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Solar thermal power

The seamless solar link to the conventional power world

Solar thermal energy has generated a lot of interest as a power source for the future. Michael Geyer and Volker Quaschning look at two solar thermal generation concepts and the various schemes that are currently underway around the world.

In May 2000 was the deadline for submitting proposals to the pre-qualification for the implementation of the first solar BOOT (Build-Own-Operate-Transfer) project in Kuraymat (Egypt). Ten international consortiums have applied to finance, set-up and operate this 35 MW_e solar thermal power plant. The incremental costs referred to a conventional fossil power plant will be paid by the Global Environmental Facility (GEF), the world environmental fond of the industrial nations that is administrated by the Worldbank. Amongst the bidders are well-known companies such as BP Amoco, ABB, Duke Energy, ENEL, Mahrubeni and others. This shows the interest of energy key players in solar thermal as future clean power option.

Solar thermal power generation

Solar thermal power is one of the main candidates to provide a major share of renewable clean energy needed in the future for the following reasons:

- Solar radiation is the largest renewable resource on earth. Approximately 1 % of the world's desert area utilized by solar thermal power plants would be sufficient to generate the world's entire electricity demand anticipated for the year 2000.
- This energy source is more evenly distributed in the sunbelt of the world than wind or biomass, allowing for more site locations.
- It is among the most cost effective renewable power technologies with near-term power generation costs in the range of 12 to 20 US¢/kWh and of 5 to 10 US¢/kWh for long-term considerations. And it is the lowest cost solar electricity in the world, promising cost competitiveness with fossil-fuel plants in the future.
- It is a well-proven and demonstrated technology. Over 100 years of accumulated operating experience, with nine solar thermal power plants of the parabolic trough type feeding over 9 billion kWh of solar-based electricity into the Californian grid, demonstrate the soundness of the concept.
- It is now ready for more wide-spread application if we start more intensified market penetration immediately.
- Accelerated application will lead to further innovation and cost reductions to meet the challenge of competitive conditions in the next millennium.

All concentrating solar thermal power (STP) technologies rely on four basic key elements: concentrator, receiver, transport-storage, and power conversion.

The concentrator captures and concentrates solar radiation, which is then delivered to the receiver. The receiver absorbs the concentrated sunlight, transferring its heat energy to a working fluid. The transport-storage system passes the fluid from the receiver to the power-conversion system; in some solar-thermal plants a portion of the thermal energy is stored for later use. As solar thermal power conversion systems, Rankine, Brayton, Combined or Stirling cycles have been successfully demonstrated. Two emerging solar thermal power generation concepts will be presented here more closely.

The parabolic trough or solar farm

The parabolic trough or solar farm consists of long parallel rows of identical concentrator modules, typically using trough-shaped glass mirrors. Tracking the sun from East to West by rotation on one axis, the trough collector concentrates the direct solar radiation onto an absorber pipe located along its focal line. A heat transfer medium, typically oil, at temperatures up to 400 °C, is circulated through the pipes. The hot oil converts water to steam driving the steam turbine generator of a conventional power block.

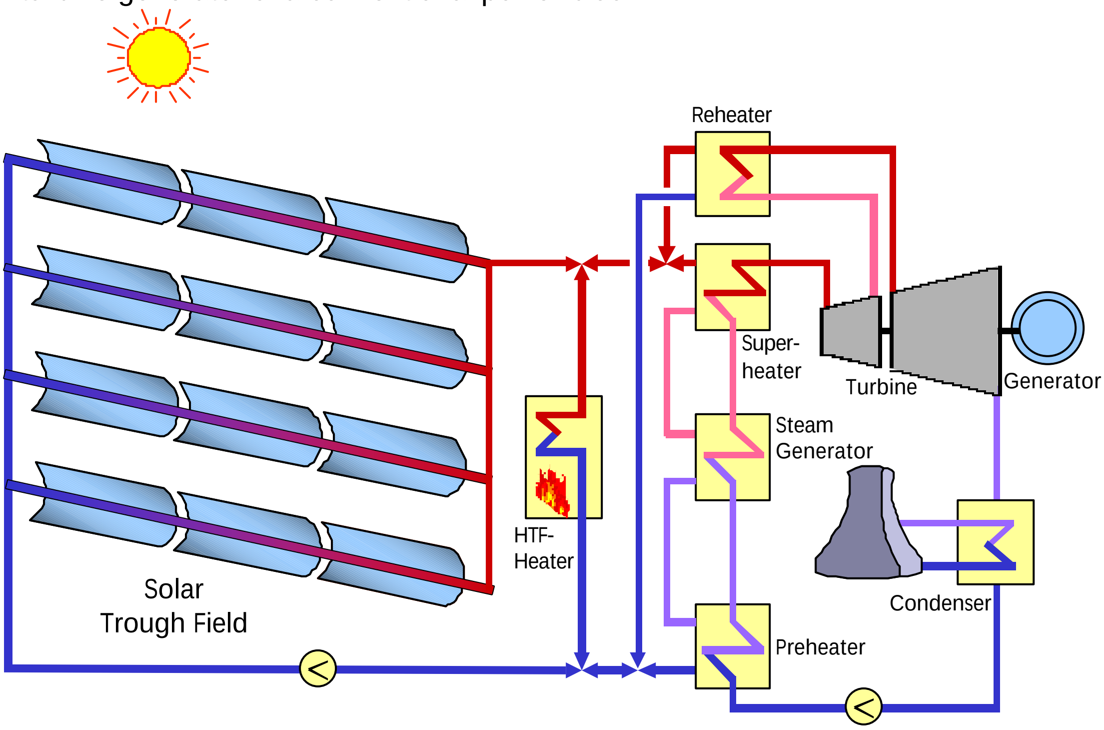


Figure 1: Schematic of a SEGS-Solar Trough Power Plant cycle

The solar central receiver or power tower

The solar central receiver or power tower is surrounded by a large array of two-axis tracking mirrors, termed heliostats, reflecting direct solar radiation onto a fixed receiver located on the top of the tower. Within the receiver, a fluid – water, air, liquid metal and molten salt have been tested – transfers the absorbed solar heat to the power block where it is used to heat a steam generator. Advanced high temperature power tower concepts are now under investigation, which heat pressurized air up over 1000 °C in order to feed it into the gas turbines of modern combined cycles.

The inherent advantage of STP technologies is their unique integrability into conventional thermal plants: All of them can be integrated as "a solar burner" in parallel to a fossil burner into conventional thermal cycles and provide with thermal storage or fossil fuel backup firm capacity without the need of separate backup power plants and without stochastic perturbations of the grid.

With a small amount of supplementary energy from natural gas or any other fossil fuel, the solar thermal plants can supply electric power on a firm and a secured basis. This is possible because the solar thermal concepts provide the unique capability to internally complement the fluctuating solar burner output with thermal storage or a fossil backup heater. With this feature, solar thermal systems are the only renewable power plants that will neither cause grid perturbations nor disturb the operation of the other existing fossil plants in the entire power park. These features make STP technologies a likely candidate for large-scale emissions reduction at reasonable cost.

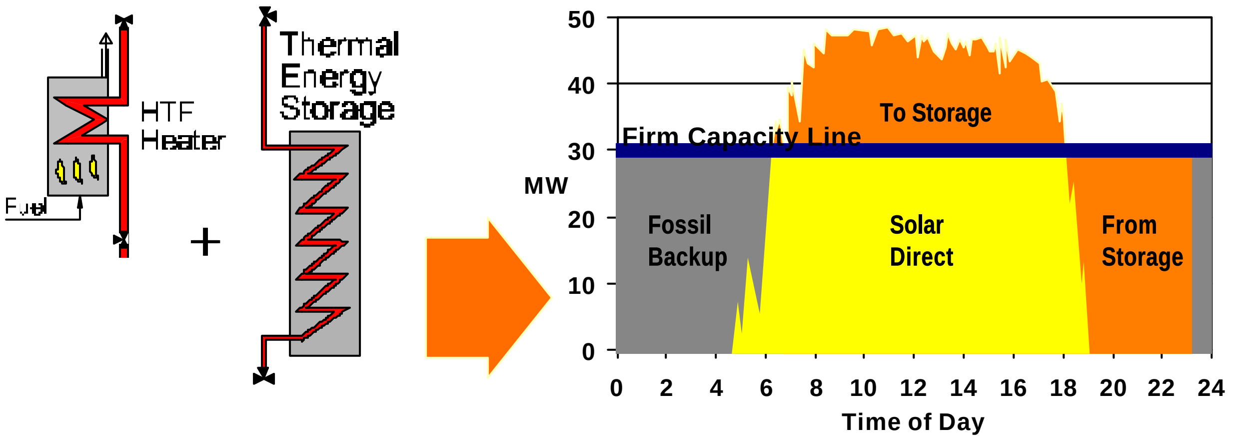


Figure 2: With minimum fossil backup firing and/or thermal energy storage, the solar capacity is transformed into firm capacity

Trough power plants

With 354 MW of solar electric generating systems (SEGS) parabolic trough power plants connected to the grid in Southern California since the mid-1980s, parabolic troughs represent the most mature STP technology. To date, there are more than 100 plant-years of experience from the nine operating plants, which range in size from 14 MW to 80 MW. The decline of fuel prices led to a 40 % reduction of electricity sales revenues in the late 1980's. This has resulted in new trough projects being no more competitive in California. However, the nine existing SEGS units continue to generate electricity, demonstrating reliability of this technology. Up to now, 9 TWh of solar electrical energy has been fed into the Californian grid, resulting in sales revenues of over US$ 1000 million.

The performance of these power plants has continued to improve over their operational lifetime. The Kramer Junction site has achieved a 30 % reduction in operation and maintenance (O&M) costs during the last five years, increasing at the same time the plant efficiencies to daily peak values in summer close to 20 %. Although higher thermodynamic efficiencies are being predicted for the higher concentrating power towers, none of the many power tower demonstration plants could yet come close to the annual performance and efficiency of the commercially operating parabolic trough plants, but fell short of the predictions.

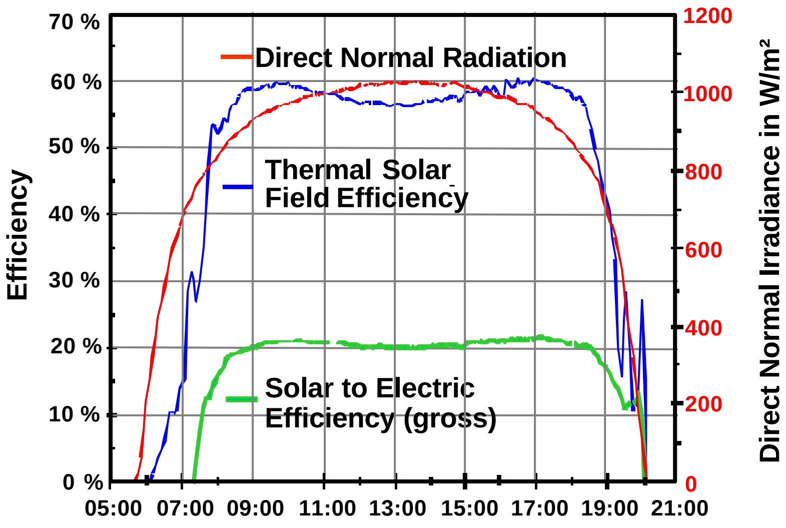


Figure 3: Solar Efficiencies measured at SEGS VI on July 1997 by KJC Operating Company

This success is the result of major improvement programs for the collector design and the O&M procedures, carried out in collaboration between the Kramer Junction Company Operating Company and Sandia National Laboratories (Albuquerque). In addition, key trough-component manufacturing companies have made advances. For example, SOLEL in Israel has improved the absorber tubes, and Pilkington Solar has developed improved process know-how and system integration and is working to initiate new projects in the world's sunbelt. Firms like Abengoa and Gamesa in Spain and Duke Solar in the USA have developed capabilities to become turnkey suppliers. It is estimated that new plants, using current technology with these proven enhancements, could produce clean solar power today for about 12 to 20 US¢/kWh.

Figure 4: Aerial view of the five 30 MW_e parabolic trough plants at Kramer Junction, California (Courtesy of KJC)

Within the DISS (Direct Solar Steam) project the oil as heat transfer medium will be replaced by water that is directly evaporated and overheated to temperatures of 400 °C at a pressure up to 100 bar. This steam can be fed directly into a steam turbine, so that the heat exchanger and the oil are no more necessary. This project will reduce the costs and increase the annual efficiency. A further cost reduction and better efficiency will be obtained within the EUROtrough project due to the development of an improved collector structure. Numerous industrial partners are involved in these projects. Prototypes of both project developments are set-up and tested at the Plataforma Solar de Almería.

Power tower plants

In more than 15 years of experiments worldwide, power tower plants have proven to be technically feasible in projects using different heat-transfer media (steam, air, sodium, and molten salts) in the thermal cycle and with different heliostat designs. U.S. and European industries (including Abengoa, Ghersa, Bechtel, Boeing and Steinmüller) have expressed interest in commercializing second-generation power tower technology and have recently constructed and operated demonstration power plants.

Figure 5: 10 MWe Solar Two power tower demonstration facility with molten salt receiver and storage at Barstow, California (Courtesy of SunLAB)

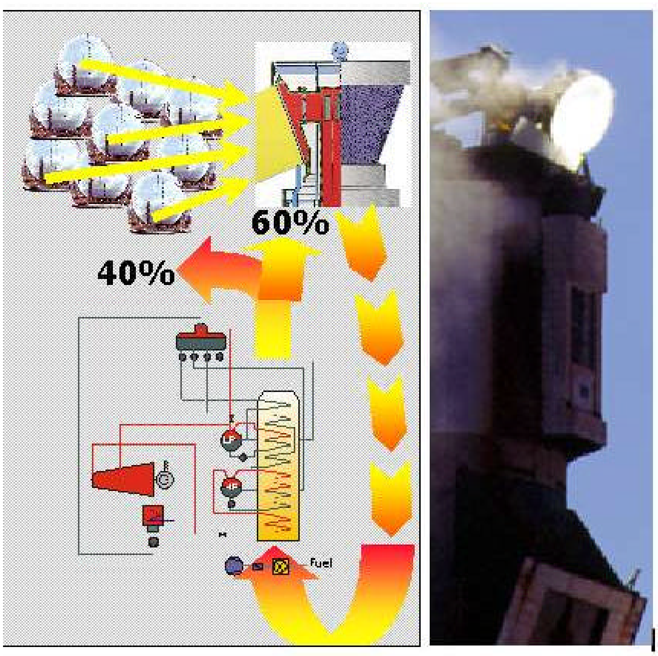


Figure 6: Phoebus power tower concept with volumetric air receiver and TSA receiver testing at the Plataforma Solar de Almería, Spain (Courtesy of Ciemat and DLR)

At Barstow, California, a 10 MW pilot plant (Solar One) operated with steam from 1982 through 1988. It recently operated as Solar Two, with molten salt as the heat-transfer and energy-storage medium, after modification of the complete plant in 1996. The system now has a few thousand hours of experience and before shutting down in April 1999, was delivering power to the electricity grid on a regular basis. Solar Two has demonstrated, via storage, the feasibility of delivering utility-scale solar power to the grid 24 hours per day, if necessary.

In parallel, European activities have demonstrated the volumetric air receiver concept where the solar energy is absorbed on fine-mesh screens and immediately transferred to air as the working fluid. Extensive validation of this concept has been demonstrated at the 2.5 MW (thermal) level by the Phoebus Technology Program Solar Air Receiver (TSA) tests conducted over the past few years in Almería, Spain.

Market Aspects

With the advent of independent power producers (IPPs) and deregulation of the electricity sector, there is intense competition within the power industry to gain market share. Profit margins on power projects are small, and consequently, IPPs are hesitant to take risks on new technology like STP plants. As a result, it is very difficult to introduce a new technology in the marketplace.

The market success of STP plants will depend heavily on the choices made between environmental protection and the lowest possible electricity cost. As these are in many ways mutually exclusive, the final outcome will depend on both energy policy decisions and international support for responsible environmental actions in a climate of scarce resources.

The international community of nations is concerned about climate change and environmental damages. The “Intergovernmental Panel for Climate Change” (IPCC)” demands drastic reductions of the greenhouse gas emissions in order to avoid a collapse of the world climate by global warming. In Kyoto 1998 the nations agreed to compelling CO_2 reduction quota; Japan committed itself to a 6 %, US to 7 % and the European Union to 8 % CO_2 reduction of the 1990 levels until 2012.

To achieve this goal, the European Commission aims at increasing the renewable share of its annual primary energy consumption from 6 % today to 12 % in 2010. This had been announced for the first time 1996 in the Madrid Declaration, was further specified in the 1998 Energy White Paper and is now being supported within the 5th Framework Program. More important, however, is the intention of the European Union, to oblige its member states to fix quota or harmonized premiums for renewable technologies in order to accelerate their market introduction. This includes the introduction of cost covering compensation tariffs and purchase obligations for renewable power in entire Europe. Together with the liberalization and deregulation of the European electricity sector this will create new market rules and private investment opportunities, since this will allow each investor in renewable power to produce his clean electricity at the sites with best renewable resources and sell them at the market places of highest revenues.

Also some of the main sponsors of energy investments in the developing world, i.e. the Worldbank Group, the Kreditanstalt für Wiederaufbau (KfW) and the European Investment Bank (EIB) have recently been convinced of the environmental promises and the economic perspectives of STP technologies: Only in spring this year, the board of the Global Environmental Facility (GEF) approved grants for first solar thermal projects in Egypt, India, Mexico and Morocco of app. US$ 200 million in total.

The world wide dramatic decrease of interest rates and capital costs has significantly increased attractiveness of investments in capital intensive renewable projects, including STP. Private venture capital for STP project development and green power investment funds are becoming available in Europe now.

Last not least, the oil price has recently achieved again the US$ 30/barrel.

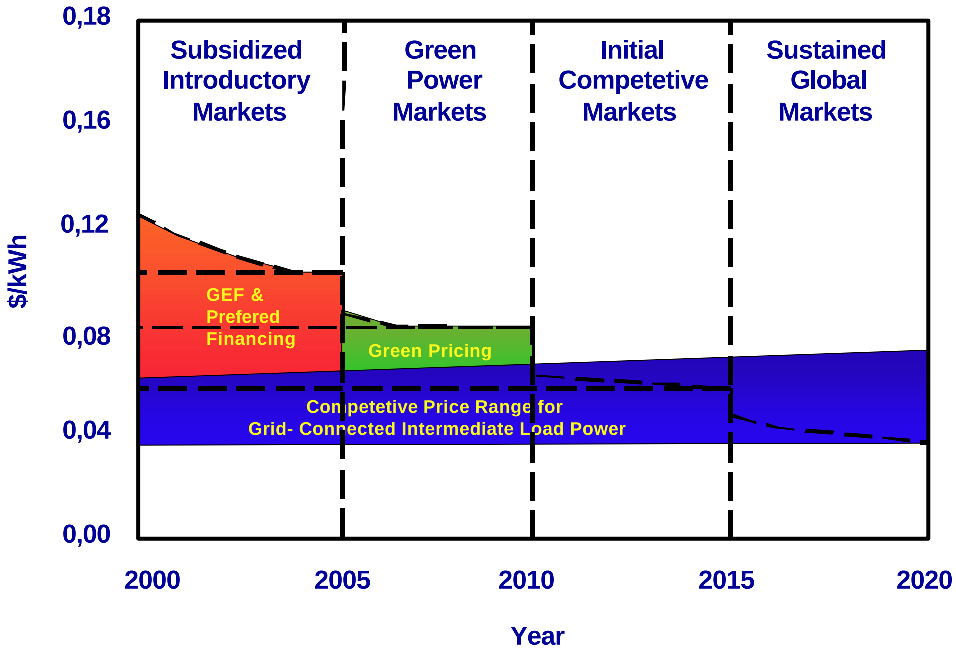


Figure 7: Market introduction of STP technologies with initial subsidies and green power tariffs (Source: SunLAB, USA)

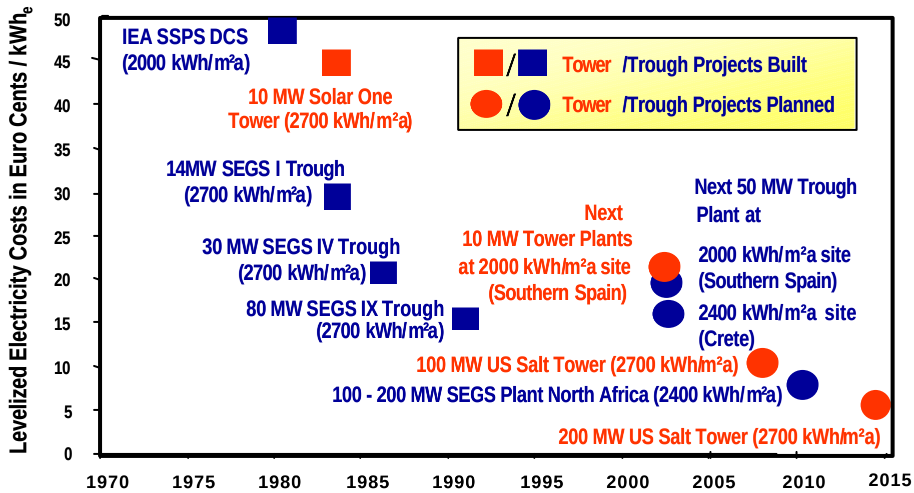


Figure 8: Evolution of levelized electricity costs for solar thermal power plants referred to solar-only production for sites with different direct normal irradiation (Source: DLR-Almería)

On this background, project developers suggest a market entry strategy for STP technologies in three phases:

Solar field additions

To respond to present market needs and reduce the amount of buy-down necessary to make STP immediately competitive, small solar fields can be integrated into combined cycle and coal- or fuel oil fired power plants. The additional investments required will be in the order of only US$ 400 to 1500 per kW installed, achieving in base load operation a modest solar share of up to 10 %

Increased solar shares

With increasing fossil fuel prices, compensation premiums for CO_2 avoidance and solar field cost reductions, solar shares can be increased to about 50 % and more when they are integrated into conventional, coal- or fuel oil-fired power stations. Here, the potential is greatest for the largest emission reduction.

Thermal energy storage

With further rising fuel price levels, thermal energy storage will be able to further substitute for the need of a fossil back-up fuel source. In the long run, base-load operated solar thermal power plants without any fossil fuel addition are in principle possible.

Figure 8 shows the reduction of the levelized electricity cost that has been achieved within the last years and the expected reduction due to the increasing market penetration.

STP Projects under Development

On this background, various commercial STP developments are currently under way:

Australia

Under the Australian Greenhouse Office (AGO) Renewable Energy Showcase Programme, a 13 MW_t Compact Linear Fresnel Reflector (CLFR) demonstration unit will be installed late in the year 2000, retrofitted to an existing 1400 MW_e coal fired plant in Queensland.

Greece

On the island of Crete, the private venture capital fund Solar Millennium together with strong Greek and European industrial partners has established the first solar thermal project company THESEUS S.A. and submitted the application for licensing a 52 MW solar thermal power plant with 300'000 m² of parabolic trough solar field, which shall supply solar only electricity to Crete's island grid.

Spain

The prospect of new incentive premiums for the generation of renewable electricity in 1999 has initiated various private solar project developments, with both parabolic trough and power tower technologies. Prominent Spanish companies as Abengoa, Gamesa and Ghersa have engaged themselves in solar thermal technologies. Three projects are coming along:

- 10 MW_e solar-only power tower plant project Planta Solar (PS10) at Sanlúcar near Sevilla promoted by the Spanish Abengoa Group with partners and application of Steinmüller's volumetric air receiver/energy storage technology.
- 10 MW_e solar-only power tower plant (Solar Tres) project at Cordoba promoted by the Spanish Ghersa and the Bechtel/Boeing with application of US molten-salt technologies for receiver and energy storage.
- 32 MW_e solar trough power plant (Andasol) in the province Almería with a 235'000 m² EUROtrough solar collector field, 16'000m² of them with direct steam generation.

USA

Green electricity and renewable portfolio policies of various states have revived the interest of prominent industrial firms like Bechtel, Boeing and Duke Solar in the further development of STP technologies.

Support of STP

Operational Program No.7 of the Global Environmental Facility (GEF) has the objective of reducing anthropogenic greenhouse gas (GHG) emissions by increasing the market share of those low GHG energy technologies for specific applications which are not yet widespread least-cost alternatives in the recipient countries, the governments of the following countries have applied for the support of STP projects:

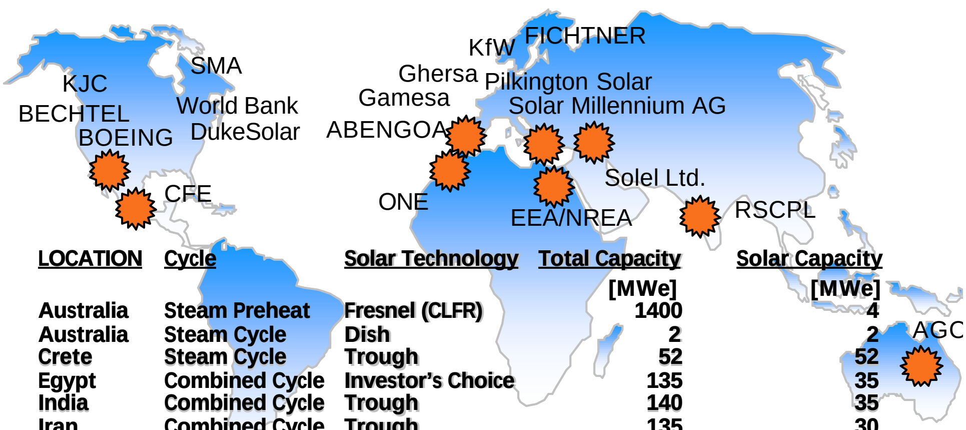
Egypt
Egypt plied at GEF for supporting the addition of 200‘000 to 500‘000 m² parabolic trough field to a new natural gas fired combined cycle project in Kuraymat, that is currently in the pre-qualification process.

India
India lied at GEF for supporting the addition of a 200‘000 m² parabolic trough field to a 135 MW naphtha fired combined cycle power project in Mathania, Rajasthan. The German KfW has offered a US$150 million soft loan for this project, for which GEF has allocated a US$ 45 million grant. The preparation of the terms of reference has just been contracted.

Iran
Iran has contracted, with its own national funds, a feasibility study for the implementation of a 100 MW natural gas fired combined cycle plant with a 200’000 to 400’000 m² parabolic trough field in the desert of Yazd.

Mexico
Mexico lied at GEF for supporting the addition of a 100‘000 to 500‘000 m² parabolic trough field to a new natural gas fired combined cycle project in the desert areas of Northern Mexico, that shall be bidden to private investors as an independent power project. The preparation of the terms of reference for has been contracted.

Morocco
has applied at GEF for supporting the addition of a 100‘000 to 500‘000 m² parabolic trough field to a new natural gas fired combined cycle close to the new gas pipeline from Algeria to Spain, that shall be bidden to private investors as an independent power project. The preparation of the terms of reference will start in the next months.



LOCATION	Cycle	Solar Technology	Total Capacity [MWe]	Solar Capacity [MWe]
Australia	Steam Preheat	Fresnel (CLFR)	1400	4
Australia	Steam Cycle	Dish	2	2
Crete	Steam Cycle	Trough	52	52
Egypt	Combined Cycle	Investor’s Choice	135	35
India	Combined Cycle	Trough	140	35
Iran	Combined Cycle	Trough	135	30
Mexico	Combined Cycle	Investor’s Choice	310	40
Morocco	Combined Cycle	Investor’s Choice	150	30-50
Spain	Steam Cycle	Trough	50	50
Spain	Steam Cycle	Tower (*PS10*)	10	10
Spain	Steam Cycle	Tower (*Solar Tres*)	10	10
US, Nevada	Steam Cycle	Trough	30	30

Figure 9: International solar thermal project developments and players

The GEF and other organizations recognize the value in developing clean and sustainable STP and are offering significant economic incentives, such as grant funding, to deploy initial plants. What appeals to these organizations is that the embodied energy of a STP plant is recovered after less than 1.5 years of plant operation and the power plant produces orders of magnitude less carbon dioxide per GWh on a life-cycle basis than competing fossil-fired plants. Construction of STP plants, with GEF grant funding, could thus help sunbelt countries meet the carbon dioxide reduction goals established at the 1997 Kyoto Climate Change Convention to reduce global warming.

The 'Cost Reduction Study for Solar Thermal Power Plants' prepared for The World Bank in early 1999 concludes that the market of STP is large and could reach an annual installation rate of 2000 MW. The best regions for STP are Southern Africa, Mediterranean countries (including North Africa, Middle East and Southern Europe), India, parts of South America, Southwest U.S./northern Mexico and Australia. The operating characteristics of STP are relatively well matched with the intermediate and peak electricity load requirements in these regions.

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