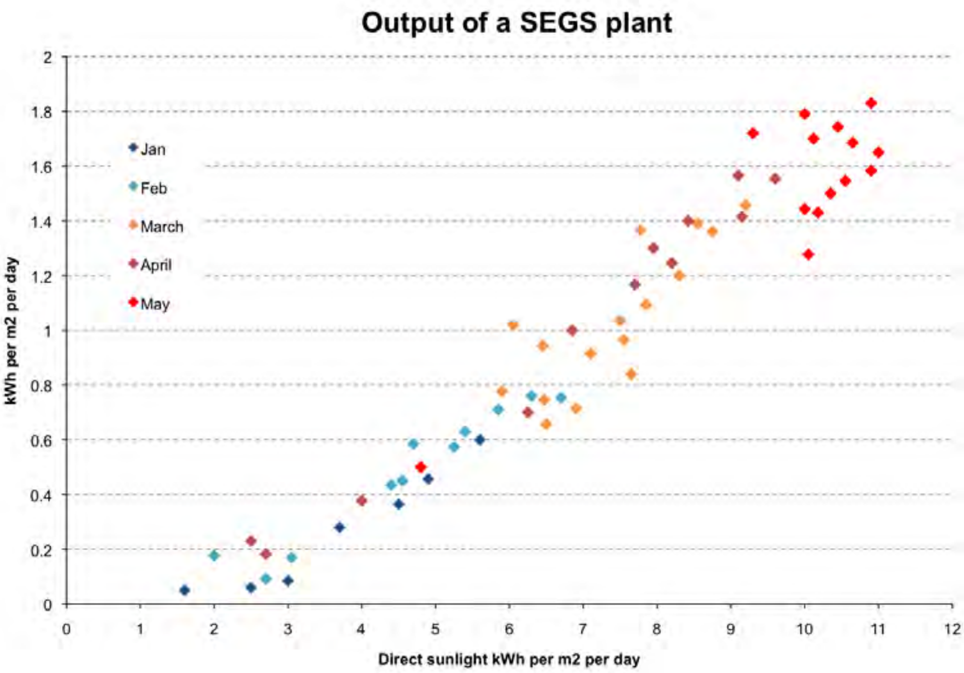


Figure 4.14: Daily output variability for a northern hemisphere SEGS plant (based on IEA 2010)

Figure 4.14 illustrates the importance of obtaining good solar resource data to assist with sizing and designing the power block and its collector field.

4.7 Summary

India has large areas of land that receive annual direct solar irradiation that, whilst not the highest in the world, is as good as areas in Spain with existing CSP systems. The north-west of India is widely recognised as having the best sites in the country. There are a range of sources of data available, however like many places in the sunbelt regions of the world, there is not as much accurate ground based data as investors desire. Predictions of future plant performance can probably only be made to an accuracy of 10 to 15% and this is an impediment to investment support.

5 Enablers for CSP Deployment

5.1 Renewable Energy Framework

India is one of the world leaders for installed renewable generation with a total capacity of almost 17.6 GW as of June 2010 (Arora et al 2010). This figure does not include about 37 GW of large-scale hydro-electric plant. Australia has approximately 2.4 GW of renewable generation with an additional 8.2 GW of large-scale hydro-electric plant.

The key drivers for renewable energy in India include:

- Good levels of resource availability.
- The forecast growth in energy demand.
- Energy security concerns in light of increasing imports of fossil energy.
- Economic and quality of life costs associated with the environmental impacts of fossil fuel combustion.

Electricity demand exceeds supply in many regions and is forecast to grow strongly. Like Australia, there are areas with network constraints, presenting both opportunities as well as challenges for renewable generation.

The Government of India has long recognised the potential business opportunities offered by growing demand for renewable energy in local and overseas markets. It established the world's first ministry focusing on renewable energy, the Ministry for New and Renewable Energy, (MNRE). The Indian Renewable Energy Development Agency (IREDA) is administered by MNRE and was established in 1987 to operate a revolving fund for development and deployment of new and renewable sources of energy. MNRE also administers national institutions such as the Solar Energy Centre (SEC) and the Centre for Wind Energy Technology (C-WET).

The Government of India has implemented several policies that support the expansion of renewable energy. As discussed in Chapter 2, the Electricity Act 2003, reformed the power market to encourage competition and allow for open access to networks for renewable generators.

India's existing capability and potential for innovation is supported by a well-educated, professional and skilled workforce. There is a thriving renewable energy sector with strong growth in biomass generation, wind turbine and photovoltaic manufacturing that offers opportunities for synergy with the CSP sector.

The availability of skilled people favours the economics of manufacturing labour-intensive renewable technologies in high DNI regions. Countries such as Australia can have skilled people shortages and high costs of labour, especially in regional areas.

The existence of a dedicated Ministry for New and Renewable Energy, the SEC and C-WET are powerful enablers for renewable energy.

5.2 National Action Plan on Climate Change

In June 2008, the Government of India made a commitment to addressing greenhouse gas emissions through its National Action Plan on Climate Change (NAPCC), (Government of India 2008). The plan promotes development goals while addressing climate change issues. Some references indicate that the NAPCC suggests a 15% renewable energy target for 2020, which may be an interpretation of the following extract:

> 'The following enhancements in the regulatory/tariffs regime may be considered to help mainstream renewables based sources in the national power system:
>
> (i) A dynamic minimum renewables purchase standard (DMRPS) may be set, with escalation each year till a pre-defined level is reached, at which time the requirements may be revisited. It is suggested that starting 2009-10, the national renewables standard (excluding hydropower with storage capacity in excess of daily peaking capacity, or based on agriculture based renewables sources that are used for human food) may be set at 5% of total grids purchase, to increase by 1% each year for 10 years. SERCs may set higher percentages than this minimum at each point in time.'

The NAPCC includes eight National Missions, one of which is for solar energy:

> 'A National Solar Mission will be launched to significantly increase the share of solar energy in the total energy mix.'

The National Solar Mission promotes the use of photovoltaic and CSP generation for both grid-connected and off-grid locations and also includes a R&D component:

> 'Another aspect of the Solar Mission would be to launch a major R&D programme, which could draw upon international cooperation as well, to enable the creation of more affordable, more convenient solar power systems, and to promote innovations that enable the storage of solar power for sustained, long-term use.'

5.3 Clean Development Mechanism

Although India has ratified the Kyoto Protocol, it has not agreed to legally binding targets to reduce emissions. The Kyoto Protocol includes a flexibility mechanism known as the Clean Development Mechanism (CDM) whereby projects that reduce emissions in countries such as India are credited with Certified Emissions Reductions (CERs), that can then be used by Annex 1 countries (those that have committed to reduce their emissions) to meet their targets.

> 'The entry into force of the Kyoto Protocol in February 2005 gave a boost to CDM activities in India. Out of the 489 projects registered with the CDM Executive Board as of January 2007, 155 belong to India and have the potential for 109 million certified emission reductions (CERs) by 2012. Wind and biomass energy are the main sectors in the CDM projects', (USAid, 2007).

Although a methodology has been approved for renewable energy projects such as CSP, (UNFCC 2010), it is unlikely that projects accessing preferential Solar Mission tariffs will meet the CDM additionality requirements. Demonstration of additionality for CDM projects is achieved using the a step-wise approach to demonstrate and assess additionality:

1. Identification of alternatives to the project activity.
2. Investment analysis to determine that the proposed project activity is either:
   a) not the most economically or financially attractive, or
   b) not economically or financially feasible.
3. Barriers analysis - is there at least one barrier preventing the implementation of the proposed project activity without the CDM? and
4. Common practice analysis - if similar activities are observed, are there essential distinctions between the proposed CDM project activity and similar activities that can reasonably be explained?

If a project fails either the barriers analysis step or the common practice analysis step, it is deemed to be non-additional and so not eligible for the CDM.

In essence, the successful Solar Mission projects will bid for a preferential tariff on the basis that the preferential tariff bid is sufficient for them to be financially viable. Thus, the project is likely to fail both the investment analysis test and the barriers analysis test. However, the CDM mechanism remains as one of the enablers that can, potentially be considered for future CSP projects.

5.4 India's coal tax

As of 1 July 2010, India applied a levy on domestically produced and imported coal, at the rate of Rs. 50 (~US $1) per tonne. This money is to be directed into a National Clean Energy Fund that will be used to fund research, innovative projects in clean energy technologies and environmental remedial programs. A levy of Rs. 50 / tonne is equivalent to approximately Rs. 14 / tonne CO_2 which, assuming an emissions intensity of 1 tonne CO_2 / MWh, would add approximately Rs. 14 / MWh to the cost of electricity. While this measure provides a source of funds for clean energy, it is not sufficiently large to effect the fundamentals and thus only has a minimal effect on the viability of renewable power generation. The direction of the funds to clean energy R&D is beneficial but the total amount is a small proportion of annual investments in the local energy sector.

5.5 Solar Mission

The main enabler for photovoltaic and CSP projects is the Jawaharlal Nehru National Solar Mission, (Solar Mission). The backbone of the policy is a target of 20 GW of grid-connected solar (either PV or CSP) to be installed by 2022. In January 2010, the Prime Minister, Manmohan Singh officially launched the Solar Mission (Singh 2010). In his speech, he acknowledged that the target of 20 GW of solar capacity by 2022 was an ambitious goal but indicated it was achievable with reduced costs through technological innovation and economies of scale.

The Solar Mission accelerates deployment through a carefully designed regulatory and incentive framework which includes an appropriately designed preferential tariff cap. A strong focus on innovation and building India's capacity are also key elements.

The Solar Mission is generating interest from all the major international players. This comes at the same time as an upsurge of interest in Australia sparked by the $1.5 billion in funding on offer from the Solar Flagships program that is aiming for 1 GW of solar by 2015 (Australian Government 2010).

The Solar Mission is motivated by national energy security concerns and future greenhouse gas emission reduction targets. The goal of establishing India as a global leader in solar energy recognises the economic benefits of playing a major role in the future of ecologically sustainable development.

In addition to the Prime Minister's speech, the principals and philosophy of the Solar Mission are described in the '*JNNSM Building Solar India*' publication, (Government of India, 2010A) that is supported by a formal resolution by MNRE. This initial statement of policy has been supported by the publication of appropriate guidelines (discussed below) as the program has progressed and this process will no doubt continue over the next decade.

The mission has a three phase approach with the key outcomes outlined in Table 5.1. In addition to main grid-connected applications, off-grid solar electric and solar hot water systems are also targeted.

Application segment	Phase I (2010-13)	Phase 2 (2013-17)	Phase 3 (2017-22)
Off-grid Solar Application (including rural solar light)	200 MW	1,000 MW	2,000 MW
Utility Grid Power, including roof top	1,000 MW	4,000 MW	20,000 MW
Solar collectors (m^2)	7 million	15 million	20 million

Table 5.1: Jawaharlal Nehru National Solar Mission phases.

In the first phase, 1 GW of grid-connected solar is targeted for 2013 with an approximate 50:50 split between CSP and photovoltaic (PV) technologies expected. The trading arm of the National Thermal Power Corporation (NTPC), the NTPC Vidyut Vyapur Nigam Ltd (NVVN) has been given the responsibility for implementing phase 1.

NVVN will offer a 25 year Power Purchase Agreement (PPA) for successful Solar Mission projects at a preferential tariff. This is then to be on sold to State Electricity Regulation Commissions bundled with electricity generated in NTPC coal fired power stations. The State Commissions, are empowered under the 2003 Electricity Act to specify the Renewable Energy Purchase Obligation that they can impose on retailers of electricity in their jurisdiction and this mechanism will be utilised for the Solar Mission generation.

The other areas of Solar Mission are less relevant to CSP but worth mentioning. Use of solar collectors for hot water applications is to be expanded by making them mandatory via building bylaws and the national building code. This is to be supported with initiatives for rating of both manufacturers and product performance and certification, plus soft loans for upgrading local products and manufacturing capability. This segment is not of direct interest to CSP considerations, however there could be synergies as the manufacturing process and skill sets are very similar. Businesses that grow as a result of this aspect of Solar Mission policies could also then be well position to branch into an aspect of component supply for CSP.

The off-grid sector components are likely to be largely met with PV systems. However, feedback suggests that there is a portion of that market with loads large enough to make small-scale CSP systems viable. This could prove to be a very good entry point for Indian companies embarking on CSP system commercialisation activities.

In addition to the specified market segments and the approaches to achieving the targeted capacities, the Solar Mission foreshadows a number of important enabling initiatives. These include:

- Manufacturing capabilities in both PV, CSP and low temperature thermal are to be built with the help of incentive packages, soft loans through IREDA and mandating a level of technology transfer for government and private procurements of foreign technology.
- R&D is to be supported via a proposed Solar Research Council, with implementation of strategic directions delegated to a National Centre of Excellence. Efficiency improvements and energy storage are identified as priorities although funding is anticipated to be technology neutral, a priority will be on building human resources

across the skill chain, with a figure of 1,000 young scientists and engineers suggested for phase I.

- Pilot demonstration projects are suggested that for CSP include:

  ‘1. 50 - 100 MW solar thermal plant with 4 - 6 hours storage (which can meet both morning and evening peak loads and double plant load factor up to 40%).

  2. 100 MW capacity parabolic trough technology based solar thermal plant.

  3. 100 - 150 MW Solar hybrid plant with coal, gas or biomass to address variability and space-constraints.

  4. 20 - 50 MW solar plants with/without storage, based on central receiver technology with molten salt/steam as the working fluid and other emerging technologies.’

Guidelines have been released for the migration of existing proposed projects to the Solar Mission (Government of India, 2010B). It is understood that three CSP projects have now been approved under the migration scheme:

- Acme with an implementation of ESolar tower technology,
- Integra with an Archimede solar trough system using molten salt, and
- Dalmia, using Tessera Dish Stirling.

The guidelines for the selection of the first phase of off-grid Solar Mission projects were released on 16 June 2010, (MNRE, 2010B). The guidelines for the selection of the first phase of grid-connected Solar Mission projects were released on 17 August 2010, (MNRE, 2010C). The grid-connected guidelines establish strict and onerous timeline to final commissioning of power stations. The phase 1 guidelines for grid-connect projects include the following features relevant to CSP:

- A target of 1,000 MW that is 50% PV and 50% CSP. There are no preferred technologies within these general categories.
- There are guidelines for the migration of projects that have applied under previous arrangements. These projects will have precedence in the selection process.
- Projects must connect to substations at 33kV or above. The guidelines for PV and CSP are significantly different.
- CSP projects must be at least 5 MW_e and a maximum of 100 MW_e, a company can propose multiple projects up to the 100 MW_e total.
- Fees / bonds / penalties:
  - Rs 1 lakh non refundable processing fee.
  - Rs 50 lakh / MW bond partly at RfS and partly at PPA signing, this bond will be refunded, when performance is demonstrated.
  - Developers offering a discounted tariff will need to provide a bigger bond.
  - Bond will be forfeited completely if commissioning is more than 2 months late, and partially if it is one month late.
  - If the project is more than 5 months late, then a further penalty of Rs. 1 million/ MW / day will be charged.
  - If the project is more than 36 Months late, the PPA will be cancelled.

- Technical
  - Only new plant and machinery.
  - Must be 30% local content in system (not counting land).
  - Require letter from State Transmission Utility confirming technical feasibility of connectivity and approval from State / local authority for the quantity of water required.
- Qualification criteria for company:
  - Net worth of company to be greater than Rs. 3 Crore / MW to 20 MW and then add Rs. 2 Crore for every MW above.
  - Essentially, the developer must either be a technology provider or have a tie-up with a provider who has either experience in design and engineering of at least 1 MW solar thermal power plant having been in operation for a period of at least one year or obtained financial closure of a solar thermal plant of at least 50% of the proposed capacity based on the proposed technology.
- On offer:
  - 25 year PPA at a preferential rate of Rs. 15.3 / kWh if proposal is shortlisted beyond reverse tariff auction and can achieve financial closure in six months and construction and commissioning in 12 months after that.

The proposed timeline for phase 1 CSP applications and actual dates (where known) are summarised in Table 5.2.

Event	Proposed Date	Actual Date
Notice for invitation of Request for Selection (RfS)	Zero date	17 August 2010
Submission of applications with documents for registration	Zero date + 30 days	24 September 2010
Selection of projects based on RfS received and decision on tariff discounting	Zero date + 75 days	
Tariff discounting process and submission of proposals by short-listed developers	Zero date + 90 days	
Evaluation of tariff discounting proposals	Within 30 days of submission of tariff discounting proposal	Newspaper reports indicating successful CSP projects appeared on 22 November 2010 (Financial Express 2010)
Issue of letter of intent	Within 15 days from evaluation of tariff discounting proposals	NVVN website announced shortlist on 13 December 2010
Power Purchase Agreement signing	Within 30 days from date of issue of letter of intent	tbc
Financial closure of project	180 days from the signing of the PPA	tbc
Commissioning of project	12 months from signing the PPA	tbc

Table 5.2: Timeline for CSP projects in Solar Mission Phase I. Columns 1 and 2 are reproduced from JNNSM guidelines. Column 3 has been added in light of developments to date.

It was reported that the Request for Selection (RfS) stage received 77 applications proposing to build 1,815 MW of CSP plants, thus the reverse auction tariff process was triggered.

On 22 November 2010, The Indian-Commodity website reported that seven CSP proposals had been selected totalling 470 MW with significant tariff discounts of up to Rs. 4.82, (more than 30%).

Bidder Name	Bidder's City	Project Type	Capacity (MW)	Location	State
Lanco Infratech Limited	Hyderabad	thermal	100	Jaisalmer, Nachna, Chinnu	Rajasthan
KVK Energy Ventures Private Limited	Hyderabad	thermal	100	Jaisalmer, Nachana-1, Chinnu	Rajasthan
Megha Engineering and Infrastructures Ltd	Hyderabad	thermal	50	Anantapur, Pamidi, Virannapalle	Andhra Pradesh
Rajasthan Sun Technique Energy Private Limited	Navi Mumbai	thermal	100	Bikaner, Kolayat, Ladkan	Rajasthan
Aurum Renewable Energy Private Limited	Mumbai	thermal	20	Jamnagar, Dwarka, Mojap	Gujarat
Godawari Power and Ispat Limited	Raipur	thermal	50	Jaisalmer, Jaisalmer, Parewar	Rajasthan
Corporate Ispat Alloys Limited	Mumbai	thermal	50	Jaisalmer, Pokhran, Nokh	Rajasthan

Table 5.3: Solar mission phase 1 CSP projects

5.6 State support

There are also state specific market factors in those regions identified as most favourable for CSP systems, such as Gujurat and Rajasthan. The Electricity Act also required SERCs to specify a minimum Renewable Purchase Obligation (RPO) and allowed for preferential renewable tariffs to be established. The RPO for each State varies from a total of 1% to 14%. Some States also include a specific RPO for solar. Details of the RPO specified by each SERC for FY 2010-11 are summarised in table 5.4.

State	Wind %	Solar %	Other%	Total%
Gujarat	4.50	0.25	0.25	5.00
Maharashta		0.25	5.75	6.00
Uttaranchal		0.25	3.75	4.00
Manipur		0.25	1.75	2.00
Mizoram		0.25	4.75	5.00
Jammu & Kashmir				1.00
Uttar Pradesh		0.25	3.75	4.00
Tripura		0.10	0.90	1.00
Jharkhand		0.25	1.75	2.00
Himachal Pradesh				10.10
Orissa				4.50
Assam				1.40 (draft)
Tamil Nadu				14.00
Delhi				1.00
Andra Pradesh				5.00
Karnataka				11.00
West Bengal				10.00
Rajasthan				9.50
Madhya Pradesh				10.00
Punjab				4.00
Haryana				10.00

Table 5.4: FY 2010-11 Renewable Portfolio Obligation specified by State Electricity Regulation Commissions, from MNRE (2010E).

MNRE has established guidelines for the preferential tariffs that should be provided for this. As of September 2008, the operating state based tariffs specifically for grid connected solar were as shown in Table 5.5.

State	PV Projects Tariff Rs. / kWh	Solar Thermal Projects Tariff Rs. / kWh	Comments
Rajasthan	15.32	12.58	Levelised for 25 years For PV to be commenced by 31 March 2012 and Solar Thermal by 31 March 2013. To be reduced by Rs. 1.59 / kWh if Accelerated Depreciation (AD) is availed.
Haryana	15.16	Not declared	For plants commissioned by 31 March 2010
Tamil Nadu	18.1	15.2	Levelised Tariff with AD Benefit is Rs. 17.10 for PV and Rs. 14.38 for Solar Thermal for the same periods.
Gujarat	15 for the first 12 years and 5 from year 13 to 25	11 for the first 12 years and 4 from year 13 to 25	For solar projects commissioned on or before 31 Dec 2011
West Bengal	12.5	Not declared	Till year 2012
Punjab	7 (Base Year 2005-06) with 5% annual escalation Up till 2011-12	Not declared	Not Updated after 2006
Bihar	CERC	Tariff	
Karnataka	14.5	11.35	For plants established before 31 March 2013
Andhra Pradesh	17.91 for financial years 2010 to 2012	15.31 for financial years 2010 to 2013	Levelised Tariff with AD Benefit is Rs. 14.95 for PV and Rs. 12.85 for Solar Thermal for the same periods.
Madhya Pradesh	15.35 Plant Capacity > 2 MW	11.26 with a discounting factor of 10.01%	Reduced by Rs. 0.97 per unit for Solar Thermal and Rs. 1.41 per unit for PV in case of AD
Maharashtra	CERC	Tariff	
Jharkhand	17.96	13.12	Rs. 14.98 for PV and Rs. 11.02 for Solar Thermal in case of AD
UP	15	13	For 20 years, plants commissioned before 31 Dec 2011
Uttrakhand	CERC	Tariff	
J&K	CERC	Tariff	
Assam	CERC	Tariff	
Orissa	5 for the first 12 years and 7.5 from year 13 to 25	Not declared	For solar PV projects which could be established in the State by March 2010
Chattisgarh	15.84	13.26	Levelised (constant) for a period of 10 years, i.e. up to 31 August, 2018 Additional Rs. 3.84 for PV and Rs. 3.26 for Solar Thermal to be given by CSEB/Distribution Licensee for the same period
Delhi	CERC	Tariff	
Kerala	CERC	Tariff	
Bihar	CERC	Tariff	

Table 5.5: Indian State Feed in Tariff's for solar power.

Since then, Gujarat (Government of Gujarat, 2009) has released a Solar Power Policy that specifies a tariff of Rs. 10 / kWh for the first 12 years and Rs. 3 / kWh for years 13 to 15, for CSP projects built before 31 December 2012. The Government of Rajasthan has also released a draft Solar Policy (Government of Rajasthan, 2010), which is yet to be finalised, but foreshadows a tariff based bidding process similar to the Solar Mission.

With the capped tariff of Rs. 15.3 / kWh under phase 1 of the Solar Mission, the state based tariffs appear less attractive, however with the revelation that the selected projects have offered tariff discounts of up to Rs. 4 / kWh, the Rajasthan state based tariff in particular is a very useful option for those developers who were not selected and it is understood that some are indeed considering this option.

In addition to state-based PPA's, a major state based enabling initiative is the concept of the Solar Park. The Clinton Climate Initiative has been working with the Governments of Rajasthan and Gujurat to set up Solar Parks. Rajasthan has established two (Government of Rajasthan, 2010). Land has been set aside for CSP projects with approvals in place. Grid-connection is to be provided. Initial land allocations to potential developers have been made. For the Solar Park in the West of Rajasthan (near Jaisalmer) water allocations from the nearby Indira Gandhi National Canal are available.

5.7 Industry capability

A large enabler is the existence of many competent, large-scale commercial operations in related fields and among these are companies that have already signalled involvement in future CSP projects.

The scope of this study does not extend to a thorough survey of all potential companies. The notes below give an indication via some examples for the benefit of non-Indian readers.

a) Steel manufacture

- Tata Steel is one of the world's largest steel manufacturing companies, with several other very large steel manufacturers in India. Almost all types of steel (sheet, section, stainless, various quantities of carbon and other types) are produced in large quantities in India.

b) Power components

- According to the India Electrical and Electronics Manufacturers Association,

> 'The Switchgear and Control gear industry in India is a fully developed and mature industry, producing and supplying a wide variety of switchgear and control gear items needed by the industrial and power sector. This industry sector in fact manufactures the entire voltage range from 240V to 800kV."
>
> There is a strong base of about 150 Transformer Companies in India, with an overall production over 90,000 MVA per annum. Besides meeting the domestic requirement, India is exporting transformers to over 50 countries covering USA, Europe, South Africa, Cyprus, Syria, Iraq and other Middle East and Far East countries all over the world. India is self-reliant in respect of the resources for prime materials and testing facilities. Manufacturing facility for CRGO, winding conductors, bushings up to 420kV class etc. are well established.', (www.ieema.org, accessed 15th Oct 2010).

c) Glass

- Flat plate and tempered glass – there are many major glass producers throughout India. Glass production is generally considered a mature industry though mostly catering to the domestic market. Not all factories produce glass to international standards, however most of the major manufacturers do.

- Saint Gobain have a large factory near Chenai.
- Low iron glass – according to solarthermalworld.org and PV-magazine.com, there is only one low iron glass factory in India. Gujarat Borosil Ltd own what is (as at 28 July 2010) the only Indian factory manufacturing low iron textured glass, from sand to finished product. The factory is located in Bharuch city, Gujarat, and was set up specifically to supply glass to the PV industry. The factory's production capacity is 13,000m^2 per day, for any glass thickness from 2 to 10mm. Their glass is tempered to European Standard EN12150.

d) Mirrors

- Guardian Industries is an international mirror manufacturer with a fully automated production line in Gujarat. Other commercial scale manufacturers are available.
- There are a large number of mirror producers, however many are small handicrafts or homewares industries. There are also many auto mirror manufacturers. Some glass manufacturers are also likely to produce mirrors.
- Custom mirrors such as those required for dish concentrators may be difficult to source from within India as there appear to be very few large-scale commercial production facilities outside the auto mirror industry.

e) Control systems

- Major international players in the controls system industry such as Honeywell Automation have production facilities in India. Production of control systems for coal-fired power plants in India is well established.

f) Civil construction

- The construction industry has experienced massive growth in the past five years and there have been capacity shortages and problems with meeting deadlines and budgets. There are approximately 200 corporate construction firms and 120,000 Class A contractors registered with government construction bodies.

g) Engineering, Procurement and Construction (EPC) services

- EPC services: companies mentioned for large projects include BGR, Essar, Gammon, GMR, GVk, Jaypee, Lanco, L&T and NTP.

h) Commercial endeavours into CSP - some snapshots not a thorough survey:

- According to Belen Gallego, founder of CSP Today:

  > 'Serious and dedicated local developers like Cargo Motors, Coramandal, Enam Infrstructure, Electrotherm, Entegra, Lanco Solar, SunBorne, Suryachakra, Welspun and Acme', (Gallego, 2010).

- Cargo Motors are based in Gujarat and include a large group of companies who started out in car dealership and now provide services in logistics, construction, hospitality and they recently established a Cargo Power entity. This part of the business will focus on green power opportunities and, according to Gallego, will be entering the CSP field. The company appears to be financially sound with a broad number of sectors, its own construction and logistics arms, should be well placed to develop CSP plants.
- Enam Infrastructure is one of India's largest finanacial service providers and are one of the largest underwriters in India. Enam are investigating the opportunities for investing in new and renewable energy projects in India.

- Electrotherm is a very large Indian company with steel manufacturing and equipment, power, and electric vehicle divisions. Electrotherm renewables are already involved in the solar water heater market and process heat reclaim. They have declared their intention to build a 50 MW CSP plant in Gujarat, to be completed by 2014.
- Entegra are an energy company that developed large-scale hydro plants and also trades in the oil, coal and gas markets. They also provide EPC services.
- Lanco Solar was set up as a subsidiary of Lanco, to develop solar PV and solar thermal power stations up to 200 MW in Gujarat.
- SunBorne Energy is a start-up company aiming to build solar thermal plant in Gujarat.
- Suryachakra Power Corporation's activities include power plant development in both fossil fuel and renewable energy, including solar thermal proposals.
- Welspun are another very large conglomerate that started out in textiles and now produces steel and concrete products, iron, piping and renewable energy products.
- Acme have acquired the exclusive right to represent ESolar's technology in India. It is developing its own utility-scale, solar thermal projects and is working with other companies that plan to build solar thermal power plants in India using ESolar technology. SustainableBusiness has reported that Acme made a $30 million equity investment in ESolar, (SustainableBusiness, 2009).

5.8 Summary

The overall enabling environment for CSP in India is very good. The Solar Mission is a world leading policy initiative. State based RPO's and Feed-In Tariffs are emerging to also assist in building renewable energy industries. The overall environment is also assisted by a small tax on coal and the Clean Development Mechanism. The industry base to move into CSP covers most of the key aspects of the technologies.

In November 2009, Ernst & Young rated the attractiveness of various countries for renewable energy investments. Table 5.6 summarises their analysis.

Rank	Country	Concentrated solar power index
1	US[1]	75
2	Spain	71
3	Italy	60
4	India	58
5	Australia	46
6	Greece	43
7	China	36
8	Brazil	28
8	Germany	28
8	Turkey	28

Table 5.6: Ranking of international investment attractiveness in CSP, from (Ernst & Young, 2009). *Note* [1]*, "this indicates US states with RPS and favourable energy regimes".*

It is interesting to note that India was ranked fourth in the world for CSP investment attractiveness and scored well above the fifth placed country, Australia.

6 Barriers to CSP Deployment

There are a range of barriers to the widespread deployment of CSP in electricity markets around the world. For India, some of these barriers have been addressed through policy initiatives such as the Solar Mission. This chapter examines the barriers, analyses how they are being addressed and discusses further options that may be considered.

Information has been obtained from a range of sources including:

- Meetings with stakeholders in India and Australia, including government, NGOs and Business.
- Presentations by stakeholders at conferences and workshops in India and Australia.
- Previously published reports that identify barriers and actions for renewable energy globally, CSP globally, renewable energy in India and CSP in India or Australia.

Barriers can be classified in numerous ways and can be broken down to specific detail or described in high level terms. For the purposes of this report, the following classifications have been chosen for barriers to CSP deployment both globally and specifically in India or Australia.

Cost

A major barrier for CSP is its current high initial capital cost that increases power generation costs compared to fossil fuels where the full pollution costs are not reflected in energy pricing. Investing in a solar collector field is effectively purchasing 25 years worth of fuel upfront. Fossil fuel plants can secure and pay for their fuel supplies on the spot market, long term contracts with monthly payments or by owning a coal mine.

Financing

This is a significant barrier as financiers are unfamiliar with CSP investments, risk averse and often focus on the short term. To achieve financial closure, the revenue equation must provide investors with an acceptable IRR with all risks appropriately mitigated and allocated. Other barriers also contribute to the risk profile that increases the challenge to securing financing.

Government policy

At present, some level of government support is required to allow CSP projects to earn sufficient revenue to be able to reward equity investors and pay back debt. Other Government policy settings are also very important, such as industry development policies, Intellectual Property (IP) law, general law and country stability. The risk of policies changing can also be a barrier for renewable energy developers.

Approvals and land

Without suitable sites and approvals, no project can proceed. There is great scope for facilitation and streamlining.

Grid and services connection

Large-scale CSP plants need a high voltage grid-connection. Gas, water, sewerage, roads and fencing must also be considered to varying degrees and according to the technology type being implemented.

Technology shortcomings

The ideal CSP technology has a low initial capital cost and achieves high performance, high reliability and minimal O&M costs. Technology shortcomings for any given technology / technology proponent include those inherent to the technology and those that emerge with the specific project.

Solar data

Reliable long term DNI and weather data collected at high frequency, is needed to predict system output accurately, mainly as an input to investment decisions. Very few areas of the sunbelt regions of the planet have adequate data of sufficient quality.

Manufacturing scale-up

For CSP to achieve significant penetration in a given market, millions of square meters of solar concentrator systems of various types along with all the supporting plant will need to be manufactured and maintained. Facilities and the skilled human resources to do this are required.

Matching business cultures

CSP like other renewable technologies, is rapidly becoming a global industry. The issue of doing business in a (business) culture other than the place of origin will be encountered by all major players.

The various reports consulted are briefly reviewed in the following section. Following this, each of the above categories of barriers are further analysed.

6.1 Previous identification of barriers and suggested actions

Many of the barriers and possible solutions to the implementation of CSP technology in India are common globally.

The *'Barriers to Commercialisation of CSP Plants'* report (Lotker, 1991), discusses in depth the lessons that can be learnt from the Luz experience that established the well-known SEGs plants in California. In the 1970's, the US Government established measures such as tax credits and RPO rules that incentivised a plethora of initiatives in renewable energy. In the early 1990's, the government initiatives such as tax credits were progressively dropped and ultimately Luz went out of business. The overall lessons are the desirability of avoiding boom-bust responses to policy and if a tightening of conditions is planned, to do it in a way that allows companies to plan and survive under a new paradigm.

The '*CSP Global Outlook*' report (Richter et al, 2009) ends with a discussion of recommended policy measures, which emphasise the need to establish a reliable revenue stream through a guaranteed Feed-In Tariff or other mechanism. Importantly, the report also notes the high value of a loan guarantee from government, an approach that has been implemented in the US. This policy option is worth further consideration in the Indian and Australian context.

The Electric Power Research Institute's technical update (EPRI, 2009), gives a comparison of costs of alternative large-scale centralised electricity generation technologies. EPRI's work has been criticised as being overly pessimistic in its projections for solar technologies. It does however have a useful discussion of the many barriers that can arise from a lack of appreciation of the technical difficulties in building collector fields that are required to cost-effectively, track and operate for more than 20 years in a harsh environment.

The '*Technology Roadmap Concentrating Solar Power*' report (IEA, 2009), presents a range of recommendations to governments globally that aim to address the financial and technical barriers to expansion of the industry. These are referenced further in subsequent sections of this report.

In Australia, the context and priorities for CSP have been examined with a 2008 '*High Temperature Solar Thermal Roadmap*' commissioned on behalf of the Council of Australian Governments, (Wyld Group, 2008). A range of barriers were indentified for the Australian context:

- Electricity market arrangements – that were suboptimal or favoured the characteristics of coal-fired plant.
- Lack or resource information – both DNI and also of other renewable resources.
- Limited understanding of business opportunities – investor understanding of claims and potential for the 'new' CSP technologies.
- Rights to the resources – alternatively interpreted as site availability.
- Network pricing and connection issues - rules that are based on the dominant paradigm that unfairly penalise some features of CSP operation and fail to reward some of the benefits.

These barriers remain in Australia today and are also experienced in India and other countries.

There have been several reports that examine barriers to renewable energy technologies in general in India.

Reddy examined the barriers to the diffusion of renewable energy technologies with a case study of solar hot water and wind energy in Maharrashta, (Reddy, 2001). The study presents the results of surveys of Indian domestic and commercial consumers, policy makers / experts and wind energy developers. It is the findings in relation to the last two categories of respondents that offer some insights of relevance to the establishment of CSP. The top seven barriers identified by each group are presented. These are referenced further in subsequent sections of this report.

An '*Indian Country Report*', (USAid, 2007) examined possible clean energy solutions for India and identified a number of concerns relating to financial sustainability and confusion in government policies.

The '*Identifying optimal legal frameworks for Renewable Energy in India*' report (Baker & Mckenzie, 2008) presents an analysis that pre-dates many of the current policies. It discusses a range of issues / barriers to renewable energy which would all apply to CSP, in particular it identifies onerous approvals processes, issues with the grid, intellectual property protection and the pros and cons of the Clean Development Mechanism.

The '*Pursuing Clean Energy Business in India*' report (Cleantech AustralAsia, 2008) analysed the results of a survey of Indian, Australian and global relevant stakeholders, seeking feedback on a series of identified barriers and possible solutions.

Most recently the '*Indian Renewable Energy Status Report*', (Arora et al, 2010) prepared to set the scene for DIREC, notes that there is no established capability in India for CSP manufacture and there is a gap in Engineering, Procurement and Construction capability for setting up and running CSP plants. In examining the barriers to technology transfer for renewable energy technologies for India, they identify:

- product suitability to Indian conditions,
- difficulty in accessing market information for foreign companies,
- limitations in infrastructure availability, and
- difficulty of financing.

A previous notable attempt to launch CSP in India was centred around a proposal to build a 35 MW trough plant at Mathania with partial funding from the World Bank's GEF. The status report notes that:

> 'the project was postponed indefinitely because no qualified contractors were able to submit a bid'.

A detailed analysis of this and the other GEF funded CSP projects around the world is given in the report, '*Assessment of the World Bank / GEF Strategy for the Market Development of Concentrating Solar Thermal Power*', (Global Research Alliance, 2005).

6.2 Cost

Chapter 3 presented some information on the present global situation regarding initial capital and energy costs for CSP plants. They are high but widely expected to reduce as the installed capacity grows. Indeed, if it were not widely accepted that this cost would reduce, there would be no point pursuing the technology without high carbon emission permit pricing.

The major barrier for CSP generation is its higher current energy cost compared to fossil fuel generation. This barrier is caused by the significantly higher initial capital costs of plant plus finance for CSP generation and the lack of pricing on externalities for fossil fuel generation. Typically, lifecycle financial analysis using discounted cash flows underestimate future fuel price risks and do not account for the environmental and health impacts of fossil fuel generation.

The cost barrier is a '*chicken and egg*' problem - cost will come down if systems are built and systems will be built if costs come down. The IEA 2010 roadmap identifies the biggest barrier to CSP is getting systems deployed so the technology can move down the cost curve. It also discusses the benefits of a Loan Guarantee program, such as available in the US as a key approach to dealing with the issue.

The 2009 EPRI report points out that there is an extended period when a new technology is entering the commercial arena, where cost estimates are very uncertain and tend to be underestimated by enthusiastic proponents. These estimates are then revised upwards as the realities of early project construction become apparent. Only after these initial developments, does the decline in costs start to be seen for future projects. The report notes in regard to new technologies in general:

> 'Large differences between original cost estimates and actual installed costs have been common. Some of these differences have resulted from the type of estimate given, such as a goal type of estimate, without explicit consideration of the likelihood of achievement. Quantifying uncertainty should be an explicit part of developing cost estimates to reduce such misunderstandings.'

Figure 6.1 illustrates the concept of technology implementation costs varying with the maturity of the technology and the experience of local providers.

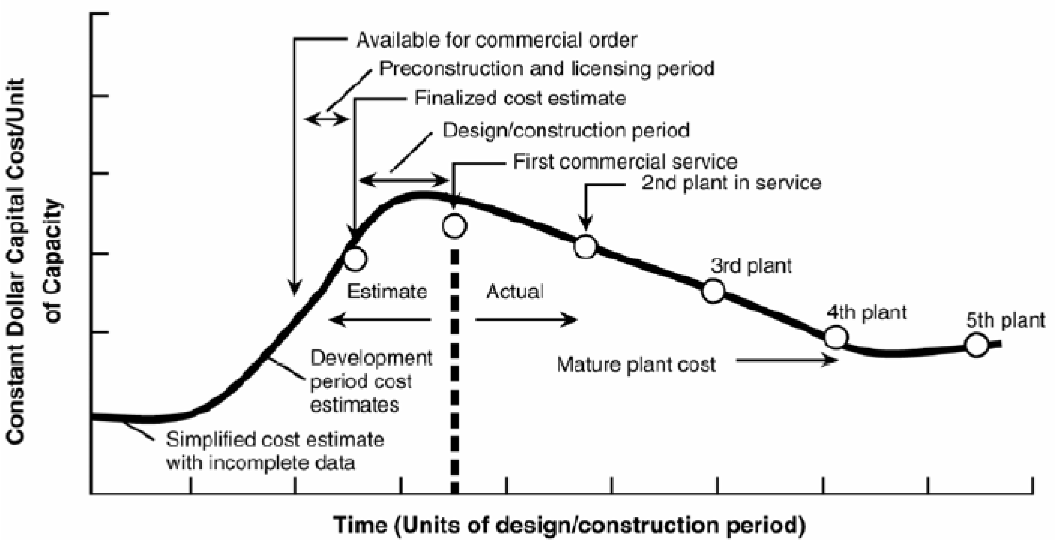


Figure 6.1: Typical cost variations for commercialising new power technologies, (EPRI, 2009)

Australia's recent Energy Resource Assessment (DRET et al, 2010), described the process in a similar way and attempted to locate particular renewable energy technologies on this time evolution as shown in Figure 6.2.

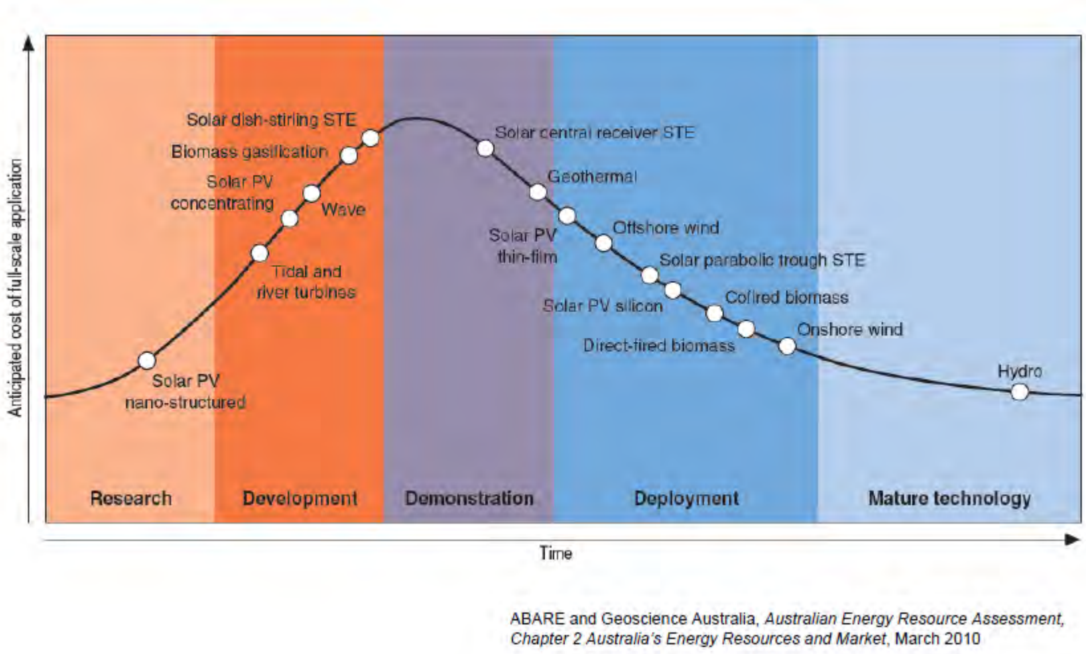


Figure 6.2: Typical cost variations for commercialising new renewable technologies, (DRET et al, 2010)

It can be argued that whilst the CSP industry is global and the different technology types can learn from each other's experience, every technology developer of every technology type in each country must face a separate version of the same type of experience curve. What this means in practice is that the CSP industry sees a pattern of the most encouraging cost estimates coming from many of the most inexperienced companies with the newest technology options. This is a trend rather than a rule and certainly does not preclude the idea that some of those technologies may be clear cost winners in the long run.

High current costs are an immediate barrier. The only sure way of addressing this is for countries to adopt policy settings that lead to the necessary deployment so that progress is made down the cost curve. Ideally, this would be done most equitably and cost efficiently, with all sunbelt countries working together to facilitate action simultaneously. India, with its exemplary and ambitious Solar Mission has indicated that it intends taking a leading role. Australia, with its Solar Flagships program has signalled an important start in the right direction, but has yet to establish policy settings that will see further commercially driven plants installed after the Solar Flagships funding is committed.

The many billions of dollars required to achieve the required deployment can be intimidating for policy makers. It is often tempting for governments to make pronouncements that more R&D funding is needed to achieve a step-change in the economics of the technology. Referring back to the Sargent & Lundy breakdown of cost reduction opportunities in Figure 2.6. Technical improvement is identified as being responsible for nearly a quarter of the potential cost reductions. So on the face of it, investing in R&D is logical, however this search for a '*silver-bullet*' via R&D can be misguided. Implicit in the Sargent & Lundy curves is the idea that a large volume of evolutionary R&D through building goes together with break-through laboratory R&D. All R&D has lengthy timelines and needs the parallel growth in industry activity to learn from doing and try out new approaches with actual projects and power plants. Further, the R&D budgets required for significant progress are a proportion of the total deployment investment, which can only come from large industry participants with significant positive cash-flows. Ad-hoc announcements of R&D programs with limited funding are a well meaning start, but no substitution for policy settings that result in significant deployment.

The question remains as to what extent current costs remain a barrier to CSP deployment in India. In December 2010, the shortlist of CSP companies given an allocation under phase 1 of Solar Mission was announced. This follows on from the Request for Selection phase which was considerably oversubscribed, with 77 CSP bids totalling 1,815 MW_e of capacity competing for the 500 MW_e of allocation available.

Prior to the closing of phase 1 applications, there was much commentary, from potential developers, suggesting that the Solar Mission CSP tariff was not sufficient. The fact that the Request for Selection was oversubscribed and that the shortlist of developers offered discounts on the tariff ranging from around Rs. 3 to 5 off the Rs. 15.3 / kWh cap, would suggest that some developers believe that cost is not an insurmountable barrier. However, until these projects actually achieve financial closure and commence construction, there remains the major concern that the discounts have been offered to speculatively secure a place in a competitive process and that the projects may turn out to not be viable. Whether a company is prepared to forego profit on a first plant to secure entry into a potential future market is yet to be seen.

Kulichenko (2010) presenting on behalf of the World Bank at DIREC reported on some fundamental analysis of CSP costs versus the Solar Mission phase 1 tariff cap. The analysis started with what are considered to be realistic financial parameters for the Indian situation as shown in Table 6.1.

Regulatory and Financial Assumptions for assessment of CSP economics in India used by World Bank			
Analysis Period	25 years	Loan Term	12 years
Inflation Rate	5.5%	Loan Rate	11.75%
Real Discount Rate	15%	Debt Fraction	70%
Minimum Alternative Tax	18.5%	ROE	19%
Property Tax	0%	Min required IRR	15%
VAT+ Excise Duties	5% on 100% of Direct Costs	Min required DSCR	1.5
Depreciation Schedule	7% first 10 years | 1.33% afterwards	EX Rs/US$	45.0 Rs/$

Table 6.1: Assumptions on Indian financial and market parameters used by Kulichenko (2010).

On this basis it was concluded that with either tower or trough technology and either wet or dry cooling, projects would not be viable even under the maximum allowed tariff. If this is the case, then cost remains a large barrier to CSP in India. On a positive note, a range of financial and regulatory incentives were analysed and it was concluded that all measures taken together were sufficient to make projects viable. Interestingly, allowing energy storage also helped profitability considerably.

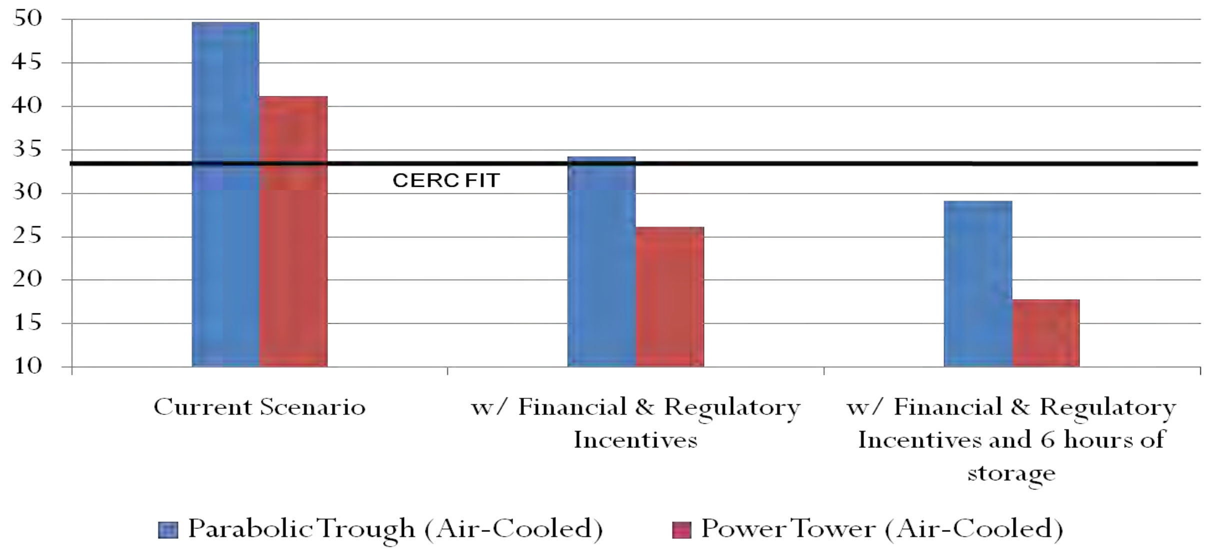


Figure 6.2: Cost (US $ / MWh) under a range of scenarios, (Kulichenko, 2010)

6.3 Financing

Improvements in CSP technologies are limited without major installations occurring over many years. Each of these projects must be successfully financed. This in a sense is the biggest barrier of all. The high capital costs of CSP technologies mean that a power station of 50 MWe requires an investment of more than US $200m. To achieve financial closure, the revenue equation must provide the investors with an acceptable IRR. All the other barriers contribute to the risk profile of the project and may be showstoppers or may lead to a risk premium on the rate of return expected. Kistner and Price (1999) review the various models for project financing that remain relevant today.

Despite the 2008 Global Financial Crisis, the indications are that there are large amounts of capital available globally, as long as the risk and returns are acceptable. Cleantech AustralAsia produced the Figure 6.3 provides a summary of global capital investment in Clean Energy in 2004, 2005 and 2006.

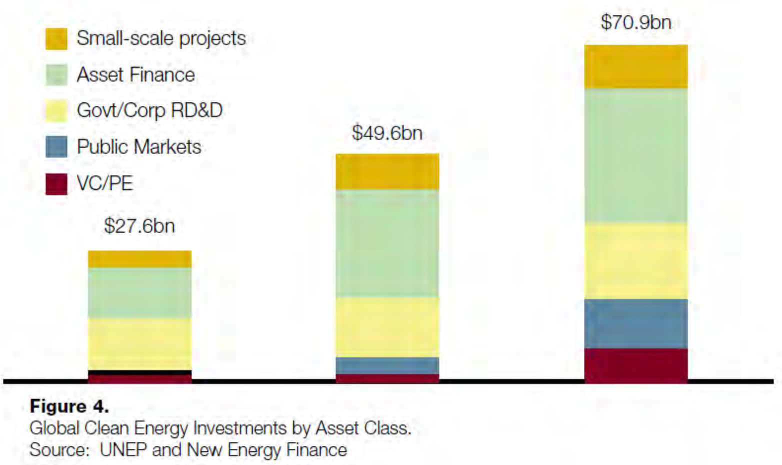


Figure 6.3: Global investments in clean energy 2004 to 2006, (Cleantech AustralAsia, 2008)

The huge growth over the period 2004 to 2006 is indicative of the establishment of favourable investment conditions in clean energy in a number of countries. The growth in investment simply represents a small shift in allocation of global investments in general. If the same data is broken down by geographical region of investment, the results are:

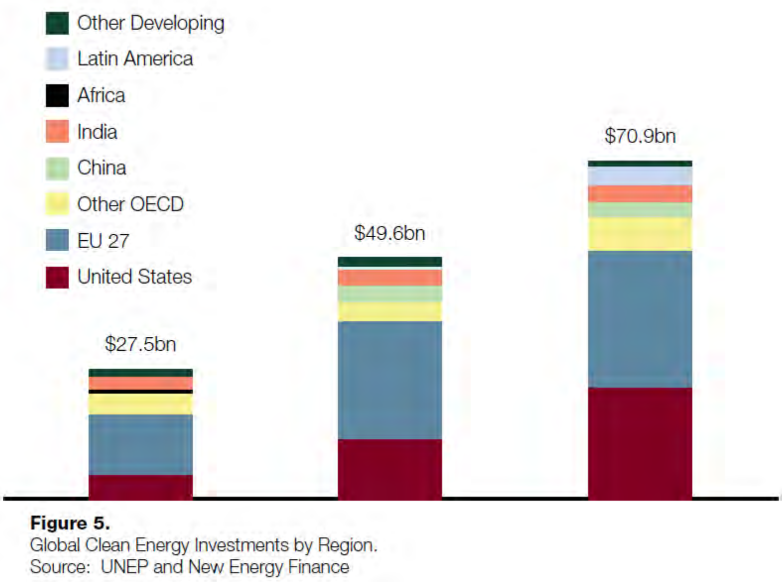


Figure 6.4: Global investments in clean energy be region, 2004 to 2006, (Cleantech AustralAsia, 2008)

Figure 6.4 indicates that the EU and the USA benefited from strong growth in clean energy investments, while India's clean energy investment growth has been relatively static. Over this timeframe, both the EU and USA (via various individual states) have had strong renewable energy support initiatives. They also benefit from low country-risk assessments by investors. India's large-scale renewable energy support initiatives are just beginning to take effect. If the other factors needed to make India an attractive investment proposition are in place, it should be feasible to attract investment and see the levels of investment growth that the EU and USA had in the period 2004 to 2006.

Cleantech AustralAsia's (2008) report includes in their ten identified barriers for clean energy in India, several that relate to financing, which are worth reproducing here:

> '5. There is a lack of early stage debt and equity financing for innovative RE companies seeking to commercialise their technology.
>
> 6. Small and medium RE project developers find it difficult to obtain capital from financial institutions at affordable rates.
>
> 7. A lack of financiers experienced in dealing with the risk profile of RE projects affects the successful financing of new projects.
>
> 8. There is a lack of RE industry information (such as successful case studies and investment grade data) avail able to investors, financiers, developers and policy makers.'

For CSP in India, the current emphasis is on establishing utility scale power systems based on existing (and by implication, imported) technology. Thus it is barriers 7 and 8 that are of most immediate relevance. Barriers 5 and 6 are however important given the goal of developing local CSP industries, skills and experience.

Included in Cleantech AustalAsia's options for overcoming the barriers were several suggestions relevant to financing:

> '2. Develop more innovative financial products and financing mechanisms (such as low interest loans for start-up companies and small-scale RE projects, RE project risk insurance, RE project bonds, RE mezzanine financing etc).
>
> 3. Establish an early stage RE fund to fill the funding gap between innovation and commercialisation.
>
> 6. Run RE investor workshops/meetings to connect RE investors and project developers/entrepreneurs.
>
> 7. Establish a RE incubator program and more international R&D collaborative models to fast track commercialisation of RE technologies.
>
> 8. Undertake targeted RE business missions between APP partner nations.
>
> 10. Develop a best practice guide and template for project developers/sponsors applying for formal financing.'

These are all relevant and appropriate for CSP. However, they are more directed to small / early stage local initiatives than immediate large-scale projects. These suggestions are certainly worth pursuing to help smaller scale local initiatives. Indeed many are being addressed commendably under the enabling aspects of the Solar Mission and other MNRE initiatives.

Cleantech AustralAsia categorised the possible sources of finance for clean energy as:

- R&D financing - including government grants and researchers personal capital.
- Micro Venture Capital - suitable for small start-ups, Micro Venture Capital often has a strong social agenda.
- Venture Capital - high rate of return expected with clear exit strategy, funds commercial initiatives in the range US $1m - $10m.
- Private Equity - global funds from Institutions and individuals taking equity, typically more than US $10m in commercial operations.
- Project Finance - debt or equity investments from banks or institutions against the projected revenue streams of specific projects.
- Corporate Finance - large corporations acquiring or establishing divisions with investments of more than US $10m.

All of these sources of financing will be relevant to India's future involvement with CSP technologies.

In a major relevant federal government initiative, the Indian Renewable Energy Development Agency (IREDA) was established in 1987 to operate a revolving fund for development and deployment of new and renewable sources of energy. IREDA provides financial support to specific projects and schemes for generating energy through new and renewable sources and conserving energy through energy efficiency. It is administered through the MNRE.

USAid (2007) identifies a list of major international donor / concessional finance agencies which are already active in clean energy in India and hence can potentially contribute to CSP industry development. These include:

- 'IFC South Asia - has a US $1.6 billion lending portfolio covering India, Sri Lanka, the Maldives, Bhutan,and Nepal, One-third in infrastructure and agribusiness.
- The Asian Development Bank - is financing several clean energy-related projects in India, including the US $250 million Kerala Sustainable Urban Development project.
- USAID India - has sponsored India-US cooperation on energy development since the 1980s.
- The World Bank - has a large project focused on improving EE in coal-fired power generation through rehabilitation (US $45 million GEF, US $157 million IBRD). The Second Renewable Energy Project is still underway, supporting both RE and EE. The Project provides a financial intermediation loan of US $200 million to IREDA, which will be lent to private companies to finance numerous small renewable energy projects.
- Japan Bank for International Cooperation - projects include Phase 2 of the Delhi Mass Rapid Transport System (DMRTS), two new large supercritical coal power plants, and a pumped storage scheme.'

The Clean Development Mechanism is a potential enabler for renewable energy and CSP particularly in India. The rules and methodologies to be followed however are complex particularly regarding the 'additionality' requirement. USAid noted:

> 'The entry into force of the Kyoto Protocol in February 2005 gave a boost to CDM activities in India. Out of the 489 projects registered with the CDM Executive Board as of January 2007, 155 belong to India and have the potential for 109 million certified emission reductions (CERs) by 2012. Wind and biomass energy are the main sectors in the CDM projects'.

Since then these numbers have grown fourfold both in total and in the number in India. As yet there are no CSP projects benefitting from the CDM mechanism, however the potential clearly exists.

The feasibility study for a CSP plant at Anta (DLR & Evonik, 2009), stated that:

> 'CDM revenue is one of the prime considerations for the project. It is likely to help overcoming the various barriers related to the project & ameliorate the Internal Rate of Return.'

However, this was before the Solar Mission details were announced. The issue for India would appear to be not one of capital or financial organisational availability, but rather whether the conditions are right to achieve financial closure on projects. Looking at the track record of the global industry, only approximately a third of the projects that have been announced have actually achieved financial closure and construction.

Discussions with stakeholders suggest that the Internal Rate of Return expected by investors before committing to a project in India is considerably higher than it is in other countries. It would appear that investors perceive that there is a higher risk profile for projects in India. In addition, the rate of growth in every industry sector is high, so there are competing opportunities, across a range of sectors seeking investment capital.

The revenue side of the equation for CSP projects largely depends on the tariff that can be secured via a Power Purchase Agreement. Despite concerns with the PPA on offer (Financial Express, 2010), the Solar Mission is still a large commitment which will assist proponents with the difficult task of achieving financial closure. The significant discounts offered on the phase 1 tariffs are likely to increase doubts about the viability of the proposed projects amongst many potential investors.

The '*Indian Renewable Energy Status*' report (Arora et al, 2010) notes that:

> 'Given the long-term energy deficit and the growth trajectory of the Indian economy, the Indian investment community has responded positively. However, international investors are still hesitant. The largest barrier to more foreign private investment in the energy market is the energy price itself. In many customer sections and regions, they are too low to generate stable and attractive returns. Despite being an impractical drain on resources, the government has so far failed to adjust prices. The key reason is that cheap or free electricity is an important political token in a country where the majority of the population still lives on a very low income.'

On a cautionary note, it is possible that policy settings can make projects too attractive. USAid (2007) identified a number of concerns relating to the design and financial sustainability of wind energy support policies.

> 'There is some concern about the sustainability and the fundamental economics of the RE investment boom, as some marginal projects may be speculative given the generous fiscal policies provided to renewable energy (e.g., accelerated depreciation, production tax credits, and guaranteed returns). The wind energy boom is especially worrisome, as India actually has a rather poor wind regime. The result is that the machines installed have poor capacity factors, eventually requiring taxpayers to make up the difference via a guaranteed return.'

Clearly it is also important to avoid policies that lead to the construction of systems that are economically or technically unsound. Such activities ultimately harm the growth of the industry overall.

The '*CSP Global Outlook*' report, (Richter et al, 2009) provides recommended policy measures, which emphasise the need to establish a reliable revenue stream through a guaranteed Feed-In Tariff or other mechanism, but importantly also notes the high value of a loan guarantee approach as implemented in the US. A government loan guarantee removes the risk of default for the provider of debt finance. This removal of risk, allows proponents to negotiate significantly lower interest rates for their debt which improves the competitiveness of the project.

The US loan guarantee scheme has another benefit, a loan guarantee is not offered unless the project proponents and the proposal successfully pass an onerous assessment process. This minimises the chance of taxpayers actually having to pay out on the guarantee. It has the added benefit of signalling to the financial market that the project is investor ready. As at November 2010, Brightsource Energy's 400 MW_e Ivanpah Distributed Power Tower project has been the only CSP recipient of a US loan guarantee.

Developments and outcomes from phase 1 of the Solar Mission will, no doubt, guide future policy deliberations. If all the successful bidders take their proposals through to a fully commissioned power station, then clearly the policy settings are satisfactory. If, as many expect, a large number fail to reach financial closure, then a re-assessment of the process for selecting successful projects may be needed. In either case, a loan guarantee scheme is a policy initiative worth consideration in India and Australia also.

6.4 Government policy

Given that fossil fuel alternatives are still cheaper than CSP solutions, particularly if environmental externalities are not fully costed, progress with CSP will be dependent on government policy settings. At the most basic level, policy is needed to allow systems to earn revenue for energy produced sufficient to achieve financial closure on reasonable projects as has been discussed above. Other Government policy settings are also very important - industry development policies, Intellectual Property (IP) law, general law and country stability. Government policy also has a key role to play in addressing all of the other barrier types identified in this Chapter.

Cleantech AustralAsia's (2008) report, includes in their 10 identified barriers, three that relate directly to government policy settings:

'1. There is a need for clear consistent long-term government RE policies to guarantee investment certainty and RE project viability.

2. Subsidies for conventional fuel sources (such as coal) cause price distortions and disadvantages for RE technologies.

3. The legal/regulatory environment is weak or unclear creating uncertainty for RE investors and developers.'

Included in their list of solutions they offer:

'1. Develop a best practice renewable energy policy guide, including a catalogue of successful case studies for APP partner countries.'

The Government of Western Australia has published a '*Renewable Energy Handbook*' (Government of WA 2010) which provides a good example of a guide for the renewable energy industry, investors and other stakeholders.

Reddy (2001) reports the results from a policy maker / experts stakeholder group, which identified barriers for wind generation, these included:

- problems in land acquisition,
- lack of infrastructure,
- changes in government policies, and
- problems in getting clearances.

It is clear that these are likely to be significant barriers for CSP, various aspects of the Solar Mission and State Government initiatives aim to address them to varying degrees. They are discussed further in section 6.5 below.

USAid (2007) examined clean energy for India and identified a number of concerns relating to government policies.

> 'There is considerable confusion at the State level regarding implementation of the Electricity Act requirement for a RE portfolio standard (REPS) to be put in place by each SERC. In some states the REPS is higher, in other states there are carve-outs for specific types of RE, and in most states there are price differentials in the power purchase tariffs that each distribution licensee must follow when meeting their REPS. All of this leads to confusion and sometimes litigation, as some distributors are balking at the power purchase tariff terms and price levels.'

Whilst this assessment is from 2007, it still appears that a significant degree of confusion and inconsistency remain.

The existence of a dedicated Ministry for New and Renewable Energy is a powerful enabler for renewable energy and CSP in particular in India. India is one of the few countries globally to give renewable energy such administrative prominence. Interestingly, USAid identifies this as a reason why progress is faster with renewable energy compared to energy efficiency in India, which does not benefit from a dedicated Ministry. However, at the CSP in India conference held in Delhi in September 2010, a common complaint from delegates was that MNRE was not answering clarification questions on the Solar Mission in a timely manner. This was also noticeable in MNRE's absence from participating in the many panel discussion sessions, where questions were asked of industry participants that would more appropriately be directed at MNRE staff. Delegates were also disappointed that the Solar Mission workshop was delivered by KPMG consultants without participation from government representatives. The most appropriate conclusion that can be drawn from this, is that MNRE is almost overwhelmed by its own success. Rapid acceleration in policies supporting a new industry significantly increase the workload of the responsible agencies. In addition, growing teams with the appropriate skills can be a challenge due to competing needs from an expanding CSP sector.

Lotker (1991) discusses in depth the lessons that can be learnt from the Luz experience that established the well known SEGs plants in California. In the 1970s, the US Government established measures such as tax credits and RPO rules that incentivised renewable energy, motivated mainly by domestic energy security concerns following the 1973 oil price shock. From this, only a few technologies and companies went forward and one of the most notable was Luz. In the early 1990's the government initiatives such as tax credits were progressively dropped and ultimately Luz went out of business. In analysing the final demise of the company, the interesting conclusion is that one of the most damaging things was the arbitrary short-term extension of the credits at the end, that lead to the final power station being constructed in a high-expense accelerated fashion to meet the arbitrary deadline imposed. In hindsight, if that final, expensive plant had not been built in that fashion, the company may have been able to go into a holding mode and save its remaining funds for more attractive future projects.

The overall lessons for governments are the desirability of avoiding boom-bust responses to policy and if a tightening of conditions is planned, to do it in a way that allows companies to plan and survive under a new paradigm.

The Technology Roadmap (IEA, 2010), presents a range of recommendations to governments that aim to address the financial and technical barriers to expansion of the CSP industry.

- 'Ensure long-term funding for additional RD&D in: all main CSP technologies; all component parts (mirrors/heliostats, receivers, heat transfer and/or working fluids, storage, power blocks, cooling, control and integration); all applications (power, heat and fuels); and at all scales (bulk power and decentralised applications).
- Facilitate the development of ground and satellite measurement/modelling of global solar resources.
- Support CSP development through long-term oriented, predictable solar-specific incentives. These could include any combination of feed-in tariffs or premiums, binding renewable energy portfolio standards with solar targets, capacity payments and fiscal incentives.
- Where appropriate, require state-controlled utilities to bid for CSP capacities.
- Avoid establishing arbitrary limitations on plant size and hybridisation ratios (but develop procedures to reward only the electricity deriving from the solar energy captured by the plant, not the portion produced by burning backup fuels).
- Streamline procedures for obtaining permits for CSP plants and access lines.'

These recommendations are valid for India and some are already being implemented. However, the last two recommendations deserve further consideration. Streamlining of approval and access procedures is discussed in Section 6.5. The technical compatibility of CSP plants to hybridisation with conventional fossil fuel technologies is a major competitive advantage. The Solar Mission[6] does not seek to fully benefit from this potential synergy. The rationale for this appears to be that taxpayer resources should be employed to support pure solar projects only. This makes sense to a degree, since the long term goal is to establish technologies that can be used independently of fossil fuel. However, it may make achieving this long term goal more difficult as opportunities for more viable projects in the short term are overlooked.

Hybridisation can take a number of forms:

- Gas-fired superheating in series with saturated steam production by a solar field. This may be a useful technical approach but does not demonstrate a solar solution that can ultimately stand on its own.
- Designing a CSP plant to generate with zero fossil fuel input on sunny days. However on cloudy days, such as can occur in the monsoon season, running the powerblock using fossil fuels to increase the revenue of the plant.
- Providing steam to a large power block at the maximum temperature and pressure of operation by parallel boosting with fossil fuels. This would demonstrate all the components needed for full solar operation, but the fossil component would allow a much larger and more efficient power block to be operated.

The IEA recommendation notes the important need to only reward the solar generation not the portion produced by burning backup fuels. This is straightforward in situations where the solar input is at the highest temperatures and pressures of plant operation, since the solar share is simply proportional to the solar fraction of input energy. However, it is a complex calculation if the solar contribution is at a lower temperature / pressure that is then boosted by fossil input. Allowing this approach on a simplistic input energy share basis would badly distort market signals on technology optimisation. Instead complex thermodynamic formulas based on the exergy concept may be needed. A methodology for calculating the renewable proportion of a hybrid power station has been developed for the Lidell solar field's steam contribution to a

[6] In contrast the Australian Solar Flagships program does allow limited hybridisation.

coal-fired power station. The Australian Office of the Renewable Energy Regulator is the agency responsible for approving this methodology.

The other obvious hybridisation option to consider is the possible hybridisation with biomass-fuelled thermal power production. As biomass can be a renewable resource, this is an approach that should be encouraged. Both India and Australia seek to enable biomass power generation under various renewable energy policies. The difficulty of combining it with CSP is that higher tariffs have been set for CSP. Hence similar issues to the fossil hybridisation case will be encountered. Discussions with an Indian company that currently operates a number of biomass-fuelled thermal power plants reveals further challenges. The PPA in place for those plants does not permit energy to be added from any other source, thus the power plant owner is precluded from adding a CSP solar field to existing biomass-fuelled plants without renegotiating the PPA, a significant but unanticipated missed opportunity for CSP.

Another major shortcoming in relation to polic.y settings in both India and Australia, is the lack of incentives for including energy storage with CSP plants. If a major goal of these initiatives is to develop large-scale technologies that can stand on their own, then incorporation of energy storage should be a high priority. As things stand, energy storage is not precluded, however given that adding storage adds to overall initial capital costs, it is unlikely to be included if the value it adds is not recognised. The most appropriate way of recognising that value would be with a tariff that is actually linked to the time-of-day with higher values at times of peak demand.

6.5 Approvals and land

Without suitable sites and approvals, no project can proceed. Generally speaking, land is available through some commercial avenue and every country has some sort of approval process that should not be inherently worse for a CSP project. However both these issues can be extremely onerous. There is great scope for facilitation and streamlining.

Baker & McKenzie (2008) discuss the approvals process for renewable energy projects in India and note that it can be quite onerous, particularly around issues that fall in the jurisdiction of both state and federal agencies. A case study is given of a wind project in Maharashta requiring 12 separate planning or no objection certification documents. Among their recommended key actions aimed at overcoming barriers to renewable energy in general, is:

> ‘Provide streamlined approvals processes for renewable energy projects’

The Technology Roadmap (IEA, 2010), discusses non-economic barriers. It indicates that the slow approvals process, grid connection issues and the difficulty of accessing water and gas are the most important difficulties. This issue also occurs in other countries, for example, the environmental approval process in California can take up to 2 years.

The ‘*Indian Renewable Energy Status*’ report (Arora et al, 2010), presents analysis indicating that the land area suitable for CSP development with DNI greater than 2,000 kWh/m^2/yr in India is around 112,500 km^2. This is sufficient for a generating potential of about 10,930 TWh per year, many times the total electricity consumption projected for the country. Thus the existence of suitable land per se is not a barrier.

Much of the land suitable for CSP plants in India is likely to currently be used for marginal grazing purposes. Whilst local community attitudes would not appear to represent a barrier at present, it is important to manage community support for new industries. Ideally, new economic activity in regional areas should help all sectors including local communities. It is important to ensure that some sectors or groups do not feel marginalised in some manner such that they later become a vocal opposition group. In Australia, there is a level of local opposition to wind farm developments, that in retrospect could have been managed better by the industry. In part, this opposition is linked or amplified by a sense that some landowners are directly benefitting financially whereas other stakeholders in the community are not.

Large CSP plants around the world have been established under a model of completely clearing and levelling a site with earthmoving equipment and then maintaining the plant in a securely fenced and patrolled precinct. It may be feasible to allow some re-growth and ongoing grazing within a plant's precinct. Actions such as this, plus ensuing that other sources of income pass to people in communities that previously used the land should ensure ongoing community support. It is also valuable to develop community education and awareness campaigns. There are reports that in some Indian regional areas, the belief that wind-farm construction effects weather / rainfall patterns has emerged. If similar perceptions developed for CSP plants, it may hamper further developments.

The ideal method for dealing with land and approvals is probably the establishment of large-scale Solar Parks, pre-approved for CSP operations. India is well progressed in this regard, with two such areas already under establishment in Rajasthan and Gujarat. The Solar Park concept has been actively supported in India by activities of the Clinton Foundation and TERI. Even solar parks will require some sort of defined land allocation procedure that represents a challenge for developers. It is important that there be some eligibility tests that developers must pass in order that allocations within parks are not used speculatively. The optimal process may include:

- A rapid in-principle allocation process that gives initial certainty to developers.
- Automatic loss of allocation if financial closure is not achieved in a reasonable timeframe.
- Permission to construct immediately following financial closure but contingent on lodgement of bonds to allow for site clearance if the project is not completed.
- Automatic loss of allocation if the project is not constructed in a reasonable timeframe.

Overall the Solar Park concept is highly commended and should be encouraged in all sunbelt countries. Once some serious CSP project construction is underway, there would be value in adding more Solar Parks in India, and including all states judged suitable for CSP activities.

6.6 Grid and services connection

All CSP plants need a grid-connection. Gas, water, sewerage, roads and fencing must also be considered to varying degrees and according to the technology type being used. The Technology Roadmap (IEA, 2010), discusses non-economic barriers and indicates that the slow approvals process for grid-connection plus the difficulty of accessing water and gas are significant barriers. Positive action on long distance HVDC grid extensions is seen as a significant enabler, including cross-border connections.

The Indian HV transmission network is extensive. However, the 11kV distribution system is limited. HV transmission is a mixture of 400kV, 132kV and 33kV, substations drop this to 11kV for the distribution system. As a substation is expensive, it needs a large load to justify the investment. There are a significant amount of people in intermediate areas where the load is not sufficient to justify a substation. This situation is in contrast to Australia, where only a fraction of the country has grid coverage, but those regions have most of the population and almost universal connectivity. For large CSP plants connections to the HV transmission system via new lines and substations are required. This represents both an extra investment and also a process of approvals that must be completed.

Purohit (2010) notes that historically there were five independent regional grids in India, Northern, Eastern, Western, Southern and North-Eastern. Since August 2006, all accept the Southern grid have been integrated and operate synchronously at the same frequency. This is an important step forward from the CSP perspective, considering that the regions with highest CSP potential are located in a few key states and do not coincide with the largest load centres.

Baker & McKenzie (2008) note that despite the moves toward improved inter-regional connectivity and a national grid, the Indian Grid system is still judged to be weak. They present wind project case studies where production had to be limited because the grid had insufficient capacity to evacuate the power generated. Voltage and frequency variations can also adversely effect the lifetime of generation equipment. They also recommend developing and strengthening the transmission network to allow for renewable energy.

In addition, the projected enormous growth of electricity demand means that major grid augmentation will be required and is no doubt under detailed consideration. The important point is to consider the likely needs and effects of large-scale CSP. Grid issues should also feed back into other policy areas, for example, treatment of storage with appropriate rewards for avoided costs.

Internationally, the Desertec initiative envisages large-scale interconnection of North Africa to Europe with HVDC transmission lines. This visionary idea is worth considering for the long term network requirements in India. Translated to the Indian context it could lead to contemplation of international connections to Pakistan and through Kashmir and the Himalayas to Western China. These are ideas that would seem extremely unlikely at the present time, but could well come to pass over a 50 year timeframe.

Water issues are important for CSP plants. As detailed in Chapter 2, some level of water usage is required for steam-cycle makeup and mirror cleaning. Employment of wet cooling systems markedly increases water consumption, but is not essential since dry cooling solutions are also available. Wet cooling however offers lower capital costs and higher cycle efficiency and so uses water to good economic benefit. Water issues present a potential barrier at several levels including the:

- potential limited physical availability of water,
- approvals process for accessing water supplies, and
- cost of supply infrastructure.

Under present rules for Solar Mission, gas usage is precluded. However, if gas use were allowed, the same potential barriers exist in regards gas supplies.

The Solar Park concept discussed in Section 6.5 can be extended further than simply the pre-approval and allocation of land. The provision of grid-connection, water and other services can be contemplated. Arguably the further the concept is taken, the more benefit there will be to the progress of the CSP industry. For the Solar Park in Western Rajasthan, it is suggested that the State government will provide the grid-connection at least to some point, however there remains doubt in the minds of some developers on the timing and funding of such initiatives. It is also understood that allocations of water from the Indira Gandhi National Canal that lies immediately to the West, is included in the offer. All such contributions are major positive contributions to overcoming the barriers.

6.7 Technology shortcomings

CSP technologies on offer range from the proven, established Trough technology to implausible new inventions. The ideal CSP technology is of course; high performance, low capital cost, high reliability and with minimal O&M costs. Technology shortcomings for any given technology / technology proponent could include any or all of:

- excessive capital cost,
- low system performance,
- lack of long term track record,
- below specification construction,
- failure of key components, and
- failure of after construction backup.

The cost issue has been discussed above. The risks associated with the other shortcomings strongly effect the difficulty of getting finance for a project.

The Electric Power Research Institute (2009) notes that:

> 'Successful R&D efforts resolve many technical uncertainties, but others persist until initial demonstration. Examples of technical uncertainties that can remain include:
>
> - Unanticipated interactions between system elements that previously were independently tested.
> - Incompatibilities between materials or incompatibilities between utility operation and the industries from which the new technology was adapted.
> - Some unanticipated operating problem that becomes significant.
>
> Demonstration and commercialization reduce technical and estimation uncertainties, but economic and other uncertainties always remain.'

Lotker (1991) comments on the evolution of the well known SEGs plants in California. Luz initially established the smaller (15 MW_e) SEGS I and II plants in 1984 and 1985. The report notes:

> 'Although the performance of SEGS I & II was not up to the level of projections (a classic example of excess optimism regarding performance of a technology yet to be deployed at commercial scale). LUZ quickly learned from the experience so that projections for later plants were more realistic. Thus early problems did not spell the end of the technology so long as the reasons for the difficulties were understood and the market for the technology remained healthy.'

The subsequent five 30 MW_e plants that were built successfully learnt from the technical lessons and outperformed design specifications. The later 80 MW_e plants also performed well.

CSP technology is conceptually simple and appealing. It is also relatively easy to build basic prototypes. The risks include that the growing interest in the field attracts new players at all levels, who may be naive in their approach and overly optimistic of the actual performance they will achieve. The level of effort and investment required to make a safe, high performance prototype compared to a basic amateur level one is immense. Similar increased orders of magnitude of effort are required to make the subsequent steps of first demonstration, first commercial plant and finally proven technology. The final goal of bankable proven technology usually takes investments in the billions of dollars and effort over decades. This is well known to those players who are operating commercial plants and rarely fully appreciated by new entrants. New entrants can be very vocal in promoting their ideas and lobbying government for support. Risks associated with new entrants need to be considered and carefully managed.

The issue for all countries with a serious interest in CSP, is how to 'hasten slowly' down the cost curve. A large value project that ultimately fails, in a country like India or Australia that has not established a CSP track record could be very damaging for the whole industry. Conversely simply continuing to duplicate the SEGs plants is a recipe for very slow progress.

Both India and Australia have adopted guidelines for their first projects that seek to minimise risk via requirements for previous successful demonstrated projects and key criteria around the financial abilities of the developers. For the Solar Mission, the key technology requirement is that a 1 MW_e system have been demonstrated for at least 12 months, multiple projects of 5 MW_e or greater are then expected in phase 1. For Australia's Solar Flagships program, the guideline is 30 MW_e having been demonstrated for at least 12 months, with the program aiming to deliver a single first plant at a size greater than 150 MW_e. These technical risk minimisation guidelines are sensible for the circumstances, however in both countries there is also a level of detail in the guidelines which allows for flexible approaches to this requirement. Together with other key factors that make project selection on a proposed least cost basis favoured (ie the reverse auction aspect of phase 1 of Solar Mission). This has the counter effect of skewing the process towards greater risk.

The requirement of 1 MW_e for at least 12 months is a very appropriate criteria and should be continued and strengthened. The 1 MW_e size is appropriate, as it is essentially the minimum size that a viable central power block based CSP plant can actually be built. It is also a plant size at which, once constructed, the electricity revenue should be more than sufficient to cover O&M costs, such that there is every incentive to continue operation and maximise performance for several years. A 1 MW_e size is also the appropriate first step scale up for a technology that has completed an initial collector prototyping phase. It is also a very good size for a new player in CSP who is licensing an existing technology, to build experience and test locally sourced components.

Thus, in addition to maintaining strict tests to minimise technical risk in large plants, the barrier of technology shortcomings in general can be greatly minimised by initiatives that enable multiple demonstration and test systems at a level of 1 MW_e or more to be put in place. This is discussed further in Chapter 8.

6.8 Solar data

Chapter 4 has reviewed the solar data available for India and concluded that as with many sunbelt countries, it could be significantly improved. Reliable long term DNI data collected at high frequency, is needed to predict system output accurately. The importance of this is mainly as an input to investment decisions. Where uncertainty remains in the prediction of future DNI levels, project developers need to assume more conservative outcomes and so this effects the probability of successful financing.

Baker & Mckenzie (2008), recommend as one of their key actions aimed at overcoming barriers to renewable energy in general:

> 'Undertake renewable energy resource studies and forecasting.'

The IEA's Technology Roadmap (2010) specifically recommends:

> 'Facilitate the development of ground and satellite measurement/modelling of global solar resources.'

Recognising the shortcomings in solar and weather data, the MNRE through C-WET have called for tenders for 51 monitoring stations. Given that this initiative is progressing, it is worth commenting that with a need for 5 to 10 years of good data needed to make an accurate prediction of plant lifetime output, it will be quite a few years before the new monitoring stations deliver the certainty needed.

There is however, scope to improve on the current situation in a much shorter time frame. Even a few months of on ground site data can serve to help calibrate the existing satellite based data. Going beyond this, there is considerable scope for deriving much greater benefit from the data that currently exists. If all possible sources of data, either DNI or global radiation measurement plus ambient temperature and humidity together with all the various satellite based predictions are assembled in a single data base, then using state of the art statistical techniques, an optimised model could be built up. Approaches like this can, for example identify when ground based DNI data from a particular site at a particular time appears to be out of calibration and can then retrospectively re-calibrate it. It should also be possible to link, by appropriate interpolation in time and location, humidity and ambient temperature to DNI results.

However, all such efforts do not address the larger issue of changes to DNI resources due to climate change and air pollution. There is scope for a thorough investigation of state-of-the-art modelling efforts in this direction also.

The absence of a robust body of solar and weather data, means that commercial project developers are installing their own monitoring stations and carrying out their own data correlation. Such activities require a considerable investment and once complete are kept commercial-in-confidence. Publicly funded investigations that place the information freely in the public domain have a high enabling potential. They remove an area of cost delay and uncertainty for all technology developers and so allow the industry to concentrate its efforts on the technology.

6.9 Manufacturing scale-up

For CSP to achieve significant penetration in a given market, millions of square meters of solar concentrator collectors of various types along with all the supporting plant will need to be manufactured. The nature of the technology is such that attempting to import all the hardware from another country would be uneconomic, not to mention a lost opportunity to the local economy. Thus manufacturing capability must be identified, established and scaled-up. This includes not just the factories but also the skills to design, manufacture, install, operate and maintain. CSP has the advantage over PV that the manufacturing techniques, infrastructure and skills, are very similar to those encountered universally in major centres with industrial activity. Nonetheless the challenges should not be underestimated.

The Technology Roadmap (IEA, 2010), discusses the issue of materials and manufacturing capability for CSP globally:

> 'The perspectives presented in this roadmap are unlikely to be impaired by a scarcity of raw materials. Large mirror areas will be required, which may exceed current global production by a factor of two to four, so timely investment in production capacity of mirrors will be necessary. This production would only account for a few percentage points of the global production of flat glasses, however. Similarly, accelerated deployment of trough plants would require investment in production of heat collector elements. Receivers for towers are a variety of high-temperature heat exchanger, which industry has largely deployed throughout the world. Only molten salts for thermal storage may raise some production problems. They are used in large quantities as fertilisers for agriculture, but their use as a storage medium requires a high degree of purity.'

This upbeat assessment is also valid for India. As outlined in Chapter 5, India has significant existing capability in all the related manufacturing areas. The requirement of 30% local content in the Solar Mission phase 1 guidelines is designed to grow Indian based manufacturing capability. Feedback suggests that the 30% content can readily be met via power block components and civil works and possibly some framework for the concentrator fields. Going forward, there is a good case for increasing the 30% requirement and also specifying a separate minimum requirement for local content in solar field components.

Cleantech AustralAsia's (2008) report includes in their 10 identified barriers that directly effect manufacturing scale up:

> '8. There is a lack of RE industry information (such as successful case studies and investment grade data) available to investors, financiers, developers and policy makers.
>
> 9. There is a general lack of awareness and skills to develop RE technologies and projects amongst financiers, investors, policy makers, developers and consumers.'

Their suggested solutions to overcoming these barriers included four of relevance:

> '5. Develop tailored capacity building programs for project developers, venture capitalists/investors, project financiers, RE technicians and policy makers.
>
> 7. Establish a RE incubator program and more international R&D collaborative models to fast track commercialisation of RE technologies.
>
> 8. Undertake targeted RE business missions between APP partner nations.
>
> 9. Standardise protocols and procedures in India for RE monitoring, measurement, verification and technical certification.'

To a large extent, manufacturing scale-up is about quality control. The discussion of the value of facilitating small test systems on a scale of 1 MW_e or more indicates the importance of providing a way of qualifying new system and component suppliers. It also provides opportunities for side-by-side performance tests of similar components from multiple suppliers.

6.10 Matching business cultures

CSP like other RE technologies, is rapidly becoming a global industry. To date, the major commercial efforts have been initiated by Western European and USA based companies. These companies are also essential players in new markets. Conversely upcoming commercial operations for countries such as Australia or India, almost certainly need to consider activities in the Spanish and US markets. Thus the issue of doing business in a (business) culture other than the place of origin will be encountered by all major players. The most obvious language and cultural differences are important but other different approaches can include:

- risk management,
- quality control,
- staffing levels,
- occupational, health and safety,
- lead times on supply,
- Intellectual Property protection,
- contract law, and
- government interactions.

Cleantech AustralAsia's (2008) report includes in their 10 identified barriers:

> '10. There is a general lack of understanding of Indian business culture and how to build partnerships and trust.'

Their suggestions to overcoming the barriers include:

> '7. Establish a RE incubator program and more international R&D collaborative models to fast track commercialisation of RE technologies.
>
> 8. Undertake targeted RE business missions between APP partner nations.'

Baker & McKenzie (2008) expresses concern in the area of IP protection. The Patents Act 1970 is the relevant law. It was strengthened with the Patents (Amendments) Act 2005. They recommend that environmental and IP laws need to be enforced to overcome barriers to renewable energy in general.

Following on Indian efforts to improve performance of IP protection, to a large extent it would appear that the issue is more one of perception held by overseas technology providers. Various stakeholders have pointed out that in India there is a stronger ethos of buyer beware. This is seen in successful businesses in India providing specifications for supply in much more precise detail than might be seen elsewhere and putting considerably more effort into quality control on products delivered. It also results in a very high recognition of brand and reputation, so that even if there is a level of activity that seeks to illegally use Intellectual property, the resulting copies do not represent a great business threat. It has also been pointed out that within the now very successful and globally significant Indian wind turbine industry, there have been no major IP related litigations.

Every country suffers from corruption and illegal activities at some level. Clearly India has had and still has issues in this area. According to IHS (2009):

> 'The problems of corruption and security are still prevalent in the country and require substantial resources to overcome – time, money, investment in education.'

However, it seems likely that there is also a level of unjustified generalisation at work on the part of outsiders.

The recent experience with the Commonwealth Games is almost a metaphor for the clash of business cultures between some in the West and India. Leading up to the Games both Western and Indian media were predicting that venues may not be finished or workable in time for the games.

The following Australian Broadcast Corporation news story, (ABC 2010), illustrates some of the challenges with bringing Western attitudes to India:

> ‘An Australian architect involved in the design of Commonwealth Games venues says he is not surprised to hear of the construction problems in New Delhi. There is growing concern among athletes and team officials about the ability of the city to host the Games, after a series of incidents, including a bridge collapse outside the main stadium. Architects say they went to India with 21st century ideas but encountered a workforce "stuck in the 19th century" and burdened by an over-complex bureaucracy.
>
> Carlo Corallo, a director at Peddle Thorp Architects in Melbourne, is involved with five of the Games venues. He says there is some truth in criticisms that construction standards are not what Australians are used to.
>
> “That's probably been the biggest source of frustration for most of the international engineers and architects, and I suppose the biggest frustration there is the bureaucracy that's in the country," he said. "No-one is really prepared to make decisions because the repercussions for bad decisions are probably life-threatening. There's certainly no-one able to make a decision, so they postpone making decisions for a long time and then time catches up on them and projects get hurried along in order to get them completed, and of course certain things can't be hurried. Structural concrete and putting together structural systems just can't be accelerated to the point that they don't work’.

Despite all the criticism and pessimistic predictions, the games did go ahead and were highly successful.

Clearly there are challenges to be met in marrying Western and Indian business cultures to accelerate progress in the CSP industry. The key is building trust in relationships. The wind industry provides some valuable precedents on the matching of business cultures and successful technology transfer. One of the most important of these lessons is that one of the best ways to fast track the process of relationship building and working together, is Indian investors taking major equity positions in key players. The story of Suzlon is a good case study in this regard. In the CSP arena, it has already been seen with Acme making a major equity investment in its US based technology partner ESolar.

6.11 Summary

Overall, the barriers faced by the CSP industry globally and in India specifically are real, but not insurmountable. An enormous amount of effort is already being directed at addressing many of them. More can always be done and the conclusions and specific recommendations make suggestions in this regard.

Based on the information collected and reviewed by the authors, Table 6.2 provides a qualitative scoring of progress in addressing barriers in four key CSP markets. The scale is out of ten with 10 being no barriers, a 5 indicating serious cause for concern and less than 5 a potential show-stopper. The assessment for the USA is based on the specific high solar resource states with favourable policies in place.

	USA	**Spain**	**India**	**Australia**
Cost / financing	8	9	6	3
Government policy	7	9	8	4
Approvals and land	5	7	7	6
Grid & services connection	7	7	6	5
Technology shortcomings	7	8	6	6
Solar data	9	9	6	7
Manufacturing scaleup	9	9	6	7
Matching business cultures	9	9	5	7
AVERAGE	**7.6**	**8.4**	**6.3**	**5.6**

Table 6.2: Progress in addressing specific barriers by country

Not surprisingly, this indicative assessment has a similar conclusion to the Ernst & Young (2009) investment attractiveness ranking already discussed in Chapter 5. Ernst & Young's overall assessment also factored in the quality of the solar resource, which helps lift Australia's position relative to many countries.

7 Developing Expertise, Research Exchanges and Secondments

7.1 Skills and expertise

For countries like Australia and India that are aiming to develop local capacity and participate in the evolution of an emerging new industry like CSP, the idea of research exchanges or secondments is often suggested as a useful policy option. Such initiatives can make an important contribution to building skills needed for the industry to advance, however, it is important that the expectations are realistic. As discussed in Chapter 6, the major barriers to the expansion of the CSP industry are associated with the high capital costs and the challenges of getting projects financed. Whilst it has been clearly identified that technical innovation (via R&D efforts) will be the source of a significant fraction of future cost reduction, the point has been made that this must be in parallel with large-scale roll out of systems and the development of expertise that this will bring. Even generously funded R&D programs are not the 'silver bullet' for cost reductions on their own.

In contemplating the area of expertise, research exchanges and secondments, the overall skill areas that the CSP industry (either in India or elsewhere) needs should be considered.

A suggested list would include:

Manufacturing

CSP manufacturing is largely an adaptation of standard manufacturing processes used in other industries. The more established CSP technologies have precisely specified manufacturing processes, with associated skill sets, that must be implemented when new manufacturing facilities are established. In addition to this, there are skills in developing improved manufacturing systems to reduce costs with existing technologies and also to roll out new technology approaches. There are engineering, management and trades disciplines all needed.

Commercialisation

Commercialisation skills are needed for establishing new commercial operations, negotiation of IP licences and Engineering, Procurement and Construction contracts etc. Standard commerce, business, management and legal skills need to be informed by the specific issues of CSP technologies and projects.

Policy

Policy expertise specific to the CSP industry is needed for people working within all levels of government, it is also needed for industry associations, NGO's and commercial organisations who are involved in dealing with and providing feedback to government policy initiatives

Market management

As energy markets become more sophisticated, particularly with the trend to continuous trading, skills in maximising the benefits of participation in such markets and understanding their dynamics are a valuable skill set for both commercial operators and government organisations. Operation of CSP systems in this context brings its own issues which would need to be understood by all market participants.

Construction

System construction for CSP is largely an adaptation of skills from existing industries, with the whole range of traditional engineering, project management, machine operator and manual construction skills needed. CSP projects have their own unique characteristics, with aspects such as installation accuracy and handling issues. These result in a particular adapted skill set best learnt from experience, assisted by targeted professional training.

Design

All the engineering disciplines are needed for CSP system design. There are CSP specific aspects to the skills and there is a distinction between system design for projects employing already commercially deployed technology versus design supporting new product development and product improvement. All the CSP specific aspects are learnt by experience and probably most effectively by newcomers receiving some specific training, then joining teams with already experienced people.

Operation

As with manufacturing, operation of CSP systems based on more established CSP technologies have precisely specified operating procedures with associated skill sets, that must be implemented when new facilities are established. In addition to this there are skills in developing improved operation practices to reduce costs with existing technologies and also to roll out new technology approaches. There are engineering, management and trades disciplines all needed.

Research & Development

Scientific and engineering R&D skills are needed, if a country wishes to be a technology leader or a fast follower. R&D activities can also work in parallel with training for the other skills areas. The approaches come from a range of engineering and science disciplines. The particular nature of CSP related R&D skills is associated with the specific instrumentation and experimental methods involved, but more importantly with being up to speed with the international cutting edge position on the particular research area. The latter is facilitated by collaborative research arrangements and secondment to international research groups.

In considering the expertise needs further, possible commercialisation models for CSP in India need to be taken into account (these models could apply in any country not yet advanced with the industry, such as Australia also):

a) Small to medium Indian company develops a technology from first principles based on technology concepts already in operation and gradually grows the business from demonstration to full commercial operation.

b) Original technology invention taken to start-up company, investment sought to follow the demonstration and then the commercial operation path.

c) Major Indian company starts a new division, possibly builds experience with some home grown technology, ultimately buys an existing overseas technology company and then proceeds to grow the business at home and globally.

d) Major overseas player establishes a division in India, possibly with equity partners. This division may ultimately spin off as an Indian company and develops its own business direction.

India has a very strong track record of success with scenario's a, c and d. In the wind industry for example, Vestas in India proceeded according to scenario d and Suzlon via a mixture of scenario a followed by scenario c. USA and Europe probably remain as the global leaders in following scenario b. It is reasonable to suppose that the path to success for the Indian CSP industry will also largely follow a mix of scenario's a, c and d.

7.2 Role of tertiary educational institutions

The natural assumption is that tertiary education and / or research institutions have a major role to play in the development of expertise. Clearly they are responsible for the basic undergraduate and post-graduate degree training of all the qualified professionals who become involved in the CSP industry. Roles that can be identified include:

- cutting edge R&D,
- training engineers for design, manufacturing, operation, and
- training managers, policy specialists, lawyers, economists etc for commercial and related activities.

In addition, vocational training of technicians for construction manufacturing, operation and maintenance is required.

As has been noted above, many of the skills needed to support the CSP industry are generic and obtained through existing courses. For undergraduate degrees, particularly in engineering, it would clearly benefit the industry for CSP issues and technology to become incorporated at least via elective units. At the other extreme, there are now examples in Australia and elsewhere of dedicated degrees in photovoltaic engineering being established. This is not necessarily a precedent that would be of benefit to CSP. At the engineering level, it could be argued that engineers are best served for CSP purposes with a multi-disciplinary and flexible general training. There is however a very good case for the introduction of specialised post-graduate courses / degrees for the CSP field. Short courses, suitable as professional development for qualified engineers can also be a good option as they would allow existing skilled engineers to move more rapidly into the CSP area.

At the vocational and trades level however, dedicated and specialised training via certificate level courses dedicated to CSP plant operation for example are very valuable. To provide greatest value in this regard, such courses should ideally be conducted with access to a working CSP system, either via a small plant on the institution's campus or else via hands on access to a commercial plant or a mixture of both approaches.

The point has already been made that R&D activities are not the main issue for the CSP industry in India at this stage. To the extent that they are, R&D skills are only a small part of the expertise base that the country needs to advance the industry. With these caveats, it is worth building the solar thermal R&D effort in India and Australia. Apart from anything else, an ongoing R&D effort in a tertiary institution keeps the academics involved fully engaged with the technology and better qualified to offer training to students.

Choice of R&D priorities for CSP in any country is worth a detailed road-mapping exercise of its own. The Solar Research Council, foreshadowed in the Solar Mission, is well placed to initiate this exercise. It can be observed, however, that there is a tendency for interested individuals (in any country) to begin investigations by designing / building new concentrators from first principles. Given the maturity of the industry globally, this is needless reinvention of the wheel. It can be argued that concentrator improvement and new concentrator design should now be carried out in the commercial arena and that institutional R&D should target fundamental changes, development of new materials and improvements to the basic energy conversion processes.

7.3 Exchange and collaboration programs

Personnel exchanges could play a useful role in building capability and overcoming barriers. They could also serve to help develop industrial activity in CSP that benefits both Indian and Australian businesses synergistically. Options to support this include:

- government and company personnel sponsored to work at overseas higher education institutions,
- sponsored exchanges of research staff from universities and research institutions,
- temporary exchanges of staff between relevant government departments, and
- Government, company or research personnel to work at overseas CSP companies.

Once again the Solar Mission foreshadows initiatives in this area.

7.3.1 Existing programs

This study has not examined all existing avenues for exchange and collaboration involving India and other countries. It is however worth considering some particular examples involving Australia.

The most prominent is the Australian-Indian Strategic Research Fund (AISRF) that is managed by the Australian Government Department of Innovation, Industry, Science and Research (DIISR) and the Government of India Department of Science and Technology. The relevant websites are:

- https://grants.innovation.gov.au/AISRF/Pages/Home.aspx
- http://www.stic-dst.org/IndoAustralianGrand.pdf

The Department of Innovation, Industry, Science and Research website states:

> 'The *Australia-India Strategic Research Fund* (AISRF) was established in 2006 to facilitate and support science and technology research cooperation between Australia and India. The AISRF assists Australian researchers from both the public and private sectors to participate in leading edge scientific research projects and workshops with Indian scientists and supports the development of strategic alliances between Australian and Indian researchers.
>
> Australia and India have laid the foundation for a productive, long term scientific and technology partnership through the AISRF. Established in 2006 it is Australia's single largest bilateral science and research fund. Australia has committed a total of $65 million to the Fund with the Indian Government providing matching funding.'

There are two funds for collaborative projects and workshops:

- the Indo - Australian Science and Technology fund, and
- the Indo - Australian Biotechnology Fund.

The first of these includes renewable energy as a priority area and thus has CSP in its scope. Funds are allocated on a competitive basis and the maximum grant is $300,000 or up to $400,000 if an industry end user is contributing. Eligible organisations are limited to publicly funded or not-for-profit research organisations.

In November 2010, a new AISRF scheme, the Grand Challenge program was announced, and a new fellowship program for short and medium term researcher exchange will begin in 2011. Under the Grand Challenge program, projects will run for 3 or 4 years and the maximum funding is increased to $3 million for the Australian consortia, with matching funding from India. The second round of the Grand Challenge program will be opened later in 2011 and will address the two separate themes of energy and health. There is potential for this program to support CSP initiatives.

India has a similar collaborative program with Korea:
http://www.dst.gov.in/whats_new/whats_new11/cop_indo_korea.pdf

India has also recently announced a collaborative program with the USA specifically on clean energy: http://www.dst.gov.in/whats_new/press-release10/pib_09-11-2010.htm

For collaborations between India and Australia, there is also the AusAID Public Sector Linkages Program: http://www.ausaid.gov.au/business/pdf/10-11-pslp-guidelines.pdf

The AusAID Public Sector Linkages Program can support Australian Public sector organisations up to a maximum of $250,000 for activities that have a developmental goal in the partner country. It requires in-kind support from the Australian applicant organisation and from the partner country. However, there is no requirement for a cash co-contribution from the partner country.

7.3.2 Issues

In an exchange or secondment, the needs of the three key stakeholders need to be met:

- the person on the secondment,
- the parent institution, and
- the host institution.

A model is needed such that all three see a direct and appropriate benefit to the process and the overall results advance the needs of the industry and the country. In addition, specific institutions may have their own lists of 'approved organisations' for collaborative research. Formal agreements are often needed between organisations prior to any specific research proposal being approved.

Whilst simplistically appealing, there are some major challenges with exchange and collaboration programs. This arises because generally speaking, the organisations most attracted to them are often those that are pursuing every possible avenue to raise the funding needed for their core activities and advance their own goals. Simultaneously all organisations are naturally protective of the capability and IP that they have that is the source of their own competitive advantage.

These factors together mean that collaborations can develop internal tensions and they may well begin as marriages of convenience to secure funding. These observations, together with the analysis above, suggests that the bulk of the capability needed to advance the industry is not in the R&D field, and that many of the skill sets needed are best developed through experience. This should inform the approach to designing programs tailored for the CSP industry in India.

7.3.3 Options

Potential options for further development include:

- Providing funds to support and facilitate recent graduate engineers' participation in extended work experience programs in overseas postings.
- Fund overseas experts to come for short visits to companies or institutions and pay them at consulting rates to provide expert input and training.
- Extend the 30% Solar Mission overall local content requirement to being 30% of solar field and 30% of balance-of-plant.
- Establish a fund to support Indian researchers on sabbaticals of six months or more.
- Establish a fund to support PhD scholarships.
- Establish visiting fellowships where senior overseas researchers visit institutions for two weeks twice a year for several years.
- Establish fellowships for working engineers to undertake secondments in overseas CSP companies.
- Investigate options to facilitate Indian company equity investment in overseas CSP companies at all stages of the commercialisation chain. Investment of any funds could be made conditional on some staff transfer and building a demonstration project in India.

It is acknowledged that some of these are already being considered in whole or in part and may already be implemented under existing programs.

8 CSP pilot plants in India

8.1 Background

Historically, India has hosted some minor activities in terms of CSP pilots and demonstrations. Prior to the announcement of the Solar Mission, Garud and Purohit (2007), presented an overview of the potential for CSP in India. They noted that Rajasthan, Northern Gujarat and parts of Ladakh had the highest solar resource, with parts of Andhra Pradesh, Maharashtra and Madhya Pradesh also representing opportunities. They discuss previous initiatives in India and describe the first solar thermal plant of 50 kW_e capacity based on 1.28m aperture trough concentrators that was installed by MNES at Gurgaon and operated from 1989 to 1990 after which it was shut down due to lack of spares. They also reported that it was being recommisioned with new components.

The most well-known attempt at establishing utility-scale CSP in India, centred on a proposal for Mathania. Garud and Purohit (2007) describe this as:

> 'A Solar Thermal Power Plant of 140 MW at Mathania in Rajasthan, has been proposed and sanctioned by the Government in Rajasthan. The project configuration of 140 MW Integrated Solar Combined Cycle Power Plant involves a 35 MW solar power generating system and a 105 MW conventional power component and the GEF has approved a grant of US $40 million for the project. The Government of Germany has agreed to provide a soft loan of DM 116.8 million and a commercial loan of DM 133.2 million for the project.'

In addition, it was reported that BHEL limited built a CSP power plant based on six dishes in the 1990's with support from the Ministry of Non-conventional Energy Sources, partly funded by the US Government. However, the availability of the technical details for this system are limited.

In addition to these, there are a number of installations of the well known Scheffler, low-concentration dish systems for cooking and process heat applications, various development efforts at various stages of demonstration, such as the Arun dish system, plus a range of small experimental / educational systems on the campuses of universities.

The MNRE Solar Energy Centre has recently added three Infinia dish Stirling systems to its facility. These are small units of 3 kW_e nominal capacity each. The Solar Energy Centre in Delhi is on track to greatly expand its role in terms of hosting pilots and CSP R&D. It is understood that plans are underway to construct a 1 MW_e test power station based largely on trough technology. This project is being lead by IIT and it is understood that Abengoa has been selected to provide the trough modules. In addition, a 1 MW_{th} tower system designed as more of an R&D facility is also planned for the site, with key involvement by Sunborne and others.

In the commercial Arena, Acme Solar are well into construction of a demonstration tower based system with a 2.5 MW_e design capacity at a site in Bikaner, Rajasthan using ESolar technology. Acme have an equity stake in the American based company ESolar and also the exclusive licence to market the technology in India. The ESolar technology is based on fields of relatively small heliostats with multiple tower modules supporting direct steam generation receivers. The frames for the heliostalts for the Bikaner demonstration are being fabricated in India, with the drives and mirrors imported. As reported at the DIREC conference in Delhi in October 2010, construction of the system was well progressed.

IIT Rajasthan has a 900 acre new campus site in Jodphur, close to the airport, of which 300 acres is to be made available for a solar test centre. They propose a mixture of R&D and pilot type activities and hope to negotiate some feed-in tariff that would allow pilot systems with generation capacity to produce revenue.

The Solar Mission has provision for a program of demonstration systems and other mechanisms for facilitating pilot systems. It is understood that this will be used strategically to fill gaps in technology that are apparent after the allocation of projects under phase 1. At this stage, the guidelines are not available, however it appears that quite large systems will be targeted.

The Australian based CSIRO has been investigating a possible demonstration of their tower heliostat system with solar reforming of natural gas for the Indian chemical process industry.

8.2 New Pilot CSP systems

With the range of CSP activities already underway, some may doubt the worth of further pilot-scale CSP systems. However, there is a substantial and vital role that pilot CSP systems can play.

Given that India wishes to grow its involvement in the CSP industry and maximise the level of local content and Indian participation in global CSP economic activity, pilot CSP systems could be designed with the aims of maximising expertise development and facilitating exchanges.

Pilot CSP systems can offer:

- Demonstration of the viability of newly developed, Indian technology.
- Demonstration of the viability of newly developed, overseas technology.
- Opportunities for established overseas technology providers to test the business environment in India.
- Opportunities for Indian companies to demonstrate technical capability of building overseas designs under license.
- Opportunities for established technology companies to trial alternative component suppliers and designs.
- Training and R&D facilities for engineers, technicians and researchers.

The major initiatives now underway are largely directed at grid-connected systems. Opportunities for off-grid systems are also being considered but it is a challenging market for CSP in India. A large proportion of India's off-grid market for electricity arises from the significant amount of the population who live in areas bordered by the HV transmission system, but with load densities that are insufficient to make the investment in a substation viable and are thus relatively small load centres by definition. In Australia, by contrast, there is a large, off-grid market that arises from the very large areas of the continent with insufficient population and load to justify extension of the transmission system over the long distances involved. A significant number of Australia's off-grid load centres also are of a significant scale, (tens of MW_e) and are potentially attractive for CSP.

In these off-grid markets, diesel engine based generation dominates and consequently costs of generation are higher than for the main-grid market. CSP technologies have the potential to be applied in the Indian off-grid markets, small systems such as individual Dish Stirling systems or PV concentrator systems, can be offered in direct competition to flat plate photovoltaic solutions for small loads. However, the increasing cost competitiveness of the flat plate PV approach makes opportunities limited. Steam or Organic Rankine cycle based CSP systems could be applied for loads of above 500 kW_e. Such small thermal systems could have competitive advantages if thermal storage can be included and if some useful cogeneration application of the waste heat is also available. In the Indian context, it is understood that there are a significant number of commercial off-grid industrial customers who could be potential candidates for such a CSP solution.

Given that the major driver for CSP technologies is to provide large fractions of energy supply in an environmentally sustainable way, the major impact will come from growth in the grid-connected market. The off-grid market is often suggested as a '*stepping stone*' to establish technologies before they are applied at a larger-scale in the grid-connected market. There would seem to be a potential, small off-grid market for CSP in India that is deserving of further analysis. Commercial organisations may overlook this sector due to the focus on the larger grid-connected projects.

A suggested set of conditions that seek to maximise the effectiveness of a pilot CSP system are:

a) Good solar resource to maximise potential operating hours.

b) Easy access from an airport to maximise demonstration value to visitors.

c) Access to neighbouring fabrication / construction / maintenance capability.

d) Reasonable accommodation options for visiting personnel.

e) Generate sufficient revenue from operation to cover O&M costs over several years of continuous operation.

f) Approvals process as simple as possible.

g) Easy connection to the electricity grid.

h) Water and gas supplies accessible.

Criteria a and e go together, as the wish for a good solar resource also maximises the possible revenue generation. Criteria b, c, d and e must be traded off against criteria a. The best solar resource in any of the sunbelt countries is inevitably in the most arid and remote areas. Towns with reasonable airport and other facilities can usually be identified at the fringes of the best solar areas. Implicit in this consideration is the idea that the best location for a pilot CSP system is probably not the same as the best location for commercial application of the technology at full scale.

For off-grid pilot CSP systems, the same considerations apply, whilst connection to the grid may be a redundant consideration, it may be that the other considerations mean that the pilot CSP system would not ideally be located in an actual off-grid location. Australia has a number of examples where renewable energy technologies intended for remote off-grid applications, have been deployed in remote locations as demonstrations. These demonstrations often have poor outcomes because the costs of maintaining and de-bugging are prohibitive in remote locations and much of the demonstration value is missed because of the time required to travel to site.

Given that the goal is to maximise the potential for the industry as a whole, criteria e and f plus c, d and g suggest the idea of a facilitated CSP demonstration precinct. In effect, a Solar Park exclusively for small, pilot CSP systems of the order of 2 MW_e or less. A small-scale, demonstration Solar Park could host a range of activities from pure R&D through to commercial demonstration. It can also readily host demonstrations of technologies designed for off-grid applications.

The MNRE Solar Energy Centre in Gurgaon, to some extent fits this description, particularly with the new projects planned. Whilst the Gurgaon site's proximity to Delhi is a plus for many of the considerations, it is however limited in land area and the greatest reservation is that the solar resource is poor. This will reduce the operating hours per year that systems can achieve, it will reduce the revenue that could be earned from exported power and it will not allow systems to demonstrate their full technical potential. An immediate example in this regard, is the Infinia Dish Stirling systems that are already installed at the site. Anecdotal reports suggest that they have not been able to operate at much more than half of their claimed design power output.

In contrast to Gurgaon, the Bikaner site chosen by Acme and the Jodhpur site of the new IIT Rajasthan campus represent ideal locations, since they combine all of the pragmatic attributes with respectable solar resource levels. IIT's plans in Jodhpur come very close to the small-scale Solar Park approach advocated here. However, it is suggested that given the outcomes expected of pilot CSP systems, that it is essential that provision be made for commercial technology developers to build and operate systems themselves. In principle, such commercially lead activities could proceed in parallel with institutional R&D and educational activities at the same site.

A pilot system Solar Park could be established with various levels of facilitation to benefit tenants. At the most basic level, an area of land can be set aside, with pre-approvals arranged for CSP system development and grid connection, plus a process established for land allocation within it. Going beyond this addition of shared infrastructure such as workshop, office, lab, accommodation facilities offered on some cost recover basis can be considered. Taking this a step further, steam based power generation systems could be further facilitated by establishing a 10 to 20 MW_e shared power block, which could accept steam from a range of pilot CSP collector fields. Such a shared power block would reduce the burden of establishing small, high cost and low efficiency power blocks for individual technology developers.

Whilst focussing effort on a single pilot system Solar Park would be cost efficient, there is an argument for several such facilities in different locations. Multiple locations around the country would help to provide visibility of CSP in general, to business and community leaders and so build understanding and support. It would also provide opportunities for Indian companies to build and operate pilot CSP systems.

8.3 Existing overseas R&D facilities

There is no existing facility that meets the description of a pilot-scale Solar Park. There is a range of overseas facilities that to various degrees meet some of the goals. Figure 8.1 indicates the geographical location of various facilities around the world. It should be noted that most of these have a strong emphasis on fundamental R&D activities.

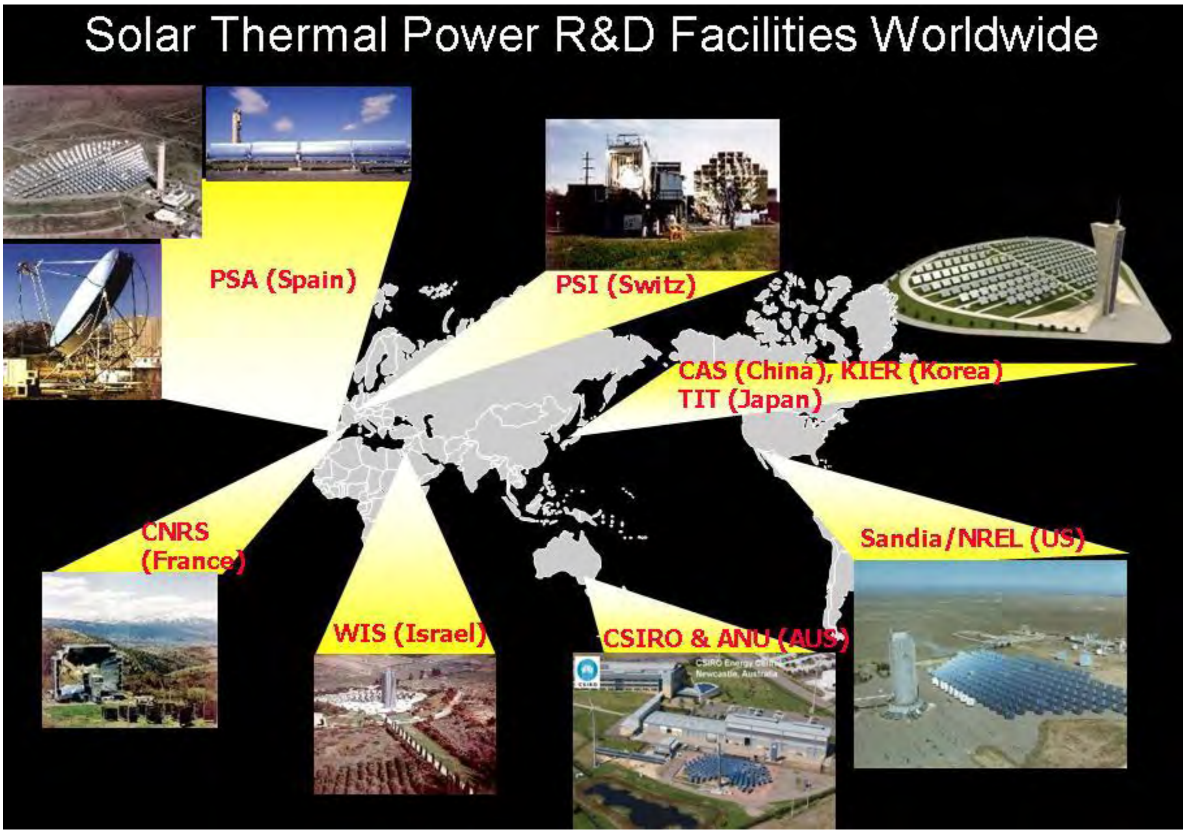


Figure 8.1: Worldwide R&D Facilities, (from SolarPACES)

An outline of the relevant key features follows.

Switzerland **PSI** www.sollab.eu/psi.html

The Paul Scherrer Institute in Switzerland is a major recearch centre that hosts a solar technology laboratory in conjunction with ETH Zurich. Facilities include:

- a 40 kW 5,000-suns solar furnace;
- a 50 kW 11,000-suns high-flux solar simulator;
- two 75 kW 5,000-suns high-flux solar simulators; and
- physical chemistry laboratories.

This is much very much a fundamental research facility.

US **Sandia** www.sandia.gov/Renewable_Energy/solarthermal/nsttf.html

The Sandia National Laboratories based in Albuquerque, New Mexico, hosts the National Solar Thermal Test facility. This centre is a closer match to the vision of a pilot Solar Park.

Figure 8.2: Sandia site

It includes a solar furnace and experimental solar tower facility for fundamental research. In addition, it hosts tests and demonstrations of commercial CSP systems. In 2010, this included an array of dish systems being trialled by Stirling Energy Systems and an array being trialled by Infinia. A multi-purpose platform also is used for performance testing of prototype commercial trough modules.

US **NREL** www.nrel/gov/solar/

The National Renewable Energy Laboratory Solar Thermal facility in Colorado is similar but smaller in extent to Sandia. The website states:

> 'NREL plays a leadership role in analysing cost and performance of solar systems, developing parabolic trough technology for solar electricity generation, and developing advanced technologies such as concentrating photovoltaics. Researchers support the development of new designs and manufacturing processes for solar components and systems with an emphasis on improved performance, reliability and service life.'

Australia **NSEC (Newcastle)** www.csiro.au/places/Solar-Energy-Centre.html

The CSIRO's National Solar Energy Centre has a small solar tower facility, experimental trough systems, various supporting laboratories and is currently constructing another small tower and heliostat field. The land area is limited and its work is very much R&D rather than commercial demonstration.

Israel **Weizman IS** www.weizmann.ac.il/ESER/People/Karni/research.html

In Israel, the Weizmann Institute of Science hosts the solar research facilities unit. The website states,

> 'A major feature of the unit is a Solar Power Tower containing a field of 64 large, multi-faceted mirrors (heliostats), each measuring 7 x 8 meters.'

Once again, the work is very much R&D focussed.

US SolarTAC, Colorado www.solartac.org

Work is underway to establish the Solar Technology Acceleration Centre, (SolarTAC). This new centre appears to be an extremely close parallel to the vision of a pilot Solar Park. It will occupy a 74 acre (30 ha) site near Denver International Airport.

It is a public-private partnership that aims to be an integrated, world-class test facility where the solar industry can research, test, validate, and demonstrate solar technologies. Both CSP and PV technologies are included in its scope. Abengoa are one of the foundation partners and are planning a significantly sized test system of commercial trough units. SunEdison is also a founding partner.

Figure 8.3: SolarTAC concept

8.4 Plataforma Solar de Almeria (PSA), South-east Spain

The Plataforma Solar de Almeria (PSA) in south-east Spain, is the largest, existing global solar thermal test facility, so is worth examining in further detail.

Figure 8.4: Plataforma Solar de Almeria site [7]

This more than 100 ha (250 acre) site is utilised for testing and optimisation of a variety of high-temperature solar technologies. PSA is owned and operated by CIEMAT. It was established through a Spanish-German collaboration and also closely collaborates with several large companies.

> 'At present, the main test facilities available at the PSA are:
>
> - CESA-1 and SSPS-CRS central receiver systems, 7 and 2.7 MW_{th} respectively
> - SSPS-OCS 1.2-MW_{th} parabolic -trough collector system, with associated thermal storage system and water desalination plant
> - DISS 1.8-MW_{th} test loop, an excellent experimental system for two-phase flow research and direct steam generation for electricity production
> - HTF test loop for new parabolic trough collector components
> - DISTAL dish/Stirling facility, 6 units.
> - A 60-kW_{th} solar furnace for thermal materials treatments.
> - DETOX Loop: A solar chemistry facility
> - Laboratory for Energy Testing of Building Components (LECE)
> - Meteorological station.' [8]

[7] www.psa.es/webeng/index.php

[8] www.sollab.eu/psa.html

In addition to the key features listed on the website, there is an extensive administration, reception, visitors centre complex and a commercial test Fresnel system on the site.

Figure 8.5: Plataforma Solar de Almeria satellite image
from http://maps.google.com.au/maps (1 km x 1 km image).

Whilst once again much of the activity is R&D based, there is a major commercial demonstration aspect to it. The physical size of the whole site and the individual installations is also suggested as being a good indication for a pilot Solar Park.

The following photographs give a feel for the scale and nature of such a facility.

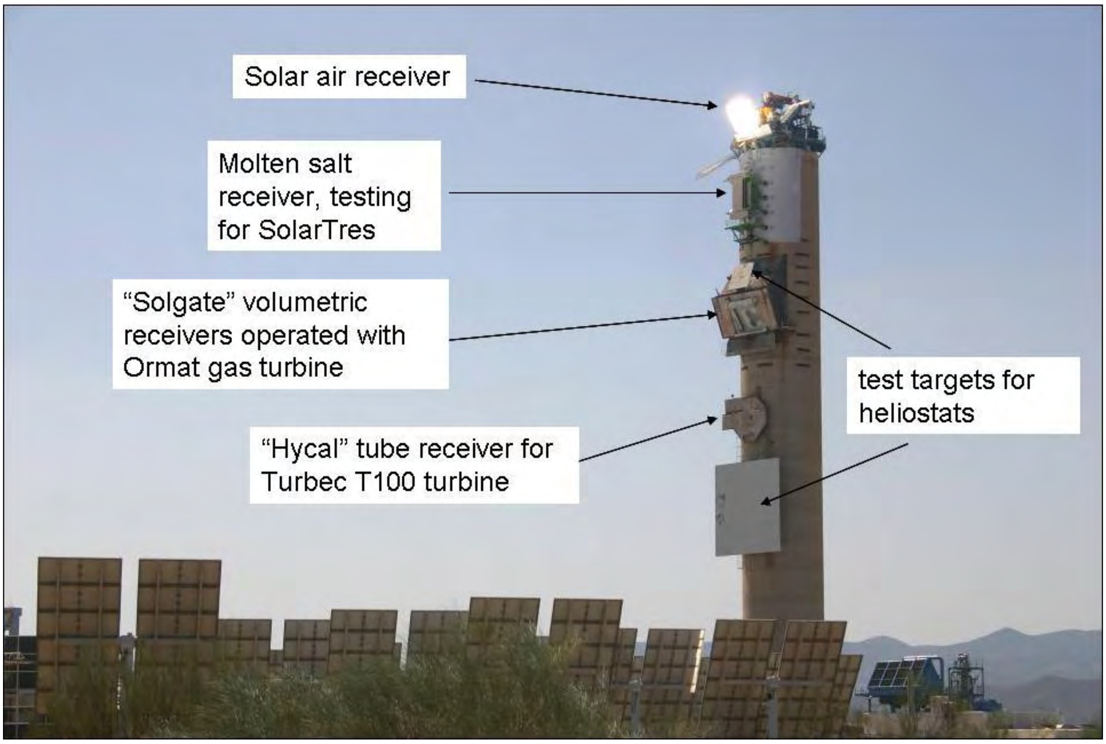


Figure 8.6: The CESA I Tower System, 300 heliostats x 40m^2 each, 12,000m^2, 7 MW$_{th}$ max

The CESA I tower system shown in Figure 8.6, is a possible indication of how a tower system could be used on a task-shared basis. Towers can be configured with multiple focal positions such that a range of receiver systems can be installed at different heights. Various heliostats can be deployed as required to each of the receiver stations. The heliostat field can be populated with heliostats from a range of providers. For commercially mature heliostat products, a significant fraction of the field could be provided for long-term operation. In addition, single new prototype heliostats can also be added to the field.

(a) A range of experimental heliostats

(b) Direct Steam Generation (DISS) test loop – 300m of ET II trough, 5.78m width,12m long modules

(c) Changing receivers on the DISS loop, note the use of a small off road capable telescopic crane.

(d) Test loop for trough prototypes, SENER tough and ET I trough combined test system, Solel trough in background

(e) Solar Furnace - 100m^2 paraboloid

(f) Solucar 120m^2 heliostat for solar furnace (DISS loop in background)

(g) Dish Array, front to back; Eurodish x 2, Distal I, Distal II x 3

Figure 8.7: PSA photos, (K. Lovegrove).

PSA has a large number of staff, (more than 60 people) and is funded on an ongoing basis mainly by government sources.

9 Conclusions and recommendations

Globally, the CSP industry has recently emerged from a 20 year hiatus and now seems set to follow the evolution of the wind and PV industries with rapid growth widely forecast over the next decade. The IEA's CSP Technology Roadmap models a scenario where the CSP installed capacity is 630 GW by 2050. The implementation of the Jawarhalal Nehru National Solar Mission, with its ambitious target of 20 GW_e of installed solar by 2022, with half expected to be CSP, positions India to become a global leader in the growth of CSP technologies.

CSP systems dominantly use thermal power generation with steam and gas turbines which are widely used in existing industries. Heat based generation means that opportunities exist to incorporate thermal storage to provide more cost-effective approaches to achieving renewable energy dispatchability.

India has very good, but not world leading, direct beam solar resources. There is more than enough suitable land with high direct beam solar, to meet the entire nation's electricity needs in principle. The regions with the highest solar resources are largely in Rajasthan, Gujarat plus Jammu and Kashmir. The high capital cost nature of CSP technology means that it is best to construct systems in the locations of highest solar resource even if they are away from existing infrastructure and load centres and some extra transmission losses are incurred. Whilst the grid in India is extensive, there are many regions where the load density has not justified the necessary substations etc for full grid-connection. Within these non grid-connected areas there are industrial sites with captive power generation in the MW range, that would be candidates for small off-grid CSP systems. However, this market is dwarfed by the potential grid-connected market created by the Solar Mission.

As with many countries, including Australia, the available data on solar resource is not ideal in quantity or quality. Any move to improve on this will help the industry as a whole, however the weakness of the data is not likely to be a determining factor for the future of CSP in India compared to other policy settings.

The Government of India's Solar Mission is a visionary and inspiring policy measure that has the potential to be a leading example for the world. Features like the eligibility requirement for CSP, that technology must have been demonstrated for at least 12 months at a scale of 1 MW_e or above are sensible and should be maintained. No doubt many lessons will be learned as the phase 1 process unfolds. It is to be hoped that the shortlisted projects succeed financially and technically. The reverse auction approach to tariff determination carries considerable risk of allocations being made to 'adventurous' bidders who may ultimately be unable to deliver.

Choosing mechanisms for determining the income stream that CSP project developers benefit from is a difficult component for government policy setting. Examining the history of worldwide approaches, it is apparent that no country has found a problem free formula for this. The Solar Mission model of setting a maximum tariff and inviting a reverse auction by bidders, has advantages but also carries risks. An important consideration will be to include technical and business capability criteria, as well as low cost, in the selection process.

Various stakeholders have suggested that adventurous bidding will lead to the failure of some selected proposals. They have also indicated that the timelines for obtaining financial close, construction and commissioning demanded under phase 1 are likely to be almost impossible to meet. It remains to be seen how this unfolds. There may be a need for dealing with this in a pragmatic manner, as inflicting significant financial penalties may not benefit the long term development of the Indian CSP sector. How revenue raised from any financial penalties is allocated for expenditure should be considered carefully to minimise any potential for perverse incentives.

Opportunities

The current Solar Mission guidelines plus those of the State based measures are missing some key opportunities. Energy storage, whilst not precluded, is not suitably encouraged by the flat-tariffs on offer. Some incentive via a time-of-generation tariff would be more likely to produce the best technical and economic solutions. The present Solar Mission design also excludes hybridisation with biomass or fossil plants and this may not be optimal given the potential synergies that exist.

With any changes, the key consideration is to make careful adjustments in light of experience. The lessons of the US experience with the SEGS plants and the Luz company should be kept in mind. A sudden and somewhat unpredictable policy reversal led to the failure of the most successful company and lead to a 20 year global CSP hiatus.

India, being a federation of states like Australia, has many aspects relevant to renewable energy that are shared responsibilities of federal and state levels of government. This adds to the potential for complexity and confusion, particularly for a new industry that is growing and encountering issues not previously experienced. Progress is clearly being made, but a lot of issues remain. A promising way of accelerating development is through the establishment of Solar Parks in obvious candidate high DNI areas. Rajasthan has well advanced plans in this regard and Gujarat is also pursuing the concept. Large areas of land that have all the necessary approval processes for a CSP development already addressed, plus the necessary grid and water supply issues addressed, have the potential to reduce project timelines by as much as two years with a consequent reduction in overhead costs. There will need to be carefully managed allocation methods for land within such parks to avoid allocations locked up by non-performers.

The Solar Park concept could also be applied to advantage small-scale demonstrations. Increasing the field of companies that can meet the 'at least 1 MW_e for at least 12 months' requirement of the Solar Mission will assist in further developing the Indian CSP sector. Demonstration Solar Parks should be similar to the large Solar Parks but should be sited next to cities with major infrastructure and air access (whilst still having as high a DNI resource as possible). Demonstration Solar Parks should limit system size to about 5 MW_e. To support these earlier stage activities, a preferential tariff for these small-scale systems should be provided, significantly above the tariff offered for large-scale CSP projects.

There are many aspects of the Indian business culture that are very different to the countries that are the current dominant CSP players. To the outsider, India can seem chaotic and unpredictable but the raw human energy and intensity of the country is immediately apparent. India's strong track record of technical success, in every new field that it has seriously engaged in, from wind turbines to information technology, makes it clear that a major player position in CSP is feasible. To accelerate the necessary technology transfer process, policy measures that facilitate Indian equity investment in existing CSP companies around the world, together with carefully designed schemes for overseas secondments and training that include the industry sector, are recommended.

India appears to have positioned itself to play a key role in global CSP developments provided the present measures continue and are implemented in a pragmatic manner with appropriate support for R&D, demonstration, standards and industry training.

The specific recommendations of this report are to investigate options to:

1. Modify State based and Solar Mission tariffs to recognise time-of-generation benefits and incentivise energy storage.

2. Modify State based and Solar Mission guidelines to allow CSP tariffs to be earned proportionate to solar contribution as part of a solar-hybrid system.

3. When the current phase 1 process is complete, review Solar Mission timelines for financing, construction and commissioning based on experience.

4. Continue and expand facilitated Solar Parks for large-scale CSP projects.

5. Establish one or more 'Demonstration Solar Parks' for small-scale, commercial demonstration systems and support these with a higher tariff.

6. Establish further projects to improve on DNI data availability, by both adding ground based data gathering and also to reverse analyse, correlate and re-calibrate all existing forms of historical data. Make all such data freely available and easily accessible.

7. Investigate facilitation measures (e.g. tax incentives, soft loans or revolving equity fund) aimed at assisting Indian companies to make equity investments in CSP companies around the world .

8. Establish and / or review targeted schemes for CSP related industrial, research and policy secondments / traineeships / fellowships around the world.

9. Maintain or even strengthen the guideline of 'at least 1 MW_e demonstrated for at least 12 months' for future phases of the Solar Mission.

10. Implement a loan guarantee program for worthwhile CSP projects, similar to that in the US.

11. Avoid any sudden changes of policy settings that cause companies nurtured under the previous policy framework to fail.

12. Investigate options to provide investment incentives for expanding network infrastructure in high DNI regions.

13. Provide more resources to MNRE to facilitate improved information flows for industry and other stakeholders, e.g. upgrade and redesign the website and include factsheet summaries, case studies and updates on key activities.

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Appendix A International Exchange Rates

The following exchange rate data is from http://www.x-rates.com/ accessed December 2010.

Data is for the second half of 2010. It reflects a weakening overall value to the US dollar and increasing value for the Australian dollar relative to the other currencies in that period.

For approximate indicative conversions:

US $1 = IN Rs. 45

US $1 = AU $1A

US $1 = EU 0.75

EU 1 = AU $1.4

AU $1 = IN Rs. 43

English language Indian documents frequently use pre-fixes from the Indian numbering system for financial quantities:

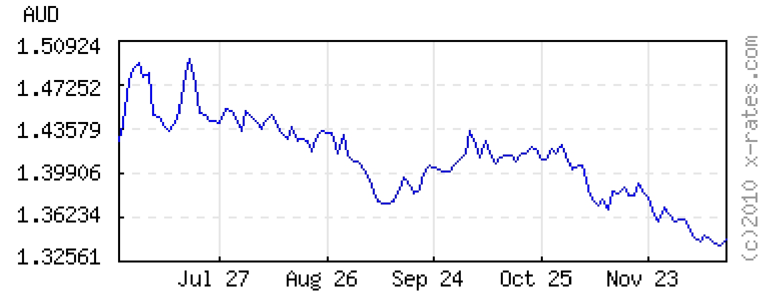
Lakh = 100,000, and

Crore (CR) = 10,000,000.

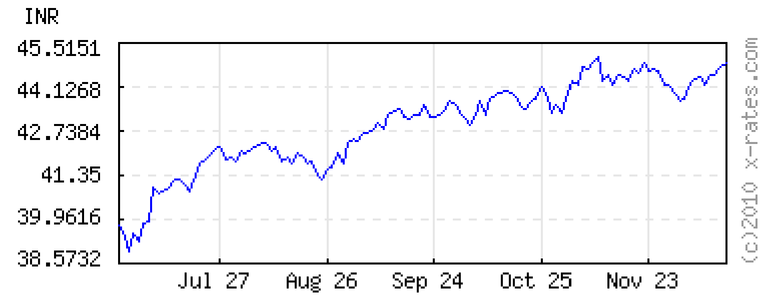
Indian Rupees (Rs) per US $

AU $ per US $

EU 1 per US $



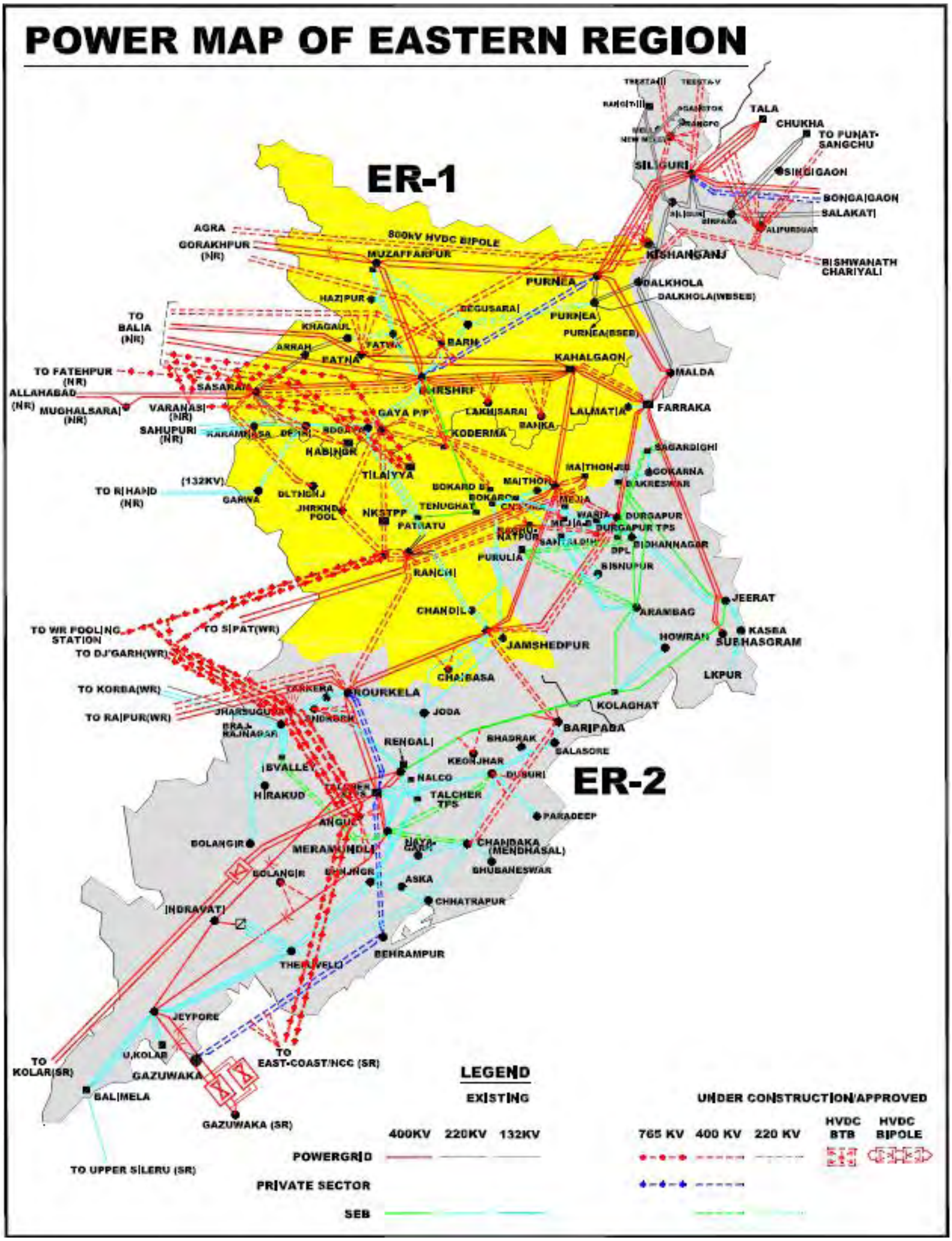
AU $ per EU 1



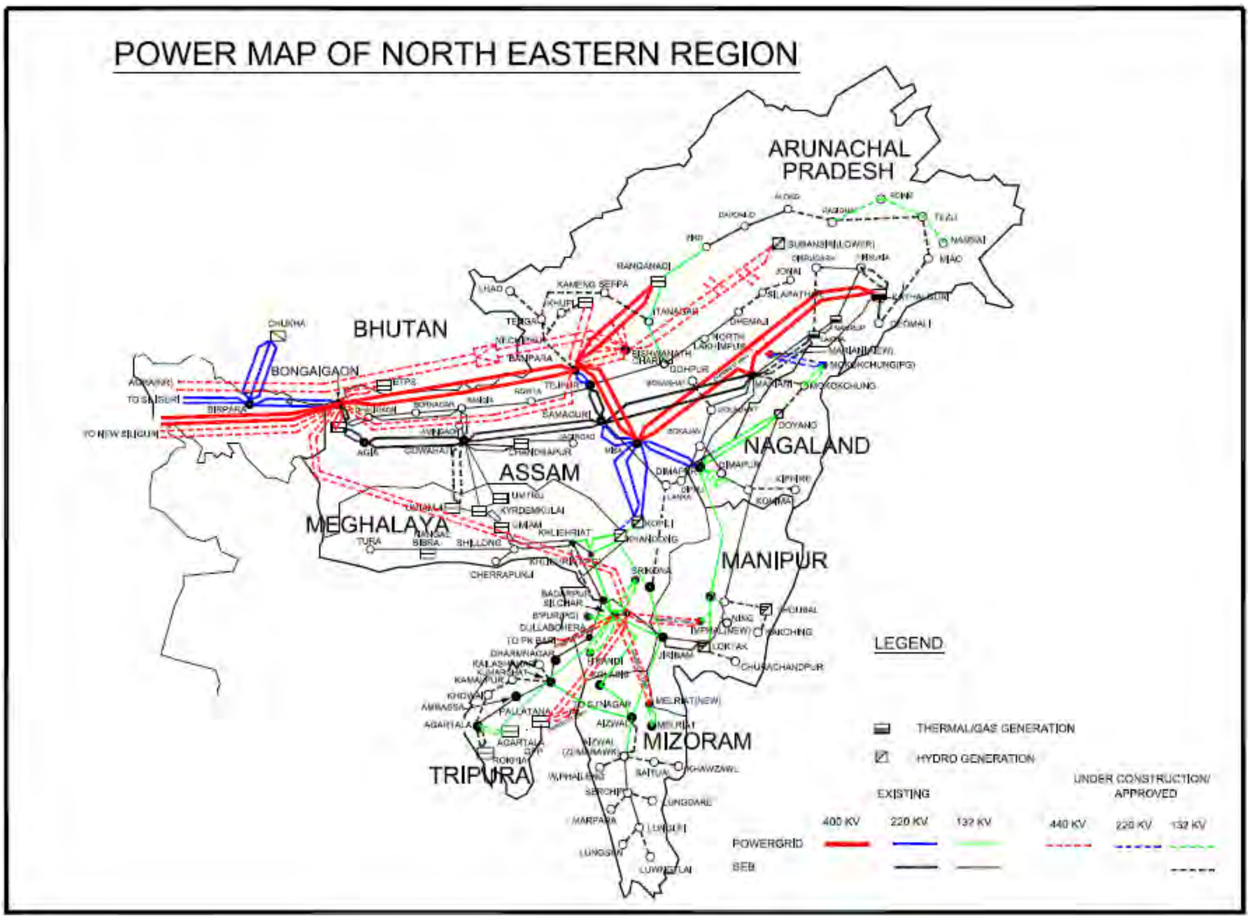
Indian Rupees to AU $

Appendix B Electricity Network Maps

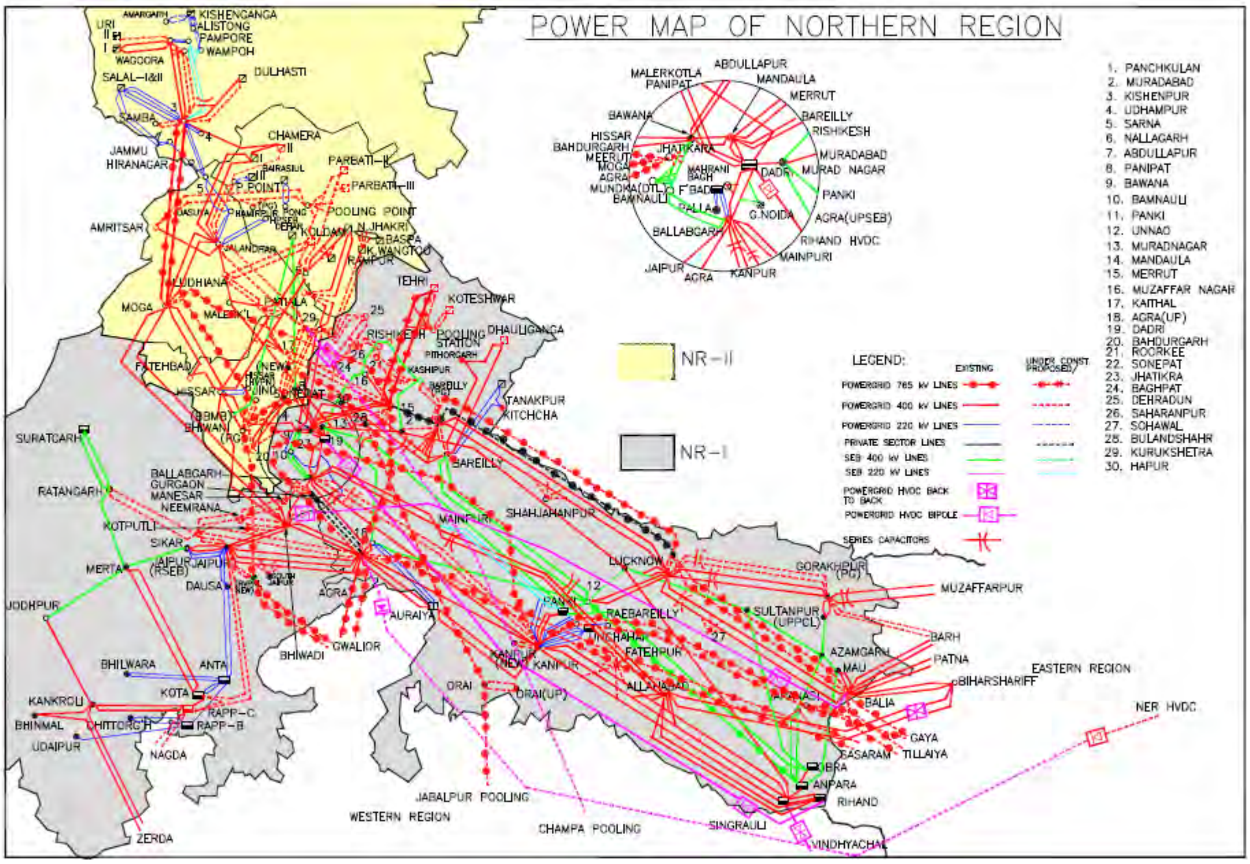
The following maps are provided by Powergrid, India's state-owned transmission utility.



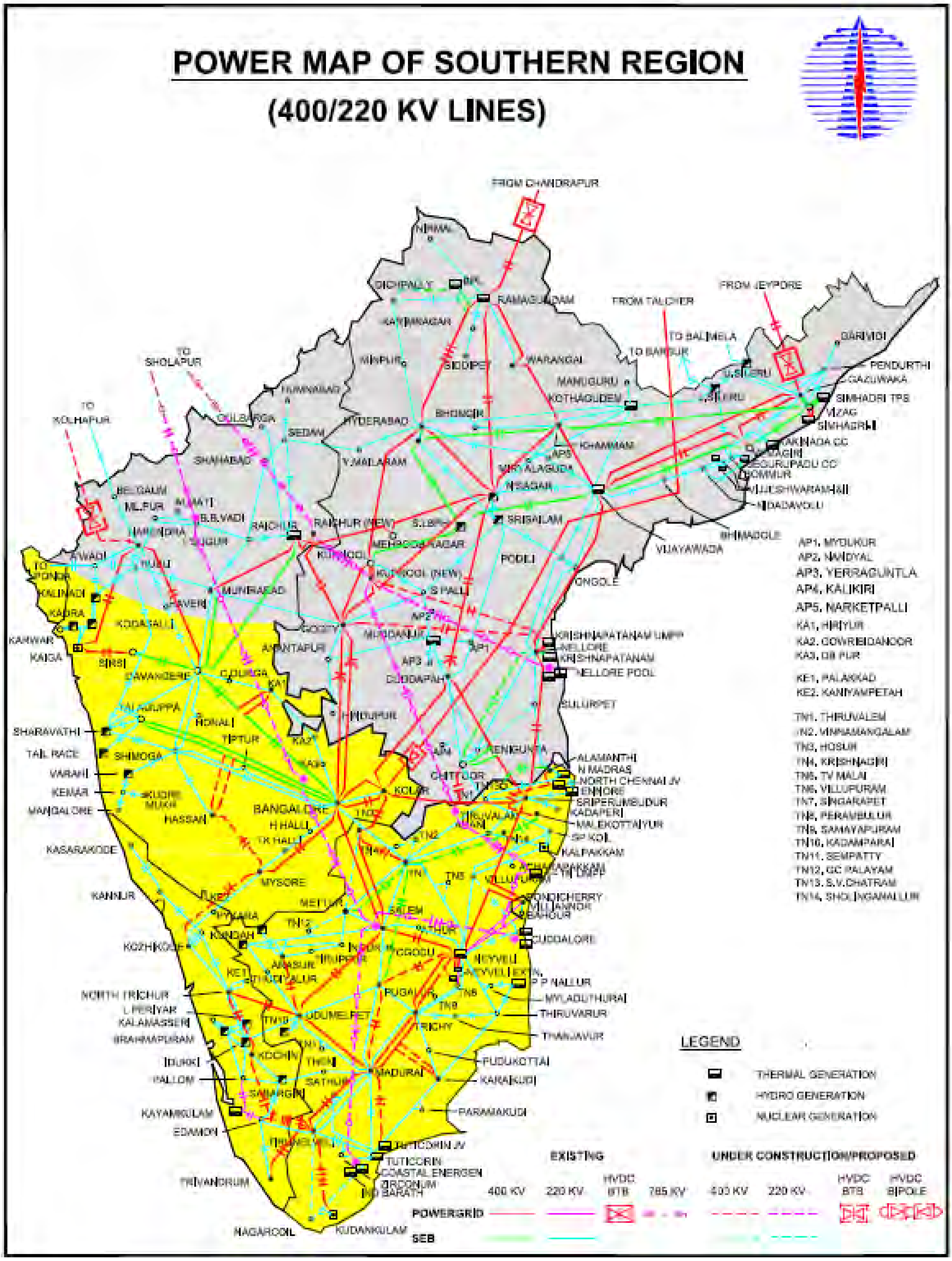
www.powergridindia.com, accessed October 2010



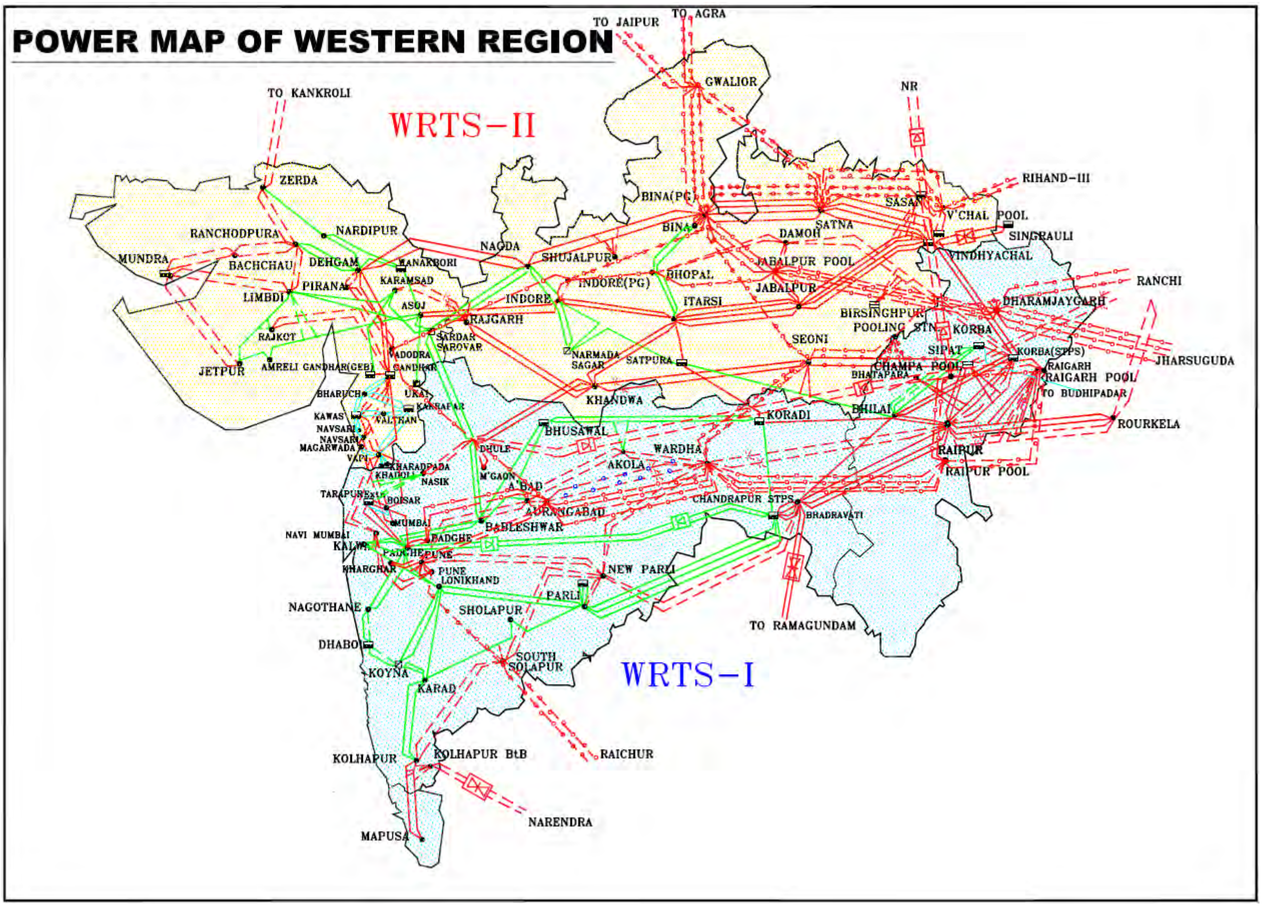
www.powergridindia.com, accessed October 2010



www.powergridindia.com, accessed October 2010



www.powergridindia.com, accessed October 2010



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Concentrating Solar Power in India

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