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SOLAR THERMAL THEMATIC REVIEW

DRAFT REPORT

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Disclaimer

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1: Introduction

Growing concern about environmental problems has stimulated the development of renewable energy technologies, which in turn will facilitate a more sustainable development of the energy system. The diffusion and adoption of these technologies will, however, depend on further development and cost cutting through innovation and experience. The Global Environment Facility (GEF), under its climate programmes, focuses on some of these technologies and fosters projects that include the private sector in the development of markets in developing countries. GEF renewable energy projects, generally, fall into two categories:

1. 'Barrier removal' projects, which develop and promote markets for commercial and close-to-commercial technologies under Operational Program 6 (OP6), and
2. 'Cost reduction' projects which conduct research, demonstration and commercialisation activities to lower long-term technology costs under Operational Program 7 (OP7).

The GEF has identified solar thermal power technology (STP) as one of the renewable energy technologies it supports in its operational programs. Development of STP represents one of the most cost efficient options for renewable bulk power production, and the most cost-effective way of producing electricity from solar radiation. Many of the GEF client countries, including the regions of Northern and Southern Africa, India, Northern Mexico and parts of Southern America, have high levels of solar radiation suitable for STP. Indeed, STP could play an important role in meeting some of the high and drastically increasing demand for electricity in these regions, with fewer emissions than alternative purely fossil-fuelled plants.

Although, great progress has been made in STP since the early 1980s, based on the commercial success of the 354 MW installed in nine Solar Electricity Generating Systems (SEGS) in California, still, it is not currently cost effective in most power markets. Thus, STP technology falls into OP7, with the aim of reducing the long-term cost of low greenhouse gas-emitting energy technologies. With these aims, the GEF, in April 1996, approved an incremental cost grant of $49 million for a STP project in India. Since then, they have approved three additional grant requests for STP plants in Egypt, Morocco, and Mexico.

These four projects represent a significant step in support of the GEF's programmatic objectives. Consequently, the GEF undertakes a 'thematic review' of the cluster of STP projects with the objectives of extracting lessons learned, understanding the relevance and linkages of GEF activities to broader international trends, tracking replication of successful project results, and informing future GEF strategic directions.

1.1: **Objectives**

The purpose of the review is to suggest, based upon project designs and preliminary implementation experience, whether GEF STP projects are contributing to technology cost reductions or other industry changes as envisioned under Operational Programme 7. In lieu of substantial operating experience, the review will provide updated perspectives on this question relative to when the projects were first proposed and early implementation experience.

The review also suggests whether alternative approaches in future projects, or even revisions to the current portfolio of projects, could have greater influence on cost and market trends for these technologies. The work plan to achieve these objectives had three main elements:

- Review the broad international technology trends for solar thermal power plants;
- Review the GEF solar thermal power projects;
- Identify the relevance and linkages of GEF projects to trends.

1.2: Methodologies

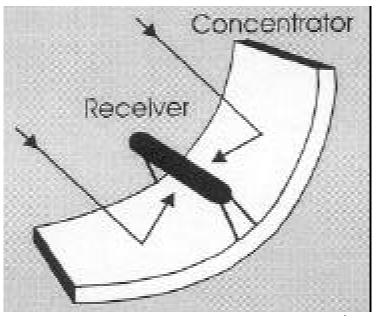
The study was carried out as follows:

- Collection of data and analysis of international trends, including interviews with key industry manufacturer's, investors, and other organizations;
- Collection and review of available information on the four solar thermal plant projects (sources included project files and interviews with project personnel, suppliers and associate agencies)
- A final synthesis of trends and projects, along with conclusions and recommendations for future GEF programming

2: International Technology Trends for Solar Thermal Power

2.1: Technology Overview

STP plants produce electricity in the same way as conventional power stations, except they obtain part of their thermal energy input by concentrating solar radiation and converting it to high temperature steam or gas to drive a turbine, or alternatively to move a piston in a sterling engine. Essentially, STP plants include four main components: the concentrator, receiver, transport-storage, and power conversion. Many different types of systems are possible using variations of the above components, combining them with other renewable and non-renewable technologies, and in some cases, adapting them to utilise thermal storage. The three most promising solar power architectures can be characterised as:



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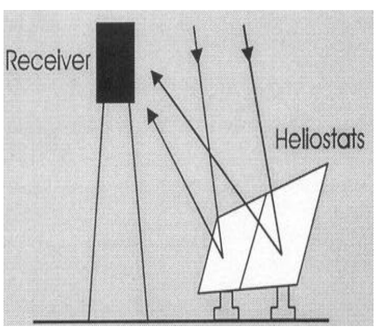
- Parabolic Trough – systems use parabolic trough shaped mirror reflectors to concentrate sunlight on to thermally efficient receiver tubes placed at the trough focal point. These receivers or absorption tubes contain a thermal transfer fluid (e.g. oil), which is heated to approximately 400°C and pumped through heat exchangers to produce superheated steam. The steam is converted to electric energy in a conventional turbine generator (e.g. Rankine-cycle/steam turbine) or alternatively a combined cycle (gas turbine with bottoming steam turbine) to produce electricity.
- Central Receiver (or Power Tower) – systems use a circular array of heliostats (large individually-tracking mirrors) to concentrate sunlight onto a central receiver mounted at the top of a tower. The central receiver absorbs the energy reflected by the concentrator and by means of a heat exchanger (e.g. air/water) produces superheated steam. Alternatively thermal transfer medium (e.g. molten nitrate salt) is pumped through the receiver tubes, which is heated to approximately 560°C and pumped either to a 'hot' tank for a storage or through heat exchangers to produce superheated steam. The steam is converted to electric energy in a conventional turbine generator (e.g. Rankine-cycle/steam turbine or Brayton-cycle gas turbine) or in combined cycle (gas turbine with bottoming steam turbine) generators.



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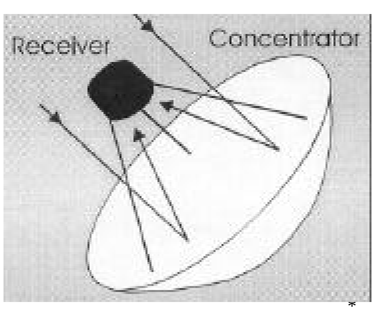
- Parabolic Dish – systems use an array of parabolic dish-shaped mirrors to concentrate sunlight onto a receiver located at the focal point of the dish. The receiver absorbs energy reflected by the concentrators and fluid in the receiver is heated to approximately 750°C and used to generate electricity in a small engine (e.g. Stirling or Brayton cycle) attached to the receiver.



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* *diagrams courtesy of U.S. Department of Energy's Concentrating Solar Program*

Each STP technology has its own characteristics, advantages and disadvantages, some of which are shown in Table 2.1. Similarly, each technology can have a number of different configurations that are being developed in various parts of the world; these are discussed in the report's 'Present Technology Status' section.

Table 2.1: Characteristics of the three main types of Solar Thermal Power Technology

	Parabolic Trough	**Central Receiver**	**Parabolic Dish**
Applications	Grid-connected plants; Process heat; (Highest solar capacity to date: 80 MWe)	Grid-connected plants; High temperature process heat; (Highest solar capacity to date: 10Mwe)	Stand-alone applications or small off-grid power systems (Highest solar capacity to date: 25kWe)
Advantages	Commercially available (over 9 billion kWh operational experience, with solar collection efficiency up to 60%, peak to solar to electrical conversion of 21%); hybrid concept proven; storage capability	Good mid-term perspective for high conversion efficiencies (solar collection efficiency approx. 46% at temps up to 565°C, peak solar to electrical conversion of 23%); storage at high temperatures; hybrid operation possible	Very high conversion efficiencies (peak solar to electric conversion of about 30%); modularity; hybrid operation; operational experience
Disadvantages	Lower temperatures (up to 400°C) restrict output to moderate steam qualities due to temperature limits of oil medium.	Capital cost projections not yet proven.	Hybrid systems have low efficiency combustion, and reliability yet to be proven.

2.11: History

Efforts to construct and design devices for supplying renewable energy began some 100 years before 'the oil price crises' of the 1970s, which triggered the modern development of renewable, and particularly STP, energy technologies. From the 1860s, and Auguste Mouchout's first solar powered motor that produced steam in a glass-enclosed iron cauldron, to the early 1900s with Aubrey Eneas' first commercial solar motors, and Frank Shuman's 45kW sun-tracking parabolic trough plant built in Meadi, Egypt[1]. These early designs formed the basis for R&D developments in the late 1970s and early 1980s, when STP projects were undertaken in a number of the industrialised nations, including the United States, Russia, Japan, Spain and Italy, and shown in Table 2.11. Many of these plants, covering the whole spectrum of available technology, failed to reach the desired performance levels, and subsequent R&D has continued concentrating on technology improvement and increasing size unit.

Table 2.11: Early Solar Thermal Power Plants

Name	Location	Size (MWe)	Type, Heat Transfer Fluid & Storage Medium	Start –up Date	Funding
Aurelios	Adrano, Sicily	1	Tower, Water-Steam	1981	European Community
SSPS/CRS	Almeria, Spain	0.5	Tower, Sodium	1981	8 European Countries & USA
SSPS/DCS	Almeria, Spain	0.5	Trough, Oil	1981	8 European Countries & USA
Sunshine	Nio, Japan	1	Tower, Water-Steam	1981	Japan
Solar One	California, USA	10	Tower, Water-Steam	1982	US Dept. of Energy & Utilities
Themis	Targasonne, France	2.5	Tower, Molten Salt	1982	France
CESA-1	Almeria, Spain	1	Tower, Water-Steam	1983	Spain
MSEE	Albuquerque, USA	0.75	Tower, Molten Salt	1984	US Dept. of Energy & Utilities
SEGS-1	California, USA	14	Trough, Oil	1984	Private – Luz
Vanguard 1	USA	0.025	Dish, Hydrogen	1984	Advanco Corp.
MDA	USA	0.025	Dish, Hydrogen	1984	McDonnell-Douglas
C3C-5	Crimea, Russia	5	Tower, Water-Steam	1985	Russia

Meanwhile, in the early eighties, the Israeli company Luz International Ltd. commercialised STP technology by building a series of nine solar electric generating stations* (SEGS) in the Californian Mojave desert. The SEGS plants ranged from 14 to 80 MWe unit capacities and totalled 354 MW of grid electricity. During the construction of these plants from 1984-1991, significant cost reductions were achieved with increased size, performance and efficiency, driving the levelised cost of electricity down from a reported 24 US¢/kWh to 8 US¢/kWh[2]. The $1.2 billion raised for these plants were from private risk capital investors, and with increasing confidence in the maturity of the technology, from institutional investors[3]. These commercial ventures were significantly aided by tax incentives and attractive power purchase contracts but by the late 80s the fall in fuel prices led to reductions in electricity sale revenues of at least 40%. Though Luz became bankrupt in 1991, after falling fossil fuel prices coincided with the withdrawal of state and federal investment tax credits[2], all nine SEGS plants are still in profitable commercial operation with a history of increased efficiency and output as the operators improved their procedures.

The first commercial plants SEGS I (14 MW) and II (30 MW) plants, located near Dagget, are currently being operated by the Dagget Leasing Corporation (DLC). The 80 MW SEGS VIII and IX projects, located near Harper Dry Lake, are run by Constellation Operating Services, whilst the 30 MW SEGS III-VII projects at Kramer Junction are operated by the KJC Operating Company. These plants which have an average annual insolation of over 2700 kWh/m^2 have generated more than 8 TWh of electricity since 1985, with a highest annual plant efficiency of 14% and a peak solar-to-electric efficiency of about 21% having been reached. Californian regulations allowed a maximum of 25% of the turbine thermal input to be from natural gas burners, thus avoiding expensive storage capacity and lowering generation costs to 12 US¢/kWh (equivalent pure solar costs would have been 16 ¢/kWh). The 150 MWe Kramer Junction solar power park, which contains five 30 MWe SEGS (III-VII), achieved a 37% reduction in operation and maintenance (O&M) costs between 1992 and 1997, as shown in Figure 2.11. During this period, the five plants averaged 105% of rated capacity during the four-month summer on-peak period (12 noon-6pm, weekdays), whilst on an annual basis, 75% or more of the energy to the plant came from solar energy[3].

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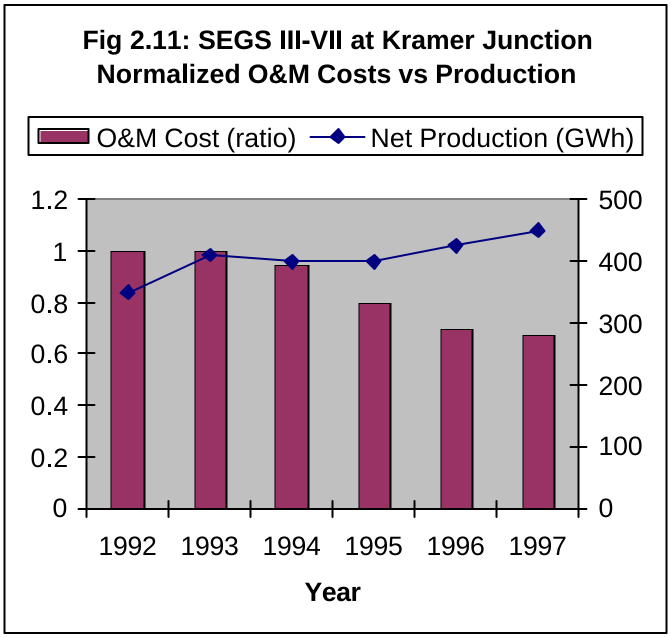
* *SEGS is the generic term relating to parabolic trough employing a Rankine cycle with approximately 75% solar and 25% fossil fuel input)*



2.12: Present Market Situation

Despite the success of the nine SEGS, no new commercial plants have been built since 1991. There are a number of reasons for this - some of which led to the demise of Luz - including the steady fall in fossil fuel and energy prices, and the uncertainties caused by a delay in the renewal of solar tax credits in California. Others stem from the fact that STP plants still generate electricity at a higher cost, at least double the cost from fossil-fuelled plants. In a regulated monopoly environment, as was the case for Luz, the higher cost of STP guaranteed in the power purchase agreement could be recovered by the utility via customer rates. Dramatic changes, however, took place during the 1990s through the liberalisation of the electricity sector worldwide, which have significantly affected the viability of large, capital-intensive generation plants. The restructuring of the electricity industry in parts of the United States, for example, has seen competition in electricity generation and supply lead to a great deal of uncertainty in the sector. Utilities that had formerly thrived in a regulated monopoly environment have found it difficult to compete in this new competitive market. Many still have to deal with the issue of 'stranded assets' for plants they were required, under regulation, to build but that now cannot compete with new low cost power stations. In Europe deregulation, to varying extents, has lowered energy prices as competition has led to considerable efficiency gains.

As a result of deregulation, uncertainty in the electricity sector has lowered the depreciation times for capital investments in new plant capacity. New plants have generally been built as Independent Power Projects (IPPs), often without a long-term power purchase agreement, and have typically been new highly efficient natural gas-fired combined cycle gas turbine plants (CCGTs). Capital costs of new gas-fired CCGT plants (approx. 2yrs to build) are still declining to below $500/kW with generation efficiencies of over 50%. In this climate, STP plant requires a significantly large unit capacity to meet competitive conditions for the generation of bulk electricity (e.g. Luz's plans for new STP plant before it went bankrupt, were for a 130 MW plant scaling up towards 300 MW plants in later years), and the large capital cost needed is deemed too high a risk by financiers.

In addition to restructuring, there has been little in the way of favourable financial and political environments to encourage the development of STP, with only the GEF Climate Change programmes fully supporting the technology. There is still some assistance in California where production subsidies (AB1890) that apply to the SEGS plants, are given when the market price is below $0.05/kWh, however, these are small and set to end in 2001[4]. Although there have been some advances in 'green markets' in Europe and North America, with premiums paid by customers for electricity generated from renewable sources, such as wind, STP generally, has not been considered because of its large scale, large capital cost, and hence, high investment risk. Similarly, aggregators for supply and sale of green energy have not yet been dealing on the multi-megawatt scale.

Despite these factors, the outlook today sees new opportunities arising for STP projects all over the world. Some of the main sponsors of energy investments in the developing world, such as the World Bank Group, the Kreditanstalt für Wiederaufbau (KfW) and the European Investment Bank (EIB), have recently been convinced of the environmental promise and economic perspectives of STP technologies[5]. Interest and funding has also been made available for demonstration and commercialisation projects from the European Union's (EU) Framework Programme 5, with particular interest in developing STP in the sunbelt Northern Mediterranean region, with projects in Greece, Spain and Italy already being planned. Other national initiatives have the potential to aid STP development. Spain, for example, as part of its CO_2 emissions reductions intends to install 200 MWe of STP by the year 2010, with an annual power production of 413 GWh, and the recent Royal Decree, described in Box 2.12, may help to meet those aims.

Similarly, Italy has recently unveiled its strategic plan for mass development of solar energy, the government Agency for New Technology, Energy and the Environment (ENEA), recommends bringing thermal-electric solar technology to the market in the 'brief term' – about three years. It said commercial ventures should be encouraged through financial incentives to show the advantages of large-scale solar energy and to reduce costs to competitive levels[6]. Bulk electrical STP transmission from high insolation sites (up to 2750 kWh/m^2) in Southern Mediterranean countries, such as Algeria, Libya, Egypt, Morocco and Tunisia may also open wider opportunities for European utilities to finance solar plants in that region for electricity consumed in Europe[7]. Reform of electricity sectors across Europe, the rising demand of 'Green power', and the possibility of gaining carbon credits are no doubt, increasing the viability of such projects.

Box 2.12: The Spanish Royal Decree for Renewables[8]

On December 23, 1998, a Spanish Royal Decree established tariffs for the production of electricity from facilities powered by renewable energy sources. The decree established different tariffs for renewable power, depending on system size and the type of renewable resource. The decree established that facilities greater than 5 kW using only solar energy as the primary energy source were eligible for payment of 36 pesetas/kWh (approx. 24 ¢/kWh). In a subsequent development, in December 1999 the Council of Ministers decided to cut the subsidies for renewable-generated electricity. The cuts of 5.4-8% affected all renewables, but newer sectors such as solar thermal and biomass were hit the hardest. The measures were part of a package aimed at reducing electricity prices. The Spanish government, however, later indicated interest in STP technology as part of its aims to meet 12% of all energy generated from renewable sources by 2010, but has not defined tariffs that apply to the technology. In light of rising oil prices in the latter half of 2000, the 24 ¢/kWh mooted has been put on hold to protect electricity customers from the already increase in prices due to oil. Because of the decree, at least six 50 MW trough projects and two-10 MW tower projects were in various stages of development in Spain.

In the U.S., the Solar Energy Industry's Association and the Department of Energy have helped create Solar Enterprise Zone's in sunbelt states. The economic development zones are aimed at helping large-scale solar electric projects and assist private companies in developing 1000 MWe of projects over a seven-year period. Projects in Nevada (50 MW) and Arizona (10-30 MWe) are in the planning stage and will benefit from Renewable Portfolio Standards, which require a certain percentage of electricity supplied to be from renewable sources, and green pricing. Interest from the Australian government has also provided 'Renewable Energy Showcase Grants' for two STP projects integrated with existing coal-fired plants and expected to be in place by the end of 2001.

Elsewhere in the Middle East, Southern Africa and South America, with some of the largest potentials for STP, interest is being shown by Governments and their utilities, with the attraction of post-Kyoto funding and the development of energy production from indigenous renewable resources for countries with oil-based electricity production. Apart from the four countries that applied for GEF grants, a number of technology assessments and feasibility studies have been carried out in Brazil, South Africa, Namibia, Jordan, Malta and Iran. Many of these countries are currently undertaking electricity sector reforms for privatisation, encouraging IPP's, which are seen as the most appropriate vehicle for STP projects. These factors have led to recent, but significant interest in constructing STP plants in the sunbelt regions from private sector turnkey companies, such as Bechtel, Duke Energy, ABB, and ENEL, and as one of these companies described "For solar thermal power to play a meaningful role in global power markets, the industry must move toward turnkey, guaranteed plants"[9]. In addition to this current interest in STP, interest rates and capital costs have drastically fallen worldwide significantly increasing the viability of capital intensive renewable projects, and rising oil prices in the latter part of 2000, once again is turning attention towards alternative energy sources.

2.2: Present Technology Status

Although no new commercial plants have been built for nearly 10 years, the demonstration and development of the three main STP technologies has continued and a number of technologies are nearing commercialisation.

2.21: Parabolic Troughs

Although SEGS have proven to be a mature electricity generating technology, they do not represent the end of the learning curve of parabolic trough technology. A number of improvements and developments have taken place since the last constructed plant that will, undoubtedly, see even better performance and lower costs for the next generation of plants.

The improvements gained with the SEGS III-VII plants have been the result of major improvement programmes for collector design and the O&M procedures, carried out in collaboration between the Sandia National Laboratories (Albuquerque, U.S.) and the KJC Operating Company. In addition to this, key trough-component manufacturing companies have made advances - for example: Luz improved its collector design with the third generation LS-3 collector considered to be state of the art; SOLEL (which bought most of the former Luz assets) has also improved the absorber tubes; and Flabeg Solar International (formerly Pilkington Solar International) has developed improved process know-how and system integration[10]. In Australia, a new trough design involving many parallel linear receivers elevated on tower structures, and called the Compact Linear Fresnel Reflector is being demonstrated in Queensland[11].

On-going development work continues in Europe and U.S to further reduce costs in a number of areas, including improvements in the collector field, receiver tubes, mirrors and thermal storage. For example, an R&D project 'EuroTrough' is underway to reduce the costs of an advanced European trough collector based on the LS-3. Similarly, a U.S. initiative called the 'Parabolic Trough Technology Roadmap' [12], developed jointly by industry and SunLab*, identified a number of areas that need attention. Table 2.21a, shows the key technology metrics given by this initiative, which further suggests that cost reductions and performance increases of up to 50% are feasible for parabolic trough technology.

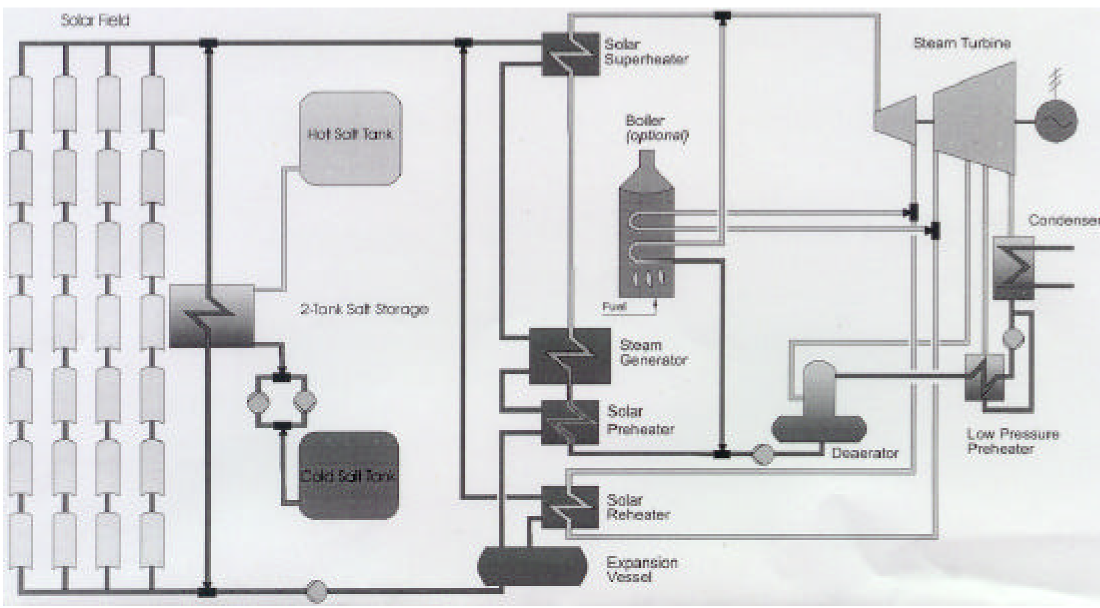
Table 2.21a: Key Technology Metrics Identified by the Parabolic Trough Technology Roadmap[12]

Component System		1990	2000	2005	2010	2015	2020
Collector							
Cost	$/m^2$	300	325	160	130	120	110
Annual Optical Efficiency		40%	44%	45%	47%	49%	50%
Receiver Tubes							
Cost	$/unit	500-1000	500	400	300	275	250
Failure Rate	%/yr	2%-5%	1.0%	0.5%	0.2%	0.2%	0.2%
Absorptance		0.94	0.96	0.96	0.96	0.96	0.96
Emittance		0.15	0.1	0.05	0.05	0.05	0.05
Operating Temperature	°C	391	400	425	450	500	500
Mirror							
Cost	$/m^2$	120	90	75	60	55	50
Failure Rate	%/yr	0.1%-1.0%	0.10%	0.05%	0.02%	0.01%	0.01%
Reflectivity		0.94	0.94	0.94	0.95	0.95	0.95
Lifetime	years	20	25	25	25	30	30
Thermal Storage Cost	$/kWh$_t$	-------	-------	25	15	10	10
Round-trip efficiency		-------	-------	0.80	0.90	0.95	0.95

* *SunLab is the U.S. Dept. of Energy's virtual laboratory that combines expertise from Sandia National Laboratories and the National Renewable Energy Laboratory to assist industry in developing and commercialising STP.*

Historically, parabolic trough plants have been designed to use solar energy as the primary energy source to produce electricity, and can operate at full rated power using solar energy alone given sufficient solar input, especially with an added storage component as utilised by the first SEGS plant. Indeed, the development of an economic thermal storage system would broaden the market potential of trough power plants. A recent study, as part of the 'USA Trough Initiative', evaluated several thermal storage concepts[13]. A preferred design was identified shown in Figure 2.21 using a nitrate salt for the storage medium. Thermal energy from the collector field would be transferred from the system through a nitrate salt steam generator, or by reversing the flows in the oil-to-salt heat exchanger and driving an oil steam generator. A cost estimate for a 470 MWht thermal storage system using this design was estimated at a total cost of around $40/kWht. A number of cost reduction approaches were identified showing that the design was a real near-term storage option for parabolic troughs.

Figure 2.21: Parabolic Trough Power Plant with Hot and Cold Tank Thermal Storage System and Oil Steam Generator[13]



To date, however, all plants after SEGS I have been hybrid in configuration, with a back-up fossil-fired capability that can be used to supplement the solar output during periods of low solar radiation. One new design involving this concept is the Integrated Solar Combined Cycle System (ISCCS), which integrates a parabolic trough plant with a gas turbine combined-cycle plant. Essentially, the ISCCS uses solar heat to supplement the waste heat from a gas turbine in order to augment power generation in the steam Rankine bottoming cycle. Although this concept has yet to be built, studies show that it is technically feasible[14], representing potential cost savings for the next trough project using this design. Both the incremental cost and O&M costs of the ISCCS are lower than a trough plant utilising a Rankine cycle, and the solar to electric efficiency is improved. Studies show that the ISSCS configuration could reduce the cost of solar power by as much as 22% over the cost of power from a conventional SEGS (25% fossil) of similar size[12].

Another concept being developed in Europe is Direct Solar Steam (DISS), where steam is generated at high pressure and temperature (100 bar/375°C) directly in the parabolic trough collectors by replacing the oil medium with water. This reduces costs by eliminating the need for heat exchanger or transfer medium, and also reduces efficiency losses. A pilot demonstration plant was set up at the Plataforma Solar de Almeria (PSA), in Spain in 1999, through an alliance of German and Spanish research centres and industry, with the aim to lower solar energy costs by 30%. A 30 MWe DISS plant is also being developed by the Spanish company Gamesa, featuring a EUROtrough solar collector field.

All these developments will, undoubtedly, lower the cost of parabolic trough plants in the short to mid-term. Cost projections for parabolic trough plants are based on the SEGS experience and the present competitive market place. The installed capital costs of the SEGS plants fell from $4500 kW to just under $3000/kW between 1984 and 1991. A recent assessment for the EUREC-Agency[15] reports that the soon to be built 50 MW THESEUS (SEGS) plant is expected to meet the near-to-term cost targets set out in the EU Fifth Framework Programme for solar systems with 2,500 Euro/kWe installed (~2200 US$/kWe). Projected electricity costs for a next 50 MW parabolic trough plant at a Southern European site with annual insolation of 2400 kWh/m^{2}a, such as on the Island of Crete, are then at 14 Euro cents/kWh (12 US¢/kWh in pure solar mode without any grant), or at 18 Euro cents/kWh (16 US¢/kWh) at a site with 2000 kWh/m^{2}a like Southern Spain. However, in hybrid mode with up to 49% fossil-based power production, the electricity costs could drop to as low as 8 Euro cents/kWh (7 US¢/kWh).

A World Bank initiated study[16] carried out to assess the cost reduction potential for STP, shows similar cost estimates (Table 4), with the exception of estimates for the ISCCS. In that study, the methodology used tends to penalise the ISCCS configuration by requiring the system to operate at 50% annual capacity factor and then penalising the solar for the inefficient use of natural gas. As Price and Carpenter[17] note, a comparison at a 25% annual capacity factor would show a much larger cost reduction for the ISCCS system over the Rankine cycle plant. Table 2.21b also shows the effect of size on the near term capital and levelised costs, with substantial reductions seen for the plant with the largest solar field. Similarly, the analysis showed that plants might be built cheaper in other parts of the world than in the U.S. In a pre-feasibility study for a STP plant in Brazil it was estimated that the construction cost of a 100 MW Rankine-cycle STP is $3,270/kWe in the U.S. and 19% lower at $2,660 in Brazil (if import taxes are removed)[18], with savings in labour, materials and to some extent equipment costs. A number of the parties interested in building the GEF projects have indicated that utilising local labour and manufacturing capabilities in India, Egypt, Morocco, and Mexico will be key to bidding at a low cost for the plants.

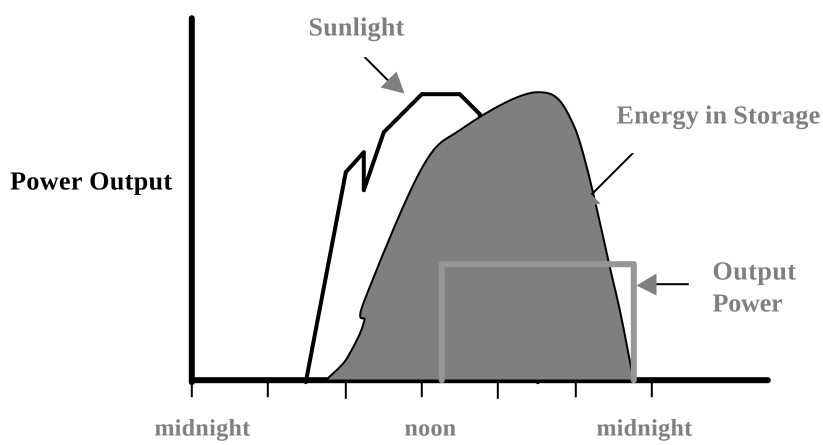
Table 2.21b: Parabolic Trough Solar Thermal Power Plant Characteristics[16]

	Near-Term (Next Plant Built)			**Mid-Term** (~5 Years)	**Long-Term** (~10 Years)	
Power Cycle	Rankine	Rankine	ISCCS	Rankine	Rankine	Rankine
Solar Field (000 m^2)	193	1210	183	1151	1046	1939
Storage (hours)	0	0	0	0	0	10
Solar Capacity (MW)	30	200	30	200	200	200
Total Capacity (MW)	30	200	130	200	200	200
Solar Capacity Factor	25%	25%	25%	25%	25%	50%
Annual Solar Efficiency	12.5%	13.3%	13.7%	14.0%	16.2%	16.6%
Capital Cost ($/kW)						
U.S. Plant	3500	2400	3100	2100	1800	2500
International	3000	2000	2600	1750	1600	2100
O&M Cost ($'kWh)	0.023	0.011	0.011	0.009	0.007	0.005
Solar LEC ($/kWh)	0.166	0.101	0.148	0.080	0.060	0.061

2.22: Central Receivers

Despite the fact that central receiver projects represent a higher degree of technology risk than the more mature parabolic troughs, there have been a number of demonstrations in various parts of the world, and plans are underway for the first commercial plant. Following on from the successful pilot demonstration of central receiver technology, with the Solar One plant operated from 1982-1988 at Barstow, California with steam as the transfer medium. A 10MWe Solar Two plant, redesigned from Solar One, was operated from 1997 to 1999; successfully demonstrating advanced molten-salt power technology. The energy storage system for Solar Two consisted of two 875,000 litres storage tanks with a system thermal capacity of 110 MWh_t. The low-cost molten-salt storage system, allowed solar energy to be collected during the sunlight hours and dispatched as high-value electric power at night or when demanded by the utility[19]. The 'dispatchability' of electricity from a molten-salt central receiver is illustrated in Figure 2.22a, where storage means that in the sunbelt regions of the U.S. the plant can meet demand for the whole of the summer peak periods (afternoon due to air conditioners, and evening). The last two summers in California and elsewhere have highlighted the need for capacity that can cover these high peak and correspondingly high price periods. In developing countries, this storage capability may be even more important, with the peak times occurring only during the evening.

Figure 2.22a: Dispatched Electricity from Molten-Salt Central Receivers



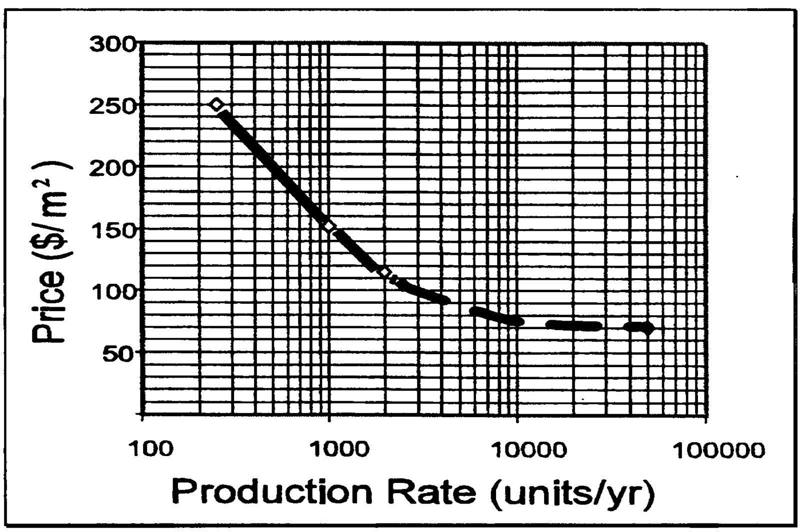
This concept is the basis for U.S. efforts in central receiver plant commercialisation with a potential for more than 15% annual solar-to-electric plant efficiency and an annual plant availability of over 90%[12]. This technology is close to being commercially ready, and a joint venture between Ghersa (Spain) and Bechtel (U.S.), with further subcontracting work from Boeing (USA), are hoping to build the first commercial central receiver plant with the help of EU and Spanish grants. This proposed 10 MWe Solar Tres plant to be built in Cordoba, Spain, will utilise the molten-salt storage technology to run on a 24-hour per day basis[20].

The European concept of central receivers, under the project name PHOEBUS, is based on the volumetric air receiver design. In this case, solar energy is absorbed on fine-mesh screens and immediately transferred to air as the working fluid with temperature range of 700 to 1,200°C reached. This concept was successfully demonstrated in Spain in the mid-90s, and companies, such as Abengoa (Spain) and Steinmüller (Germany) have expressed interest in commercialising this technology, with the Planta Solar (PS10) 10 MWe project utilising energy storage near Seville, Spain[21].

As with parabolic troughs, efforts are underway to develop early commercial central receiver solar plants using solar/fossil hybrid systems, especially in the ISCCS mode. Presently, however, the ISCCS configuration favours the lower temperature of the trough designs. One concept undergoing demonstration in Israel, is one in which a secondary reflector on the tower top directs solar energy to ground level for collection in a high-temperature air receiver for use in a gas turbine. Coupling the output of the high temperature solar system to a gas turbine could allow a higher efficiency than current steam turbine applications, faster start-up times, lower installation and operating expenses, and perhaps a smaller, more modular system[10].

Heliostats represent the largest single capital investment ($100-200/m^2) in a central receiver plant and efforts continue to improve design with better optical properties, lighter structure, and better control. Activities include the 150-m^2 heliostat developed by Advanced Thermal Systems (USA), the 170-m^2 heliostat developed by Science Applications International Corporation (SAIC, USA), the 150-m^2 stretched-membrane ASM-150 heliostat of Steinmüller (Germany), and the 100-m^2 glass/metal GM-100 heliostat in Spain[10]. Initiatives to develop low-cost manufacturing techniques for early commercial low volume builds are also underway, and price levels are expected to drop for manufacture in a developing country by roughly 15% below the U.S/European costs. As with many STP components, the price should be brought down significantly through economies of scale in manufacture, shown in Figure 2.22b.

Figure 2.22b: Heliostat Price as a Function of Annual Production Volume [16]



As far as estimations for costs of central receivers are concerned, there is less information than for parabolic trough systems. In Europe, near-term central receiver project developments in Spain have indicated the validation of installed plant capital costs in the order of 2700 Euro/kWe ($2500/kWe) for power tower plant with Rankine-cycle and small energy storage system, with the range of predicted total plant electricity costs of about 20-14 Euro cents/kWh (17 to 12 US¢/kWh)[15]. Capital costs for the Solar Tres plant are estimated at 84 million Euros (US$70 million), with annual operating cost about 2 million Euros (US$1.7 million)[22]. The World Bank study[16] indicates higher estimated costs for near-term central receiver plants expected in the range of 3700 US$/kWe (next 130 MWe ISCCS plant with 30 MWe solar capacity with storage) to 2800 US$/kWe (next 100 MWe Rankine-cycle plant with storage) with the range of predicted total plant electricity costs of about 14 to 12 US$/kWe.

2.23: Parabolic Dishes

Since efforts in the 1970s and 1980s by companies, such as Advanco Corporation and McDonnell Douglas Aerospace Corporation, there have been a number of developments made in parabolic dish technology. In the early 1990s, Cummins Engine Company attempted to commercialise a dish system based on a free-piston Stirling engine. However, after running into technical difficulties and a change of corporate decision, the company cancelled its solar development in 1996. A number of demonstration systems have been built in recent years through collaboration between Science Applications International Corporation (SAIC) and Stirling Thermal Motors (STM), including the 25 kWe APS II stretched-membrane dish installed in 1998 for the Arizona Public Service Company in the U.S. Scaling up development work continues with the aim of producing a 1 MW dish system for the U.S. utility environment. A number of states (e.g. Arizona and Nevada) are planning to use the APS systems in meeting the requirements of their Renewable Portfolio Standards (RPS).

A number of demonstration projects are also taking place in Europe, with six 9-10kWe Schlaich Bergmann & Partner (SBP) dishes at the PSA in Spain, accumulating over 30,000 operating hours. A 25kWe dish developed by Stirling Engine Systems (SES) using a McDonnell Douglas design is to be installed in Spain. Solargen of the UK are developing 25 and 100 kWe generation systems with heat receivers tracking the sun, whilst the mirrors remain fixed. This allows for a low-cost collector with temperatures generated at 1000°C[23]. In, another development, the Australian government is funding a 2.6 MWe plant, using eighteen of its 'Big Dish' technology, to be added to a 2640 MW coal-fired plant near Sydney, promising a peak efficiency of over 37% solar to net electricity. The dishes will generate steam at high temperatures and pressures for direct injection to the turbine's steam cycle[24].

Once again, parabolic dish system commercialisation may well be aided by use in a hybrid mode. Hybrid operation, however, presents a greater challenge for systems using Stirling engines, with hybrid dish/Stirling systems currently running in an either/or mode (either solar or gas), or two engines are used, one dedicated to the solar system and one to generate from gas. Gas turbine based systems may present a more efficient integrated hybrid system.

Dish system costs are currently extremely high at around $12,000/kWe, with near-term units estimated at 6,500 $/kWe (at 100 units/year production rate) based on the SBP 9-10 kWe[15]. However, in the medium-to-long-term, these costs are expected to fall drastically, with a growing number of dish systems produced in series. A recent study estimated utility market potential for dish systems in the U.S. for 2002, and concluded that cost will need to fall between $2000/kWe and $1200/kWe to gain any significant market uptake[25]. For initial market areas, such as distributed generation, reliability and O&M costs will be crucial factors that need further R&D.

2.3: Conclusions

Overall, it is clear that parabolic trough plants are the most mature STP technology available today and the technology most likely to be used for near-term deployments, this is highlighted in Table 5 by the larger number of trough projects in development. Although this technology is the cheapest solar technology, there are still significant areas for improvement and cost cutting. Central receivers, with low cost and efficient thermal storage, promise to offer dispatchable, high capacity factor, solar-only plants in the near future, and are very close to commercialisation. If the European projects (Table 2.3) show successful demonstration and are able to be run commercially, central receivers may well be competing with trough plants in the mid-term. Whilst the modular nature of parabolic dish systems will allow them to be used in smaller high-value and off-grid remote applications for deployment in the medium-to-long-term, further development and field-testing will be needed with significant potential for cost cutting through economies of manufacture.

Table 2.3: Current STP projects in development

Name/Location	Total Capacity (MWe)	Solar Capacity (MWe)	Cycle	Companies/Funding
Parabolic Troughs				
THESEUS – Crete, Greece	50	50	Steam cycle	Solar Millennium Flabeg Solar Int. Fichtner, OADYK, EU grant under FP 5
ANDASOL – Almeria, Spain	32	32	Direct Steam EUROtrough	GAMESA Energia + EU/Spanish grants
Kuraymat, Egypt	137	36	ISCCS	Open for IPP bids GEF grant
Ain Beni Mathar, Morocco	180	26	ISCCS	Open for IPP bids GEF grant
Baja California Norte, Mexico	291	40	ISCCS	Open for IPP bids GEF grant
Mathania, India	140	35	ISCCS	Open for IPP bids GEF grant, KfW loan
Nevada	50	50	SEGS	Green pricing, consortium for renewable energy park incl. 3 major energy companies
Stanwell Power Stn Queensland, Australia	1440	5	Compact Linear Fresnel Reflector	Austa Energy & Stanwell Corp + Australian Government grant
Central Receivers				
Planta Solar (PS10), Seville, Spain	10	10	Volumetric air receiver/energy storage	Abengoa (Spain) group with partners incl. Steinmuller + EU/Spanish grants/subsidy
Solar Tres, Cordoba, Spain	15	15	Molten-salt/direct-steam	Ghersa (Spain) and Bechtel/Boeing (U.S.) EU/Spanish grant/subsidy
Parabolic Dishes				
SunCal 2000, Huntingdon Beach, California, USA	0.4	0.4	8-dish/stirling system	Stirling Energy Systems (SES)
Big Dish, Eraring Power Station, nr Sydney, Australia	2.6	2.6	18 Big Dishes in association with coal plant	ANUTECH (incl. Australian National University, Pacific Power & Transfield) + Australian Government grant

Scaling-up of plants will, undoubtedly, reduce the cost of solar electricity from STP plants, and this was seen with the larger 80 MW Luz plants. Studies have shown that doubling the size reduces the capital cost by approximately 12-14%, through economies of scale due to increased manufacturing volume, and O&M for larger plants will be typically less on a per-kilowatt basis[12]. Current cost estimates, however, are still highly speculative with no plants built for nearly a decade. A number of projects have been proposed and are in various stages of development, as shown in Table 2.3, which if successful, will give valuable learning experience and a clear indication of today's cost and potential for cost reduction in the next generation of STP plant.

3: GEF Solar Thermal Power Projects

Since the pilot-phase of the GEF in 1991, STP has been seen as a technology that the GEF could support, and a possible project in India was questioned in 1995. Since then, three more projects have been approved. Each of the projects is now at various stages and this section will review the 4 projects, and their experience to date.

Table 3: The GEF Portfolio of Solar Thermal Power Projects

Location	Expected Technology	Size	Project Type	Cost (US$)	Status – Jan 2001	Anticipated date of operation
Mathania, India	Naphtha-fired ISCCS (Trough)	140 MW. Solar component: 35 MW, Solar field: 219 000 m^2	Greenfield: BOO (5 yrs)	Total: 245 million 49 million-GEF, 150 million loan from KfW, 20 million-Indian government, balance from private IPP	Pre-qualification, dec 2000. GEF Block C grant approved	2004
Ain Beni Mathar, Morocco	Natural gas-fired ISCCS (Trough)	180 MW. Solar component: 26 MW;	Merchant IPP: BOO/BOOT	Total: 200 million 50 million-GEF, balance from private IPP	Project award planned for mid-2002	2004
Kuraymat, Egypt	Natural gas-fired CCGT based, Technology open: (Trough or Tower)	137 MW. Solar component: 36 MW	Merchant IPP: BOO/BOOT	Total: 140-225 million. 40-50-GEF, balance from private IPP, risk guarantee-IRBD	Pre-qualification, may 2000. GEF Block C grant approved	2003-2004
Baja California Norte, Mexico	Natural gas-fired ISCCS (Trough)	291 MW. Solar component: 40 MW	Merchant IPP: BOO	Total: 185 million 50 million-GEF, balance from private IPP	GEF Block B grant approved	2005

3.1: India

This project first considered in the late 1980s has been 'on and off' a number of times over the last decade, but finally through the persistence of the KfW (Kreditanstalt für Wiederaufbau), GEF and other parties, is back on track to be one of the first STP plant to be built for ten years or more.

In 1990, a feasibility study for a 30 MW STP project to be built at Mathania village near Jodhpur in Rajasthan, was carried out by German engineering consultants, Fichtner, with assistance from the KfW. The study established the technical feasibility of such a project at this location, and Bharat Heavy Electricals Ltd. prepared a detailed project report, in 1994 for a 35 MW demonstration project at Mathania. In light of the GEF's interest in projects of this nature the detailed project report was submitted to the GEF with a request for funding under its Climate Change programmes. The German government was also approached for extending loan assistance as they had expressed interest in the project[26].

In 1995, Engineers India Ltd. (EIL), completed a Comprehensive Feasibility Study for the project, which was followed by EIL and Fichtner evaluating the option of integrating the solar thermal unit (35-40 MW) with a fossil fuel based combined cycle power plant for a total of 140 MW, costing around US$ 200-240 million. Since the selected site had no access to natural gas, the choice of the auxiliary system and fuel choice was left open, with suggestions including Naptha and low sulphur heavy stock (LSHS). Insolation per square metre was measured reaching 6.4 kW/h on a daily basis in the Thar desert region of Rajasthan, believed to be the highest such figure in the world[26].

The project approved for funding by the GEF in early 1996 floundered due to a number of disagreements between various parties over financial and policy matters. With these disagreements finally resolved, the project was up and running again , until 1999 when it hit another hurdle. The 'ISCCS crisis' was triggered when a U.S SunLab analysis indicated that an efficient combined-cycle plant with 9% solar contribution might only offset 0.5% of carbon emissions as a result of inefficient duct burning during non-solar hours[27]. In a meeting in September, 1999, the Mathania issue was discussed by representatives of the World Bank/GEF, KfW, Fichtner, Bechtel, and SunLab. Fichtner, consultant to the KfW, presented a detailed analysis showing much higher carbon reduction figures than that of SunLab's and suggested that the discrepancy was due to simplifying assumptions used in the latter's analysis. Based on the Fichtner analysis, the World Bank and GEF concluded that the Mathania ISCCS plant sufficiently met their objectives to continue forward with the project.

Consequently, the World Bank, as Implementing Agency of the GEF, and the KfW entered into a cooperative agreement designating KfW as an executing Agency for administration of GEF grants. In addition to the GEF commitment of US$49 million towards the project, KfW has committed the equivalent of a US$150 million loan (partly soft loan, partly commercial loan), and the Indian Government will contribute a little over $10 million. In June 2000, the Rajasthan State Power Corporation Ltd (RSPCL) advertised for parties interested in bidding for the contract to build a 140 MW hybrid naphtha/solar ISCCS plant to be sited at Mathania, with a 219,000 m^2 parabolic trough field[28]. The tender is at the pre-qualification stage and applications were due for the 4th December 2000. The project may begin in July 2001, and is expected to be complete by 2004.

The On/Off nature of this project can be attributed to a common factor in many projects where Government owned monopolies are involved. That is, projects involving government owned utilities, such as RSPCL, are vulnerable to changes in government, which has led to the delay or termination of a number of large energy projects. On top of this bureaucracy in India continues to delay the project, and the signing of the Power Purchase Agreement (PPA) has been difficult because of the current high cost of liquid fuel and the poor financial state of the off-taker. Pre-qualification for this project has resulted in lower interest than expected from IPP/ STP developers, with only six pre-qualification bids out of which three should qualify (N.B. final decision will be made by RSPCL, March 2001). The reasons for hesitance from those interested in building STP plants can be attributed to the fact that, unlike the other three GEF projects, this is not an IPP project[29]. The possibility to make profits from a state-owned plant project, compared to an IPP project, is smaller due to control of the state on prices, but the project risks are still, comparatively high.

3.2: Morocco

This project has been developed in a relatively short time, with progression being relatively smooth compared to the Mathania project, having already been the subject of a four-year pre-feasibility study carried out by Pilkington Solar International. The pre-feasibility study, funded by the EU provided an economic analysis of 11 designs at selected sites. The project involves the construction and operation of a solar/fossil fuel hybrid station of around 120 MW, with the site expected to be Ain Beni Mathar, in the northeastern Jerada province. The project includes the integration of a parabolic trough collector field producing a minimum energy output with a natural gas-fired combined cycle, and will be sited close to the new gas pipeline from Algeria to Spain[30]. The Independent Power Producer (IPP) will be secured through either a Build Own Operate and Transfer (BOOT) or Build Own Operate (BOO) scheme, with the final design and choice of technology for this project to be relatively open with power plant configuration and sizing chosen by the project sponsors after competitive bidding. The open specification will help to ensure that the resulting design is more likely to be replicated by the private sector in the future.

A pre-feasibility study was presented to the GEF council in the form of a project brief in May 1999. The Moroccan state utility, the Office National de l'Electricite (ONE) have contracted consultants who are preparing the request for proposals (RFP) for the project, which is expected to go out for bidding some time in mid 2001[31]. ONE will conclude negotiations of the Power Purchase, Fuel Supply, and Implementation agreements with the selected IPP. For this project the power output from the solar-based power plant component throughout the project life, will be monitored by concerned parties under the corresponding contractual covenants.

3.3: Egypt

This project has also been developed relatively smoothly to date. In 1994, The Egyptian New and Renewable Energy Authority (NREA) prepared a Bulk Renewable Energy Electricity Production Program (BREEPP), which focused mainly on solar thermal power. A project was proposed for a first plant involving the construction of a solar/fossil fuel hybrid power station in the range of 80-150 MW to be implemented through a BOOT or BOO contract with an IPP.

In 1996, Egypt was the venue for the first IEA SolarPACES START* Mission, which was valuable in providing an international perspective on the suitability of STP for Egypt. In 1998, a GEF grant was awarded to NREA, and a multi-national consortium led by Lahmeyer International prepared a pre-feasibility study for this project, named Hybrid Solar Fossil Thermal (HSFT). Pre-qualification was carried out in May 2000, with 11 consortia submitting proposals. Amongst the bidders were well-known companies such as BP Amoco, ABB, Duke Energy, ENEL, Mahrubeni, Bechtel[5], as well as the established solar thermal plant developers and component manufacturers, such as Solel and Flabeg Solar International.

The Egyptian government has endorsed NREA's long-term solar thermal program, with planning underway for two subsequent 300 MW hybrid fossil STP plants to be on grid in 2007 and 2009[32]. Key to success for this project so far, has been credited to the absolute engagement of NREA and the support of the Egyptian Electrical Authority (EEA) and the Ministry of Energy. NREA, had very successfully conducted a series of activities investigating the national solar thermal potential, national technology capacity and industrial resources, and their implications for the national energy plan, as a means of gaining the support of the EEA and Ministry of Energy, as well as international development agencies[30].

* START = Solar Thermal Analysis, Review and Training

3.4: Mexico

A solar thermal dissemination mission was conducted in October 1998, in Mexico City, co-sponsored by IEA SolarPACES and the Comisión Federal de Electricidad (CFE). 31 experts attended the dissemination mission from Europe, the U.S., and high-level representatives from the Mexican Ministry, CFE, industrial firms and the Mexican Solar energy research community[29]. Interest was shown on all sides for a possible solar thermal project as part of CFE's expansion plan under which up to 500 MW each of combined cycle gas turbine systems would come online in 2004 in the sites of Laguna or Hermosillio, and in 2005 in Cerro Prieto.

In August 1999, the World Bank and the Comision Federal d'Electricidad (CFE) selected Spencer Management Associates (SMA) to conduct a study on the economic viability and technical feasibility of integrating a solar parabolic trough with a CCGT at the Cerro Prieto, Baja Norte site owned by CFE. The study was presented to the GEF council in November 1999, in the form of a project brief, and was approved for entry into the Global Environment Facility (GEF) Work Program in the December 1999.

Since, then there has been some delay with this project due to restructuring in the power sector required by the World Bank, and more recently the Presidential elections putting Government support for the project in doubt. The CFE was supposed to be preparing the documents for bidding from December 2000, but this has now been delayed. Signs are that the new government in Mexico is supportive of the project, and there will be a high level mission between the World Bank, the Secretariat of Energy and the CFE in February 2001, to clarify the future of the project with hopes that will come online in 2005[33].

Again, this project, like India, highlights the potential vulnerability of Government owned utilities, such as CFE, with changes in Government potentially affecting projects already in the pipeline. However, prospects for the resumption and subsequent completion of this project are good. One excellent advantage of this project is the fact that Mexico has a well-developed industrial base and skilled labour force with potential to manufacture domestically most of the solar plant's equipment and components. This would lower the total cost and possibly increase manufacturing of solar thermal components for other plants around the world. Mexican companies have already been manufacturing parabolic collectors for the Luz installations and have demonstrated their ability to meet international quality standards.

4: Relevance and linkages of GEF projects to trends

"Perhaps the most significant event of this decade to help spur the commercial deployment of STP technology"

This was the response of an official from the U.S. National Renewable Laboratory reporting on a 1999 decision of the GEF Secretariat to move forward with some US$200 million funding support for the first phases of projects in India, Egypt Morocco, and Mexico.[34]

The main and clearest observation of this report is that by showing support for STP with these four projects, the GEF is lending credibility to the technology, creating fresh interest, and positively affecting the development of other projects in both the developed and the developing world. Industry, governments, and research organisations are now anticipating a possible revival in the 'STP industry' through construction of the GEF plants. GEF support has helped put STP technology on the agenda of other organisations and given credence to or helped expand ongoing STP R&D and commercialisation programs in Europe, the U.S, Israel, and Australia. Consequently, a great deal of R&D and commercialisation work has continued in the aftermath of the Luz projects, and the improvement in technology components, designs, and project implementation approaches have kept moving in the last decade.

As identified earlier in this report, a small, but not, insignificant number of both demonstration and commercial projects are now being planned and developed in the U.S., Europe, and elsewhere for which a number of methods (including grants, subsidies, green pricing etc,) have been found or are being pursued by consortia, such as Bechtel/Ghersa, the Abengoa group, Solar Millennium Group[*] etc., to cover the present high cost of this technology. Similarly, the strong response to pre-qualification requests for projects in Egypt and to a lesser extent in India, have already shown that the GEF program is cultivating IPP developers that may be able to lead industry teams that will build, own and operate new plants – an approach fully consistent with the recent paradigm of liberalisation in the electricity industry.

In developing regions, the four projects have created interest from a number of other countries, including South Africa, Namibia, Brazil, Iran, and Jordan, that may take a further step towards projects in their own countries if STP technology is successfully demonstrated through the four GEF projects. If the GEF projects are implemented successfully, then some of these countries, will be endeavouring to gain funding from a number of sources, including the GEF, but also other equity investors and organisations that have already shown initial interest. Similarly, there are signs that successful implementation of STP projects in India, Egypt, Mexico, and Morocco could also lead to further projects in these countries. Egypt, for example, is already at the planning stage for two further projects as part of an ambitious programme for STP. If costs fall dramatically in the next decade, through wider take up, STP may become a common choice for many of these countries with high solar insolation, especially if 'Kyoto mechanisms', such as the Clean Development Mechanism (CDM) come to fruition.

Overall, the GEF can take a lot of credit for giving life to an industry that was in danger of stagnating, providing the impetus to what is hoped will be a successful path towards

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[*] *The Solar Millennium Group functions as project manager to several companies and partnerships to finance research and development work of STP technology, identify and qualify possible locations for STP projects, and finally prepare the financing and construction of STP plants. The group has been involved in developing a number of projects in Spain, Greece and elsewhere. Partners include, Flabeg, Schlaich Bergermann, Fichtner, DLR, and Solel*

commercialisation of one or more of the STP technologies. Despite these positive observations, however, the projects themselves and aims of this GEF programme still have a long way to go. The three broad goals that success can be measured by will be:

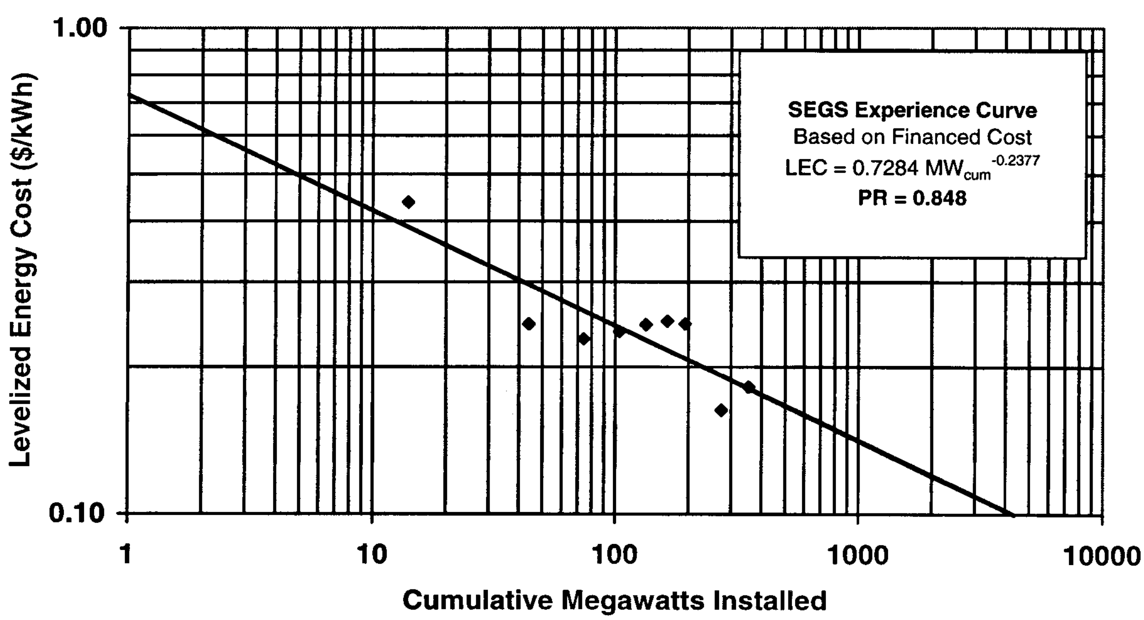
- ***Successful implementation and demonstration of STP in a developing country environment;***
- ***Cost reduction and innovation of STP technology, towards a cost competitive with other power generation technologies;***
- ***Wider take up of STP throughout the world***

It is important, now, to look more closely at how the GEF portfolio is progressing towards meeting these goals, with suggestions on how these might be achieved in a more effective manner.

4.1: Experience so far

There are no quantifiable affects on costs and learning experience from any of the GEF projects so far, as it is still too early in the evolution of the STP portfolio. Although all of the projects have had pre-feasibility studies completed. These studies, including the World Bank Cost Reduction Study are based on similar information as referenced in the earlier international trends section, and based on experience gained from the Luz plants. Data from the Luz plants, for which the experience curve, shown in Figure 4.1a, is downwards and reported to have a progress ratio of 85%[2], could be misleading. Data charted was for actual financed price, design plant performance, and an estimate of the necessary O&M costs rather than the actual plant costs. Adjusting for this the experience curve would be lower[16].

Figure 4.1a: SEGS Plant Levelised Electricity Cost (LEC) Experience Curve as a Function of Cumulative Megawatts Installed[17]



Other information for deciding on a starting point cost for the next plant, ultimately stems from the 'best guesses' of equipment suppliers involved in the Luz SEGS projects, that can be traced back to, literally, a handful of individuals based largely in Israel, Germany and the U.S. This information is all relatively dated since no new plants have been tendered for almost a decade, and no new information will be available until the bidding process, forthcoming in 2001 for at least 2 of the projects. However, for solar field investment, where at least 75% of the cost is tied up in the heat collection elements (HCEs), mirrors and structure, reasonable cost data is available today mostly because of spare parts being purchased at the Kramer Junction plants[35]. Essentially though, the bidding process will, undoubtedly provide new market-based information on costs, risks, appetites to construct plants, proposed technologies, competition etc., some initial indications of which have been shown in pre-qualification.

It is clear that the GEF projects will lower the costs of STP to some extent in the near term, but it is still uncertain how far down the experience curve these four projects will take STP. Interestingly, when the GEF approved the four STP projects for financing, there was no major framework or clear path set out for cost reduction intended by these projects. Also the GEF cannot guarantee that all four projects will be successfully completed, and it is conceivable that only 1,2 or 3 are built. This lack of guarantee, however, is true of most large energy projects in developing regions.

Table 4.1 below gives the market diffusion steps for STP plants, of which STP can be taken as being at step 4, although some of the technology types e.g dish/engines and thermal storage for troughs are not yet at this stage. The programmatic aims, however, of the GEF portfolio will be to move STP through Steps 4 to 6. Four projects are unlikely to take STP that far in terms of experience and cost (to Step 5&6). However, if as is already being shown, these projects influence a number of other projects financed from various sources, the impact could and should be greatly enhanced. As Figure 4.1b shows that a large amount of grants and subsidies will be needed to bring the cost of STP down towards competitive levels. This step should not be borne by the GEF alone and efforts to coordinate projects through combined and other funding should definitely be pursued.

Table 4.1: General Market Diffusion Steps for Solar Thermal Power Plants[16]

Step 1: ***Research and Development*** – A new technology is explored at a small scale and evaluated for the potential to be significantly better than existing approaches;

Step 2: ***Pilot Scale Operations*** – System level testing of components provides proof of concept and validates predicted component interactions and system operating characteristics. The size of operation is sufficient to allow relative engineering scale-up to commercial size applications;

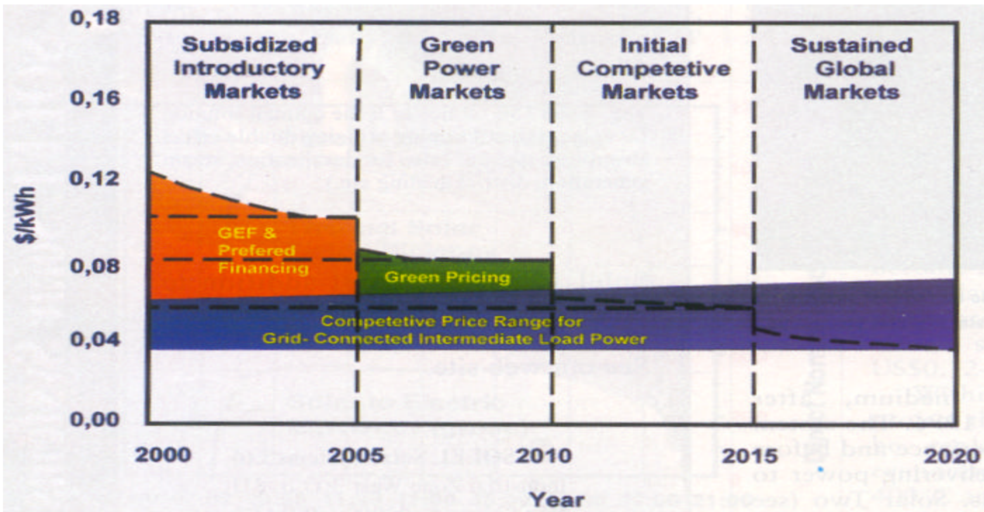
Step 3: ***Commercial Validation Plants*** – Construction and long-term operation of early projects in a commercial environment. Operation of these projects validates the business and economic validity of the design, and provides an element of economic risk reduction that goes beyond that which is accomplished at pilot scale.

Step 4: ***Commercial Niche Plants*** – Sales of technology into high-valued market applications that supports the technology costs. Costs are reduced with learning, manufacturing economies of scale and product improvements.

Step 5: ***Market Expansion*** – As cost decreases and other attributes improve, sales become possible in a broader range of market applications. The expanded market further reduces cost.

Step 6: ***Market Acceptance*** – The technology becomes competitive with conventional alternatives and becomes the desired choice in its market. The cost of the technology levels out and the market reaches maturity.

Figure 4.1b: Market introduction of STP technologies with initial subsidies and green power tariffs[36]



Without further information from the bidding process, it is difficult to suggest any useful redesign of the current programmatic approaches. However, there are a number of issues still worth considering, which can be augmented and assessed as further information becomes available with the progression of the STP portfolio. Some of these issues discussed below would also benefit from discussion amongst the wider 'STP community', with a view to finding the best path towards commercialisation of which the GEF projects are a key part.

4.11: Sequencing of the projects

The portfolio approach of the GEF programmes has a number of advantages. It reduces the risk of non-performance of individual projects. It gives a signal to developers and the industry of serious support for the future of the technology. Most importantly, having a number of projects in development could lead to greater cost cutting and learning experience, through cross-learning from one project to another during various stages of development, and also through the potential of lowering manufacturing costs through aggregation of components for more than one project.

The potential for cross-learning can be diminished , however, by the present bunching of projects. If, as is possible, projects are all built around the same time, lessons learned from one project may not be passed on to the next project. At worst, this leaves a possibility that the STP costs for the last project built could be more expensive than the first. However, delays that have resulted for the India and Mexico projects have not been through actions in the GEF, but rather have been through problems associated with the development and implementation of large energy projects in developing countries, especially in dealing with government owned-utilities, whose personnel and support for projects can disappear with changes within the government itself. With the World Bank requiring certain restructuring commitments by donor countries - such as in the case of Mexico - and changing politics within those countries, these delays are often unavoidable and make it difficult for proper sequencing. In these cases, it would also be unfair to make one country wait for implementation of its STP project, whilst delays are occurring elsewhere.

Bearing this in mind, it is important that implementing agencies for the GEF are fully aware of the programmatic nature of the STP portfolio, and seek, in the very early stages of the project planning and development, to get as much support as possible from the relevant client country agencies, energy departments, and utilities to be sustained through the course of the project.

4.12: Cross-learning from one project to another

As noted above the portfolio approach of the GEF allows for cross-learning from one project to another. However, at the present stages in the development of the STP projects, there seems to have been very little input from project-to-project. Although all the parties involved certainly know of the other projects, very minimal cooperation or dialogue has been observed, except where World Bank staff have been advising on more than one project. For maximum learning experience from the GEF portfolio efforts must be made at various stages to assess and disseminate information for all the projects, and sharing this information between projects. It is important to note at this stage in the STP projects there is only a little that can be learned and the real opportunities for cross-learning should occur once consortia have been selected for one or more of the projects. The GEF should take a lead role in facilitating this cross-learning process.

4.13: One consortium building all four projects

The potential for cost cutting can be increased through the mass procurement of solar components for multiple plants, with economies of manufacture and the incentive for lowering manufacturing costs high. Cost reductions in components through mass procurement have already been shown to some extent for the SEGS plants, but much greater reductions are possible, especially if manufacturing capability can be achieved in some developing countries. This scenario of mass procurement, however, may happen unintentionally for the GEF projects, with relative monopolies present for parabolic trough components, such as HCEs, and mirrors. Similarly, there are a number of advantages that could be gained by all interested consortia bidding once to win the contract for all four plants, with incentives to reduce costs included in the terms over the course of the work. This could be desirable in terms of maximum learning experience and lowering costs over the course of building the four plants.

This issue, however, is debatable as one of the aims of the programme is to help market expansion of STP by encouraging a number of competitive IPP led consortia capable of developing further projects. For this aim, GEF projects would be better encouraging low electricity prices and a competitive industry for STP plant development, through competitive bidding for each individual project. These projects would then encourage at least two or even four consortia to gain learning experience in building STP plants, thereby creating a more competitive environment, again helping lower costs. This issue should be explored further before planning or financing any further projects.

4.14: Technology choice should be left open to the developers

It is in the interest of GEF aims for cost cutting and learning experience that the design and technology is left as much as possible to the competitive bids, keeping in mind the perceived technology risks. It is clear and well documented that large public organisations tend not to be good at picking technology winners, and ultimately, the market is better at deciding whether the various parabolic trough or central receiver configurations will become the market leaders.

Although for these projects, the GEF incremental cost grants will lower project risk. In general, many investors still consider STP to be a 'new technology' and are often unfamiliar with recent advances in designs. Presently, all STP technologies require a risk premium on both equity and debt over rates charged to conventional power technologies. To minimise technology risk it is important to utilise a technology design very similar to the existing SEGS facilities, and to show how performance expectations can be justified from real plant operational experience. It is expected that the substantial operating experience with these plants will help minimise the premium charged for debt and equity[37]. If as may happen, the solar thermal industry is re-established with parabolic trough technology, much learning can be transferred from trough technology to power towers because there are significant similarities.

Bearing this in mind, there is a perception from some parts of the private sector that the request for proposals (RFP) for some of the projects may be constraining with regards to the type and configuration of the STP plant. It was stated early on in the project briefs that the choice of technology would be left open to the IPP developers. Efforts must be taken by the implementing agencies to make sure that this is followed through to the RFP, or innovation in design and improved components could be suppressed. Although risks may be deemed higher for central receiver designs, IPP developers may be willing to take on that risk and bid a convincing robust design at a competitive price. Bids of this nature using alternative designs to the SEGS plants should certainly be assessed on their merits.

4.15: Maximisation of the solar component for hybrid projects;

As shown from pre-qualification in Egypt, where 10-11 consortia showed interest in constructing the 120 MW plant, there is already a great deal of interest. Some of this can be attributed to the involvement of the GEF, and the existence of the grant for incremental costs. But also due to the fact that the likely technology, the gas-fired combined cycle configuration which is a fully mature technology, has attracted a number of turnkey companies who have constructed and operated these types of IPPs for a number of years, albeit without the solar component.

This raises an issue critical for the success and maximum learning from these projects. It is essential that measures be undertaken to ensure that the solar component is maximised through the lifetime of the plant. Operating strategies for the present SEGS plants highlight the need for enough incentives to maximise the solar component in the GEF projects. The SEGS III-VII plants at Kramer Junction are operated with a good level of O&M (at significant cost), replacing solar components regularly, keeping the plant operating at a high output level. For the SEGS III and IV plants at Harper Lake, the operating strategy is to have lower O&M costs which results in lower plant output, in this case often around 15% of the mirrors are out of service most of the time[38].

Preliminary observations show that efforts are underway to ensure the sustainable operation of the solar component. For the India project, evaluation of bids will be based on so-called 'Levelized Electricity Cost (LEC) adjusted for solar share', i.e. a factor>1 will be given for solar generated electricity. Consultants preparing the contract have devised a formula, whereby during operation, the operator will be obliged to generate as much solar power as offered by him for the contract, corrected for the actual meteorological conditions, and reflected in the operating fee[39]. For the Mexico project, the consultants, Spencer Management Associates, have advised that bids submitted should be evaluated not only, on cost and meeting the technical requirements of the RFP, but also those that:

a) Maximise the annual MWh produced from the solar thermal field (50% weight);
b) Maximise the total MWe installed of solar thermal technology (30% weight);
c) Maximise the annual MWh produced from the solar thermal field as a function of the total MWh produced from the CCGT (20% weight)[40].

Other methods have been suggested for the other projects, including giving the GEF grant as a loan, whereby the successful consortia that build and operate the plant, will pay back the loan in solar kWh. It has also been argued that the proper technical optimisation of integration of the STP component with the CCGT should provide a natural incentive for the operator to maximize use of the STP. Suitable methods to ensure a sustainable solar component should be obligatory for the release of GEF grants for these and any future STP projects.

4.16: Role of private sector and other organisations in the GEF portfolio

One contradiction with OP 7 is that it is, essentially, country driven (i.e. responds only to requests from donor countries); however the programmatic aims are global encompassing. Working within this limitation, the GEF does not and should not take sole responsibility for the future 'global' development of STP. Therefore, in trying to maximise learning benefits and minimise funding requirements, gaining interest from the private sector and maximising co-funding from non-GEF sources is paramount. For most of the four projects, consultants and STP developers have been essential for advising host countries and performing the numerous pre-feasibility and project studies in those countries. However, the GEF has had little dialogue with the industry interested in building STP plants, even though the numbers are fairly small. From the start of these projects it would have been more advantageous to open dialogue with the private sector on how STP could best be taken forward towards commercialisation. Whereas the World Bank's Prototype Carbon Fund is trying to demonstrate the possibilities of public-private partnerships, the GEF has not pursued these possibilities for STP. The GEF has, however, through cooperation with the KfW, demonstrated the advantages of partnerships with other funding organisations in the realisation of STP projects.

A number of ways forward for the GEF and STP commercialisation have been suggested. It is clear that more than four STP projects will have to be subsidised in some way, and the STP industry, potential investors and other finance organisations would feel more confident about the short-to-mid-term future of STP, if more projects were supported by the GEF. The World Bank study suggests that the GEF would need to provide financial support in the order of \$350 to 700 million to fund approximately nine projects (750 MW)[16]. However, rather than the GEF bearing lone responsibility for the initial commercialisation phase, a Global Market Initiative currently being developed, could provide a sustained effort towards full STP commercialisation with lower financial support required by the GEF. Such an initiative could explore some of the issues discussed in this report and other possible market issues, concerns, and approaches, through discussion among a wide spectrum of stakeholders including:

- Funding sources, such as the GEF, public banks, commercial lenders and venture capital providers;
- STP programs such as the IEA, EU and U.S. Dept. of Energy;
- Government and utility representatives from countries and states where future STP power plants may be located;
- The STP industry;
- Interested IPP developers.

The end result of such an initiative would be a strategic market intervention leveraging an unprecedented volume of venture capital for STP investments, through an alliance of public and private technology sponsors that would help to pull the market through aggregation and economies of scale[41]. The GEF's role in STP development, could then move to providing smaller grants with the remainder incremental costs supplied by other sources, or providing a guarantee for future projects. Guarantees, themselves, can reduce risk-surcharges by a rate of 20:1; with a guarantee covering 100% of the investment will reduce the capital cost by 5%[42].
A global initiative, facilitated by the GEF, should be given serious consideration and developed as soon as possible, to include these four GEF projects and gain maximum learning experience and cost cutting.

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